Innovative Drone Use in Riparian and Wetland Restoration

Best Practice Guidelines

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Greening Australia

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Executive Summary

The use of drones in ecological restoration, and specifically for applications in riparian and wetland restoration in the Great Barrier Reef catchment, are rapidly changing. This document outlines information relating to drone applications for revegetation, weed treatment, and monitoring and provides best practice guidelines when considering using drones for these activities. The information provided here is based on a case study innovation project funded by the Great Barrier Reef Foundation Reef Trust Partnership and on industry research completed in 2023.

Drone use in ecological restoration is a rapidly evolving field and over time this guide should be used in conjunction with current research on industry drone capacity. The best practice guidelines are outlined in each section in green boxes and a full list is provided at the end of the document. Three key guidelines are listed here.

I. **Assess the site suitability for drone application as compared to manual approaches including safety, restoration capacity, and known limitations.** Consider canopy cover, site accessibility for vehicles and personnel, on-ground hazards such as crocodiles, rough terrain (mud or steep slope), flight restriction zones, cost, and effectiveness.

II. **Assess the cost-effectiveness of drone applications compared to manual by researching comparative effectiveness of seeding applications in similar environments and obtaining quotes from providers for drone and manual applications (a cost-effectiveness matrix can be used).** Consider effectiveness of planting methods in the region and relevant literature indicating effectiveness of drone applications in similar habitats, as well as insights from providers when obtaining quotes.

III. **Assess if a drone or manual approach aligns better with the desired project and ecological outcomes.** Consider site impact by vehicle and foot traffic, precision of weed treatment application requirements, and potential to engage with local providers.

1 Introduction

The purpose of this document is to provide restoration practitioners with best practice guidelines for drone use in wetland and riparian restoration.

The case study and foundation for the development of these guidelines is the project ‘Trialling the Use of Drones in Riparian Restoration’, delivered by Greening Australia’s Reef Aid Program from April 2021 to June 2023. The project was funded by the Great Barrier Reef Foundation Reef Trust Partnership.

The project objective was to compare drone and manual approaches in riparian and wetland restoration in the Great Barrier Reef catchment to identify where using drones may be more cost effective or address other limitations associated with manual approaches. Drone applications for revegetation, weed treatment, and monitoring are discussed in this document.

The applications for wetland and riparian restoration have been investigated in the context of the Queensland region, therefore consideration should be given to the variability of these habitats and applications in other regions. Best practice guidelines are listed in green boxes at the end of each section and in a complete list at the end of the document.

The case study took place in three regions in the Great Barrier Reef catchment (**Figure 1**):

1. Ross Road – Mulgrave-Russell Catchment (50 km from Cairns);
2. Viv Cox – Burdekin Catchment (100 km from Townsville); and
3. Big Dune Reserve – Fitzroy Catchment (10 km from Yeppoon).

Figure 1: Location of case study sites

2 Use of Drones in Ecological Projects

2.1 Drones and Ecological Restoration

Drones have increasingly been used in environmental management and commercial projects over the past decade (Frankelius *et al*. 2019; Naughtin *et al*. 2019). Drones have been used in restoration projects for applications including weed treatment, monitoring, and revegetation. Benefits of using drones can include:

- improved water quality: e.g., using drones to directly spot spray weeds can lead to a more controlled volume of herbicide being used and therefore reduce runoff into waterways.
- lower risk for site access: e.g., wetland and riparian restoration sites can be dangerous to access due to rugged terrain or presence of dangerous animals. Using drones at boggy sites that are inaccessible to other equipment or near waterways with crocodiles can reduce the risk of injury.
- increased cost-effectiveness: e.g., the cost for drone services may be lower than manual applications, especially in remote areas and where the manual task might require higher costs for personnel, travel, and equipment.

The Queensland Government supported four years of drone weed treatment at wetland restoration sites as part of the Queensland Reef Water Quality Program Wet Tropics Major Integrated Project (MIP) from 2017-2021 (Wet Tropics Major Integrated Project 2021). Recently drones and associated analysis software have been used successfully for monitoring approaches including plant identification, quantifying change over time, monitoring land cover and pasture quality, identifying threatened species, and measuring plant biomass remotely (Suir *et al.* 2021; Rummell *et al.* 2022; Akumu *et al.* 2021; Wilson *et al.* 2022; McCann *et al.* 2022).

Drone use for weed treatment can be over 90% effective from a single treatment, working best when there are distinct patches of weed that can be treated (Milling 2018). This weed treatment approach has shown improvements for agriculture, habitat restoration, and water quality (Queensland Drone Strategy 2018). In the Great Barrier Reef catchment, regional managers including the Queensland Government Department of Agriculture and Fisheries, Hinchinbrook Shire Council, and Townsville City Council are using drone technology for weed control.

Revegetation by drone technology is becoming more common using approaches including direct seed dispersal, seed balls, and seed puck distribution (Robinson *et al*. 2022). These approaches can be particularly useful in areas that are unsafe or hard to access, including steep hillslopes inaccessible by vehicle. These approaches have also been used to infill manual planting to increase the seed base and survivability of plants.

There are a wide range of drone applications for monitoring, with an increasing variety of imagery sensors and post-flight software analysis applications. When used for monitoring, drones can be safer and more cost effective than manual monitoring approaches, depending on the site conditions and monitoring requirements.

Deciding whether to use drones as part of a restoration project involves many considerations. The following sections of this document examine various drone applications and provide guidelines for decision making. Some general criteria to assist with decision making include:

- suitability of the proposed work site(s); e.g., canopy cover, site accessibility for vehicles and personnel, on-ground hazards such as crocodiles, rough terrain (mud or steep slope), flight restriction zones.
- cost effectiveness of using drones compared to manual approaches; and
- alignment with desired ecological outcomes.

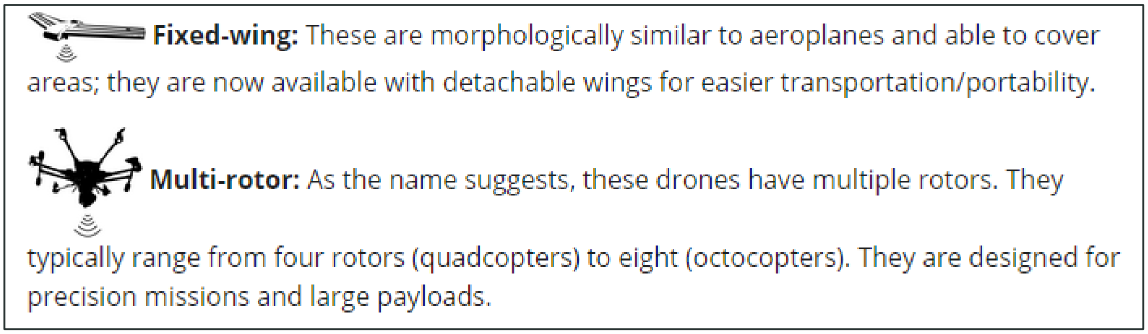
I. **Assess the site suitability for drone application as compared to manual approaches including safety, restoration capacity, and known limitations.** Consider canopy cover, site accessibility for vehicles and personnel, on-ground hazards such as crocodiles, rough terrain (mud or steep slope), flight restriction zones, cost, and effectiveness.

II. **Assess the cost-effectiveness of drone applications compared to manual by researching comparative effectiveness of seeding applications in similar environments and obtaining quotes from providers for drone and manual applications (a cost-effectiveness matrix can be used).** Consider effectiveness of planting methods in the region and relevant literature indicating effectiveness of drone applications in similar habitats, as well as insights from providers when obtaining quotes.

III. **Assess if a drone or manual approach aligns better with the desired project and ecological outcomes.** Consider site impact by vehicle and foot traffic, precision of weed treatment application requirements, and potential to engage with local providers.

2.2 Drone Technology and Commercial Availability

There is a vast range of sizes and types of drones that can be used in ecological restoration (**Figure 2**) and this is changing rapidly as the technology continues to develop. Drones range from small camera wielding units to large units that can carry a more substantial weight payload (**Figure 3**). Drones can be fixed wing or multi-rotor, where the rotor drones have capacity to take off and land vertically, hover in the air, and have quick direction change, but cannot fly as quickly or long range, and require more battery power (Robinson *et al.* 2022). These drones, or unmanned Aerial Vehicles (UAV), are usually battery powered and piloted via a remote controller. Attachments for drones can include a variety of cameras, sensors, and payload containers.



Fixed-wing: These are morphologically similar to aeroplanes and able to cover areas; they are now available with detachable wings for easier transportation/portability.

Multi-rotor: As the name suggests, these drones have multiple rotors. They typically range from four rotors (quadcopters) to eight (octocopters). They are designed for precision missions and large payloads.

Figure 2 Two main types of drones (Robinson *et al.* 2022).

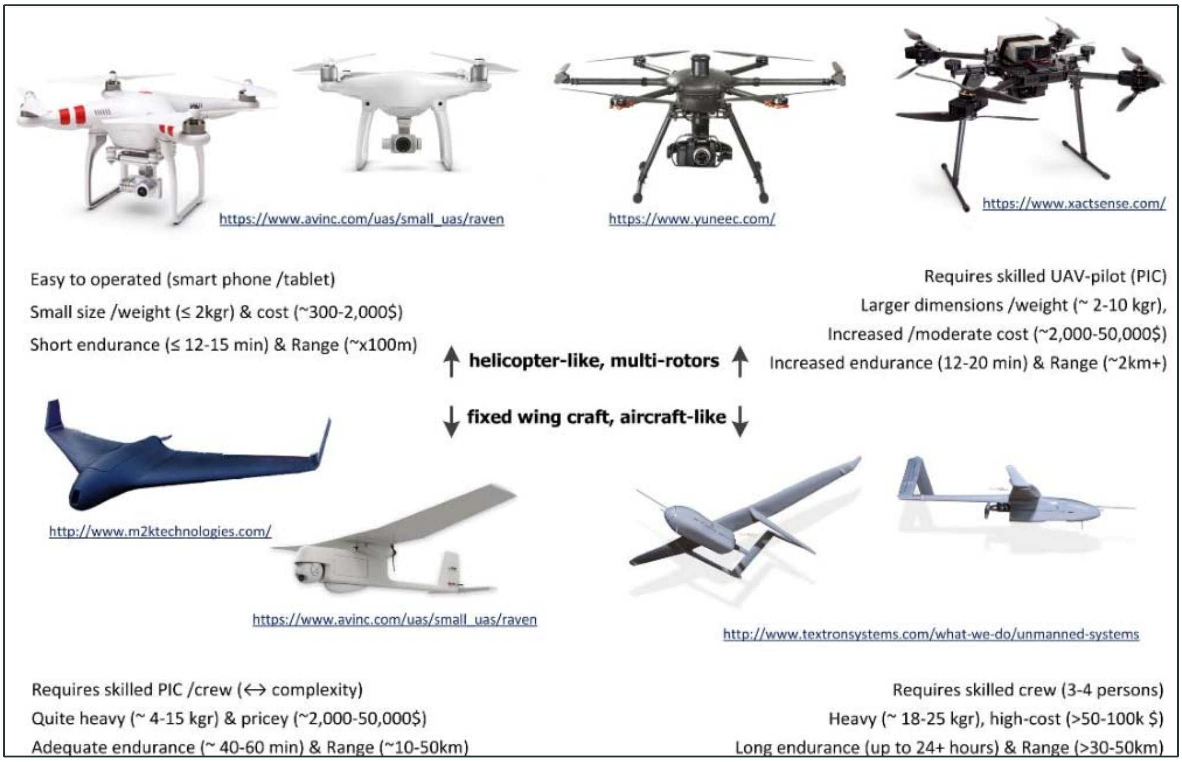


Figure 3 Drone size examples (Ntalakas *et al.* 2017).

Drone size, weight, and battery life are all factors which affect flight capacity. Battery time often ranges from 20 minutes up to 50 minutes and can vary substantially by type of drone and weight. Providers will frequently have a bank of batteries to allow for extended fly time and quick changeover on larger jobs.

Continued advancements in the production and capabilities of drones, attachments, and batteries means that there may be new developments and capacities that suit a project. This should be researched and discussed with prospective providers to understand potential options (Rao *et al.* 2016). Drone use in ecological restoration is a rapidly evolving field and over time and this guide should be used in conjunction with current research on industry drone capabilities (**Figure 4, Figure 5**).

Figure 4 Ground truthing equipment and monitoring drone (DJI Mavic) use in case study.

Figure 5 A larger drone used to distribute herbicide for weed treatment in the case study (photo credit: Marcus Bulstrode, DAF).

As a long-term business approach, you may consider in-house drone operation. Some considerations include:

- Regulation requirements
- Alignment with work applications when considering adding drone operation to your business
- Magnitude of projects
- Frequency of drone use
- Specific requirements of drones (i.e., is it custom or can a provider do it for you?)
- Maintenance requirements for drones
- Technology development (i.e., will the technology become dated quickly?)
- Qualifications required to operate
- Cost of in-house vs outsource (including sometimes they can acquire imagery whilst they mobilise for other jobs)

There is increasing availability of drone providers for ecological restoration work. A consideration when looking at providers may include what range of work they are capable of delivering if you have multiple requirements. Providers can often travel to other areas so consider contacting businesses even if they are not the closest provider. Providers may also be able to do more than the standard options advertised, so it is a good idea to consult with them about any specific needs. This is a rapidly changing and growing industry, so it is important to review industry providers and costings between projects (Buters *et al.* 2019).

IV. **Assess your business strategy to determine if drone equipment, tools and training should be sourced in-house or via contracted providers.** Consider cost, business strategy, and accessibility of equipment, training, and providers.

V. **Assess provider suitability to deliver against the project costs and needs.** Consider industry availability and pricing between projects (there may be new providers or lower cost options), and consult with providers about project needs, they may be able to do more than standardly advertised.

2.3 Flight Conditions and Requirements

2.3.1 Site Condition Considerations

Most drones require dry weather for flights and data collection or payload delivery. The planned work schedule should include considerations for flight conditions and requirements. When planning works weather considerations (most often wind, rain, extreme heat, and extreme cold) should be accounted for and buffer time for weather impacts should be included. A communication plan with delivery providers is recommended to assess weather conditions and finalise travel prior to field work. Including providers in a site visit can be very valuable to receive feedback on site conditions that may affect drone applications. Providers may still need access to multiple areas of the work site to service the drone or to be in compliance with regulations for flight such as maintaining a visual line of sight. Additionally, drones require a minimum number of satellite connections (especially for mission planning) which can sometimes be obstructed by dense aerial coverage such as trees or large buildings.

Considerations for drone flight planning may include assessing the canopy cover of the site and discussion of manual or automated flight paths. Canopy cover can affect monitoring capacity (if too dense), flight height, and payload delivery like seed distribution or targeted weed treatment. Low canopy cover is preferable. Drone flight paths can be a pre-programmed automated path, or a manually piloted flight (**Figure 6**). Automated flights allow for control of site coverage, flight speed, and height. This can allow for seed distribution or spraying weed treatment at a controlled rate of delivery across a site and allows for precise imagery acquisition during monitoring. Alternatively, manual flights allow for targeted areas, avoidance of obstacles such as trees and where no GPS location can be obtained due to satellites locked or strong electromagnetic fields.

Figure 6 Automated flight path example on the left (Beaver *et al.* 2020), and a manual flight path example on the right (phantomhelp.com).

2.3.2 Drone Regulations

Commercial drone use in Australia is regulated by the Australian government Civil Aviation Safety Authority (CASA). CASA provides a full list of drone regulations and authorisations which vary by drone type, size, and use. Commercial operators are required to have the appropriate licenses and registrations.

The rules for recreational drone operators:

- You must not fly your drone higher than 120 metres (400 feet) above ground level.
- You must keep your drone at least 30 metres away from other people.
- You must only fly one drone at a time.
- You must keep your drone within visual line-of-sight. This means always being able to see the drone with your own eyes (rather than through a device, screen, or goggles).
- You must not fly over or above people or in a populous area. This could include beaches, parks, events, or sport ovals where there is a game in progress.
- Respect personal privacy. Don't record or photograph people without their consent – this may breach other laws.
- If your drone weighs more than 250 grams, you must fly at least 5.5 kilometres away from a controlled airport, which generally have a control tower at them. Use a drone safety app to find out where you can and can't fly.
- Remember, you must not operate your drone in a way that creates a hazard to another aircraft, person, or property.
- You must only fly during the day and you must not fly through cloud or fog.
- You must not fly your drone over or near an area affecting public safety or where emergency operations are underway. This could include situations such as a car crash, police operations, a fire or firefighting efforts, or search and rescue.
- If you're near a helicopter landing site or smaller aerodrome without a control tower, you can fly your drone within 5.5 kilometres. If you become aware of manned aircraft nearby, you must manoeuvre away and land your drone as quickly and safely as possible.
- If you intend to fly your drone for or at work (commercially), there are extra rules you must follow. You will also need to register your drone and get a licence or accreditation.

A business operator is required to have an operator accreditation, and if the drone is more than 2 kg a remote pilot licence and the business must hold a remotely piloted aircraft operator's certificate. You can ask the provider you're working with to share their certifications with you for confirmation of compliance.

VI. **Plan a site visit and develop a project communication plan with your provider.** Consider taking providers for a site assessment, they may identify additional opportunities or constraints. Developing a communication plan with the provider will enable you to plan for weather restrictions and discuss any changed plans.

VII. **Assess if a manual or automated flight path is more suitable for your site(s) and project.** Consider your site conditions (trees, site layout), project drone application needs (such as swath consistency), and implications of flight path and associated swath on analysis. It is also important to discuss the options and implications with your provider.

3 Drones for Mapping and Monitoring

Drones can be an effective tool for collecting imagery and tracking environmental change over time for project sites. These outputs can come in many forms and can be used for mapping and monitoring.

Drones can be used for mapping with standard camera attachments or with more advanced attachments (Cruzan *et al.* 2016). A common output for mapping from drones is to generate an orthomosaic. This is developed from many aerial images which are combined using photogrammetry to create the orthomosaic, which has high clarity of imagery and can be georeferenced. This imagery can be gathered from a standard drone camera. Other forms of mapping include LiDAR technology using radar attachments to collect measurements of the terrain using light detection and ranging (**Figure 7**). 3D models and maps can be developed from these approaches, with varying precision depending on method, with LiDAR producing a higher accuracy model (Harrison *et al.* 2021). Infra-red or multispectral imagery can also be used to detect changes in the environment (e.g., NDVI (Normalized Difference Vegetation Index) for plant vigour).

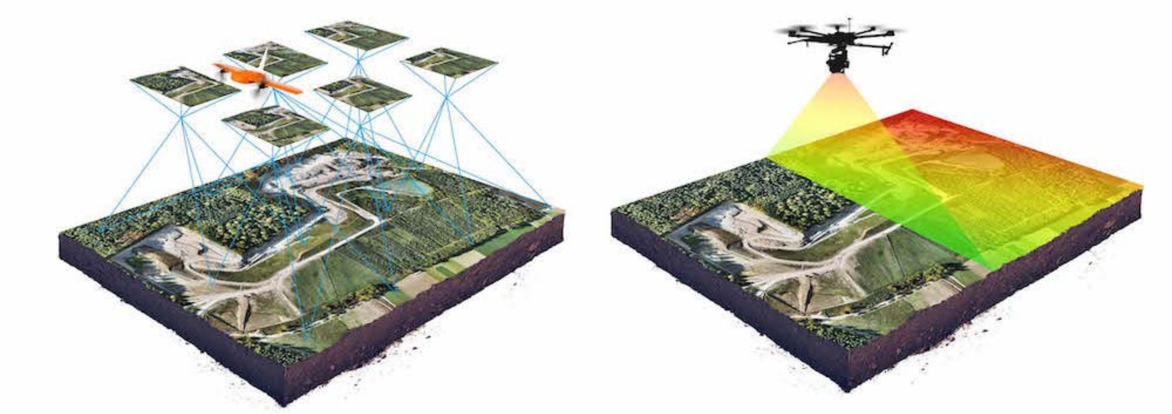


Figure 7 Example of photogrammetry, combining images to create an orthomosaic (left) compared to LiDAR radar data capture (right) by drone (wingrata.com).

Features (sometimes referred to as rasters or images) can be georeferenced to a high level of accuracy by using ground control points or on-board Real-Time Kinematic (RTK) corrections via Networked Transport of RTCM via Internet Protocol (NTRIP), noting a RTK compatible drone is required for this approach. Accuracy can be refined to a scale of centimetres when using surveyed ground control points or RTK. Ground control points are locations with known coordinates that can be precisely pinpointed. Software can be used to generate various maps and models from the drone data including 3D point cloud models, digital elevation models (DEM), and thermal mapping (Hamylton *et al.* 2020). These outputs can show change over time in vegetation and other habitat features. Furthermore, in contrast to satellite-derived data, on-demand data sources offer a cost-effective alternative for obtaining high-resolution imagery. This feature enables the monitoring of changes with a greater frequency compared to satellite-based methods, which can be hampered by the presence of cloud cover.

There are many sensors and attachments that can be used for monitoring by drone that facilitate collection of environmental data including multispectral and hyperspectral sensors, cameras, thermal sensors, pressure sensors, and LiDAR sensors (Camarretta *et al*. 2020). For example, hyperspectral sensors capture images in hundreds or even thousands of wavelengths of light, and this information can be used to identify specific plant species and to assess their health. The type of sensor that is best for monitoring vegetation health will depend on the specific application. For example, multispectral sensors are a good choice for general vegetation monitoring, while thermal sensors are a good choice for identifying areas of water stress. LiDAR sensors and hyperspectral sensors are more specialized and may be more expensive, but they can provide more detailed information about vegetation health (Jones & Vaughan 2010).

There is additional analysis potential beyond assessment of change over time, including using artificial intelligence (AI) analysis of imagery including machine learning, object-based image classification, and supervised and unsupervised classification. AI systems can be 'trained' to analyse data for your specific needs, such as presence of a specific plant or animal species (Camarretta *et al*. 2020). There is also significant capacity for manual analysis of imagery due to the high resolution. This might include photo identification for certain features and habitat analysis. Furthermore, AI can be used in drones for navigation, for example using machine learning software to identify target weeds for real-time weed treatment.

Drones and accompanying software have been used successfully for monitoring approaches including plant identification, quantifying change over time, monitoring land cover and pasture quality, identifying threatened species, and measuring plant biomass remotely (Suir *et al.* 2021; Rummell *et al.* 2022; Akumu *et al.* 2021; Wilson *et al.* 2022; McCann *et al.* 2022).

VIII. **Discuss data resolution and accuracy, data format options, and analysis needs with provider(s) to align with your project budget, analysis, and reporting requirements.** Consider your needs and allow for open communication with providers on their capacity and needs across the duration of the project (e.g., ground control mapping, flight path planning, and monitoring data analysis and software needs).

IX. **Assess if using a single provider or multiple providers is more beneficial for your project.** Consider capacity, consistency, and collaboration scope if using multiple providers (e.g., sharing ground control point mapping).

4 Drones for Weed Treatment

As previously discussed, wetland and riparian restoration sites can be risky when undertaking weed treatment manually with hazards including boggy terrain, steep slopes, crocodiles, and restricted access during weather events. The use of drones may address some of these hazards. Drones are commonly used for weed treatment in agriculture and increasingly in ecological restoration (Robinson *et al*. 2022). In addition to safety benefits there can be an environmental benefit of reduced runoff by using a more controlled volume of herbicide in spot spraying applications. Using drones for weed treatment has shown improvements for agriculture, habitat restoration, and water quality (Queensland Drone Strategy 2018).

Drone use for weed treatment works best when there are distinct patches of identifiable weed that can be treated, and can be over 90% effective from a single treatment (Milling 2018). In the Great Barrier Reef catchment regional managers including the Queensland Government Department of Agriculture and Fisheries, Hinchinbrook Shire Council, and Townsville City Council are using drone technology for weed control. Spraying drones can also be used for treating pests and crop disease, in addition to weed treatment. Drones can be coupled with technology and software for weed detection which can allow for real-time weed identification and spraying.

Spraying drones usually have a large container to hold liquid and a spraying mechanism either from the base or from the arms (**Figure 8, Figure 9**). Providers can give specific information on the volume capacity and battery turnover rate for their drones. An additional space near the work site will be necessary for diluting the herbicide and filling the drone tank. Some considerations for weed treatment drone flights include the height for spraying and whether to use an automated or manual flight path. The height for spraying may be determined by the canopy cover, height of weeds and other vegetation, wind conditions and desired application swath. The spraying flight path can be automated or manual, depending on the weed distribution and the site conditions.

Figure 8 Example of drone spraying apparatus (equinoxdrones.com).

Figure 9: Example of a spraying drone used in the case study.

The herbicide application rate can be planned by defining the flight speed, spray rate, and concentration of the liquid. However, beginning with a test section is also a good idea as the spray can be affected by wind conditions. Habitat conditions and project goals are important considerations when deciding on an application rate and discussing this with the provider.

Additional consideration should be given to the climate and weather conditions including any standing water on site (which should not be sprayed), and wind forecast (low wind is preferable). Providers can advise on their requirements. Best results have been shown for monoculture weed species in dense patches (Roslim *et al*. 2021).

X. **Assess the site hydrology and revegetation conditions to determine if a drone or manual approach is more suitable.** Consider standing water at seasonally wet or flooded sites and investigate the regional ecosystem and any known planting and seeding revegetation results from nearby sites.

5 Drones for Revegetation

Using drones for revegetation is becoming more common, particularly in forestry applications in areas with challenging terrain that may have been affected by natural disaster or deforestation (Marzuki *et al*. 2021). Drone revegetation methods can be cost effective, especially in remote locations (Robinson *et al*. 2022). Using drones for revegetation in ecological restoration is relatively new and there are limited peer-reviewed studies. Some examples include using drones for mangrove revegetation in Myanmar and the United Arab Emirates (Mohan *et al*. 2021).

There is a large range in the effectiveness of restoration methods demonstrated in survival rates for drone revegetation with some studies showing less than 20% success in seedling establishment (Aghai & Manteuffel-Ross 2020). In some regions, these low rates are comparable to success rates from manual seeding however manual seeding success rates are often over 80% (Shackleford *et al*. 2021, Woods *et al*. 2019). This is a key consideration when deciding what method to use and weighs heavily on cost-effectiveness.

The site should be assessed for suitability for drone seeding, including on-site assessments and desktop research. The site ecology, resilience and diversity of present species, weather conditions, and proposed area for revegetation should be considered.

The two main approaches for seed dispersal by drone are broadcast seeding with loose seed, and a distribution of a seed packet or puck (Robinson *et al*. 2022). The selected method between these two approaches will depend on the site conditions (including soil types, hardness, and proposed vegetation), seed species and sizes, timeframe and budget of project, and capacity of drone providers. Using a packet or puck has the ability to increase germination potential by increasing seed-soil contact and potentially including fertilising or water retention agents in some habitats. However, there are higher costs and longer timeframe considerations when designing and testing these pucks.

Regardless of the seeding method selected, it is important to discuss the drone seed dispersal mechanism and apparatus with the provider. It is usually helpful to provide a sample of seed to the provider so they can test the hopper with the actual seed shape and size, and work on refining the dispersal rate. The dispersal rate will be achieved by the flight time, flight height, and the size of the seed release aperture opening. A single type or a mix of seeds can be delivered at one time, though there are limitations in the size and shape of the seeds, which should be discussed with the provider. They may have potential adaptations or additional attachments to accommodate for a variety of seed shapes and sizes (**Figure 10**).

Figure 10 Examples of seed payload (left), and a modified claw attachment (right) supplied by provider as a solution to disperse uniquely shaped seeds from the case study.

The revegetation flight path can be manually flown to target certain areas or automated for a uniform dispersal. The drone seed dispersal aperture can be separately activated so that the seed is not dispersed until the drone reaches the desired location. This can be very important for mid-flight battery changes and refilling the seed hopper. Ideal site conditions for seed germination should be considered when planning the timing for drone seeding. The site conditions, selected seed species, weather conditions and seeding method used should all be considered.

XI. **Assess specialized manufacturing options, cost, and timeframes (e.g., development of a seed puck or specialized drone attachments).** Consider providers capacity for specialized needs and associated requirements, with regular consultation with providers as this is a rapidly developing area. Consider testing new methods and applications with the providers ahead of the planned field work.

6 Full List of Guidelines

I. **Assess the site suitability for drone application as compared to manual approaches including safety, restoration capacity, and known limitations.** Consider canopy cover, site accessibility for vehicles and personnel, on-ground hazards such as crocodiles, rough terrain (mud or steep slope), flight restriction zones, cost, and effectiveness.

II. **Assess the cost-effectiveness of drone applications compared to manual by researching comparative effectiveness of seeding applications in similar environments and obtaining quotes from providers for drone and manual applications (a cost-effectiveness matrix can be used).** Consider effectiveness of planting methods in the region and relevant literature indicating effectiveness of drone applications in similar habitats, as well as insights from providers when obtaining quotes.

III. **Assess if a drone or manual approach aligns better with the desired project and ecological outcomes.** Consider site impact by vehicle and foot traffic, precision of weed treatment application requirements, and potential to engage with local providers.

IV. **Assess your business strategy to determine if drone equipment, tools and training should be sourced in-house or via contracted providers.** Consider cost, business strategy, and accessibility of equipment, training, and providers.

V. **Assess provider suitability to deliver against the project costs and needs.** Consider industry availability and pricing between projects (there may be new providers or lower cost options), and consult with providers about project needs, they may be able to do more than standardly advertised.

VI. **Plan a site visit and develop a project communication plan with your provider.** Consider taking providers for a site assessment, they may identify additional opportunities or constraints. Developing a communication plan with the provider will enable you to plan for weather restrictions and discuss any changed plans.

VII. **Assess if a manual or automated flight path is more suitable for your site(s) and project.** Consider your site conditions (trees, site layout), project drone application needs (such as swath consistency), and implications of flight path and associated swath on analysis. It is also important to discuss the options and implications with your provider.

VIII. **Discuss data resolution and accuracy, data format options, and analysis needs with provider(s) to align with your project budget, analysis, and reporting requirements.** Consider your needs and allow for open communication with providers on their capacity and needs across the duration of the project (e.g., ground control mapping, flight path planning, and monitoring data analysis and software needs).

IX. **Assess if using a single provider or multiple providers is more beneficial for your project.** Consider capacity, consistency, and collaboration scope if using multiple providers (e.g., sharing ground control point mapping).

X. **Assess the site hydrology and revegetation conditions to determine if a drone or manual approach is more suitable.** Consider standing water at seasonally wet or flooded sites and investigate the regional ecosystem and any known planting and seeding revegetation results from nearby sites.

XI. **Assess specialized manufacturing options, cost, and timeframes (e.g., development of a seed puck or specialized drone attachments).** Consider providers capacity for specialized needs and associated requirements, with regular consultation with providers as this is a rapidly developing area. Consider testing new methods and applications with the providers ahead of the planned field work.

7 References

Aghai, M. and Manteuffel-Ross, T., 2020. Enhanced direct seedling efforts with unmanned aerial vehicle (UAV) “swarms” and seed technology. *Tree Plant. Notes*, *63*(2), pp.32-48.

Akumu, C.E., Amadi, E.O. and Dennis, S., 2021. Application of drone and worldview-4 satellite data in mapping and monitoring grazing land cover and pasture quality: Pre-and post-flooding. *Land*, *10*(3), p.321.

Beaver, J.T., Baldwin, R.W., Messinger, M., Newbolt, C.H., Ditchkoff, S.S. and Silman, M.R., 2020. Evaluating the use of drones equipped with thermal sensors as an effective method for estimating wildlife. *Wildlife Society Bulletin*, *44*(2), pp.434-443.

Buters, T.M., Bateman, P.W., Robinson, T., Belton, D., Dixon, K.W. and Cross, A.T., 2019. Methodological ambiguity and inconsistency constrain unmanned aerial vehicles as a silver bullet for monitoring ecological restoration. *Remote Sensing*, *11*(10), p.1180.

Camarretta, N., A. Harrison, P., Lucieer, A., M. Potts, B., Davidson, N. and Hunt, M., 2020. From drones to phenotype: Using UAV-LiDAR to detect species and provenance variation in tree productivity and structure. *Remote Sensing*, *12*(19), p.3184.

Cruzan, M.B., Weinstein, B.G., Grasty, M.R., Kohrn, B.F., Hendrickson, E.C., Arredondo, T.M. and Thompson, P.G., 2016. Small unmanned aerial vehicles (micro-UAVs, drones) in plant ecology. *Applications in plant sciences*, *4*(9), p.1600041.

Frankelius, P., Norrman, C. and Johansen, K., 2019. Agricultural innovation and the role of institutions: lessons from the game of drones. *Journal of Agricultural and Environmental Ethics*, *32*(5), pp.681-707.

Hamylton, S.M., Morris, R.H., Carvalho, R.C., Roder, N., Barlow, P., Mills, K. and Wang, L., 2020. Evaluating techniques for mapping island vegetation from unmanned aerial vehicle (UAV) images: Pixel classification, visual interpretation and machine learning approaches. *International Journal of Applied Earth Observation and Geoinformation*, *89*, p.102085.

Harrison, P.A., Camarretta, N., Krisanski, S., Bailey, T.G., Davidson, N.J., Bain, G., Hamer, R., Gardiner, R., Proft, K., Taskhiri, M.S. and Turner, P., 2021. *From communities to individuals: Using remote sensing to inform and monitor woodland restoration* (Vol. 22, pp. 127-139).

Jones, H.G. and Vaughan, R.A., 2010. *Remote sensing of vegetation: principles, techniques, and applications*. Oxford university press.

Marzuki, O.F., Teo, E.Y. and Rafie, A.S.M., 2021. The mechanism of drone seeding technology: a review. *Malays Forester*, *84*(02), pp.349-358.

McCann, J.A., Keith, D.A. and Kingsford, R.T., 2022. Measuring plant biomass remotely using drones in arid landscapes. *Ecology and Evolution*, *12*(5), p.e8891.

Milling, P., 2018. Unmanned aerial vehicles used to control giant reed (Arundo donax L.). In *21st Australasian Weeds Conference," Weed Biosecurity-Protecting our Future", Sydney, New South Wales, Australia, 9-13 September 2018* (pp. 177-180). Weed Society of New South Wales Inc.

Mohan, M., Richardson, G., Gopan, G., Aghai, M.M., Bajaj, S., Galgamuwa, G.P., Vastaranta, M., Arachchige, P.S.P., Amorós, L., Corte, A.P.D. and de-Miguel, S., 2021. UAV-supported forest regeneration: Current trends, challenges and implications. *Remote Sensing*, *13*(13), p.2596.

Naughtin C, Horton J, Pham H. 2019. New smarts: Supporting Queensland’s knowledge-intensive industries through science, research, and innovation. CSIRO Data61: Brisbane, Australia.

Ntalakas, A., Dimoulas, C.A., Kalliris, G. and Veglis, A., 2017. Drone journalism: Generating immersive experiences. *Journal of Media Critiques [JMC]*, *3*(11).

Queensland Drone Strategy. 2018. Queensland Government, State of Queensland

Rao, B., Gopi, A.G. and Maione, R., 2016. The societal impact of commercial drones. *Technology in society*, *45*, pp.83-90.

Robinson, J.M., Harrison, P.A., Mavoa, S. and Breed, M.F., 2022. Existing and emerging uses of drones in restoration ecology. *Methods in Ecology and Evolution*, *13*(9), pp.1899-1911.

Roslim, M.H.M., Juraimi, A.S., Che'Ya, N.N., Sulaiman, N., Manaf, M.N.H.A., Ramli, Z. and Motmainna, M., 2021. Using remote sensing and an unmanned aerial system for weed management in agricultural crops: A review. *Agronomy*, *11*(9), p.1809.

Rummell, A.J., Leon, J.X., Borland, H.P., Elliott, B.B., Gilby, B.L., Henderson, C.J. and Olds, A.D., 2022. Watching the Saltmarsh Grow: A High-Resolution Remote Sensing Approach to Quantify the Effects of Wetland Restoration. *Remote Sensing*, *14*(18), p.4559.

Shackelford, N., Paterno, G.B., Winkler, D.E., Erickson, T.E., Leger, E.A., Svejcar, L.N., Breed, M.F., Faist, A.M., Harrison, P.A., Curran, M.F. and Guo, Q., 2021. Drivers of seedling establishment success in dryland restoration efforts. *Nature ecology & evolution*, *5*(9), pp.1283-1290.

Suir, G.M., Saltus, C.L., Sasser, C.E., Harris, J.M., Reif, M.K., Diaz, R. and Giffin, G., 2021. Evaluating drone truthing as an alternative to ground truthing: an example with wetland plant identification.

Wet Tropics Major Integrated Project – Final Performance Report: Putting Local Knowledge into Reef Action. 2021. Queensland Government

Wilson, J., Amano, T. and Fuller, R.A., 2022. Using Drones to Survey Shorebirds.

Woods, M.J., Cobb, M., Hickle, K. and McEwan, R.W., 2019. Assessing the efficacy of seedling planting as a Forest restoration technique in temperate hardwood forests impacted by invasive species. *Forests*, *10*(8), p.699.

Greening Australia

Innovative Drone Project

Cost Effectiveness Matrix

June 2023
Greening Australia

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1. Introduction

The project ‘Trialling the Use of Drones in Riparian Restoration’ was delivered by Greening Australia’s Reef Aid Program from April 2021 to June 2023. The project was funded by the Great Barrier Reef Foundation Reef Trust Partnership. The project’s objective was to compare drone and manual approaches for riparian and wetland restoration in the Great Barrier Reef catchment to identify where using drones may be more cost effective or address other limitations with manual approaches. These insights have been shared with regional delivery stakeholders so that they can understand when and how they may integrate drone applications in their riparian and wetland restoration projects, in the Best Practice Guidelines report.

This technical report provides the cost effectiveness matrix and supporting context from this project, as well as a blank template which can be used for user-based assessments as a decision support tool.

2. Background

Riparian and wetland restoration projects are often constrained by site access due to boggy terrain and safety issues such as crocodiles. Additional limitations of cost can prevent upscaling of efforts, as project sites are often remote, costing more to access and deliver outcomes. This project has conducted *in-situ* trials to identify where using drones in wetland repair can address these limitations. Three aspects of restoration have been evaluated for drone application including revegetation, weed treatment, and monitoring.

Drone technology is rapidly developing with a more accessible commercial industry for environmental applications. A limitation for using these technologies in restoration projects is the lack of information about best practice applications and when it is cost effective. This project will provide information that can be used to support decision making around this.

This cost effectiveness matrix includes context and analysis for comparing drone and manual applications for revegetation, weed treatment, and monitoring. The case study took place in three regions in the Great Barrier Reef catchment (Figure 1):

1. Ross Road – Mulgrave-Russell Catchment (50 km from Cairns);
2. Viv Cox – Burdekin Catchment (100 km from Townsville); and
3. Big Dune Reserve – Fitzroy Catchment (10 km from Yeppoon).

Figure 1 Location of case study sites.

3. Cost Effectiveness Ratings

To compare drone technology to manual approaches for cost and effectiveness, a rating system has been created which can be used in decision making (Table 1), adapted from the decision-making tree in Rasanen 2007.

	Less effective	**Same effectiveness**	**More effective**
Less costly	No clear decision, situational assessment required	Adopt drone technology	Adopt drone technology
Same cost	Keep using manual approach	The approaches are equal, use other situational assessments to decide	Adopt drone technology
More costly	Keep using manual approach	Keep using manual approach	No clear decision, situational assessment required

Table 1 Cost effectiveness ratings comparing drone technology to manual approaches.

4. Revegetation

The revegetation approaches being compared are manual broadcast seeding and drone broadcast seeding. Drone seeding for environmental restoration has been used increasingly in recent years with identified potential for upscaling impact with reduced cost (Robinson et al. 2022). Drone uses must be considered under the context of national and regional regulations and ecological conditions. Therefore, the understanding of drone methods and uses for revegetation are best considered with regionally specific context. In this project the drone applications fall under the Australian National Civil Aviation Safety Authority (CASA) regulations, managed by the contracted drone operator. The environmental context includes the Queensland state regional ecosystems descriptions, habitat assessments, site history, and local and expert knowledge. These environmental components are all also considerations for manual revegetation.

The effectiveness of the drone and manual seeding were measured by average percent germination. The seeding zones were sub-sampled with quadrat assessments for germination using a 50cm quadrat assessing native species germination percent cover with a minimum of ten replicates per seeding zone. The project vegetation assessment methodology was adapted from the Queensland Government Habitat Quality Assessment Guide (QLD Government 2017; p.13, step 3).

The cost for drone and manual seeding were calculated as cost per hectare to de-identify contractor costings and provide comparative values. Considerations for increasing scale should be made around cost, with potential for cost differences to increase greatly as the project scale increases. The cost for drone applications has relatively minimal increased costs with increased project scale, while the cost for manual applications increases more rapidly. This understanding has been developed from consultation with delivery partners and contractors.

Case Study Analysis Results – Revegetation

Revegetation Effectiveness and Cost

Revegetation effectiveness has been assessed from percent germination based on a representative sample under the method described above. The percent germination effectiveness is categorised for the matrix in the following three categories of High (51-100%), Medium (21-50%), and Low (0-20%). The sites were assessed for germination at three points following seeding with the first assessment 6-10 weeks following seeding, the second at start of the wet season and the third at the end of the wet season, in order to capture optimal germination windows and seasonal variations. Germination in both manual and drone seeding zones was low, ranging from 0-18.5% (Table 2, Figure 2).

	Average of Native germinating % cover	Effectiveness Categorisation
Ross Road		
drone	**0**	**Low**
1	0	
2	0	
3	0	
manual	**0**	**Low**
1	0	
2	0	
3	0	
Viv Cox		
drone	**1.66**	**Low**
1	2.5	
2	0.42	
3	2.08	
manual	**2.22**	**Low**
1	3.33	
2	0.83	
3	2.5	
Big Dune		
drone	**7.33**	**Low**
1	12	
2	7	
3	3	
manual	**10.83**	**Low**
1	1.5	
2	18.5	
3	12.5	

Table 2 Averages of native germination percent cover for trial zones (drone and manual) by site (Big Dune, Ross Road, Viv Cox) for the three germination assessments.

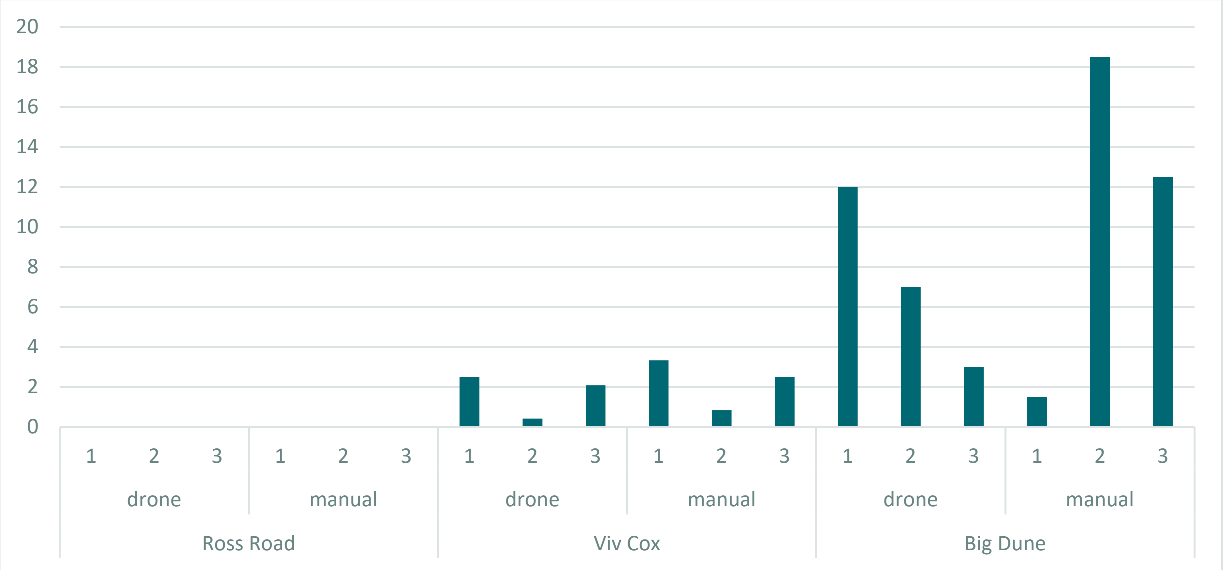

Figure 2 Graph of averages of native germination percent cover for trial zones (drone and manual) by site (Big Dune, Ross Road, Viv Cox) for the three germination assessments.

Revegetation costs from the project are listed in Table 3 and do not include provider travel costs.

Manual seeding	$2,105.52/Ha
Drone seeding	$1,568.00/Ha

Table 3 Manual and drone seeding costs per hectare.

5. Weed Treatment

The weed treatment approaches being compared are drone manual flights with targeted delivery around trees and manual weed control also following this approach but with backpack on-foot spraying. The effectiveness of weed treatment has been proven for both methods in commercial use (Esposito et al. 2021). The effectiveness for this project was checked following treatment with visual and photo point assessments. The cost for drone and manual weed treatment are calculated as cost per hectare to de-identify contractor costings and provide comparative values.

Similar to revegetation, considerations for increasing scale should be made around cost, with potential for cost differences to increase greatly as the project scale increases. The cost for drone applications has relatively minimal increased costs with increased project scale, while the cost for manual applications increases more rapidly. This understanding has been developed from consultation with delivery partners and contractors. The type of drone weed treatment applied will affect cost, with automated flights potentially taking less time than manual flights.

Case Study Analysis Results – Weed Treatment

Weed Treatment Effectiveness and Cost

Weed treatment effectiveness for drone and manual treatment has been assessed from visual assessments and photo point monitoring under the method described above, with two treatments at the Viv Cox site. The effectiveness is categorised for the matrix in the following three categories of High (51-100%), Medium (21-

50%), and Low (0-20%). The site was assessed for weed treatment effectiveness following treatment, with high treatment effectiveness achieved for both drone and manual approaches (Table 4, Figure 3).

	Weed Treatment Effectiveness	Effectiveness Categorisation
Viv Cox		
Manual	95%	High
Drone	95%	High

Table 4 Weed Treatment percent effectiveness and categorisation for drone and manual applications at Viv Cox.

Figure 3 Manual (top left) and drone (top right) weed treatment conducted at Viv Cox and repeated photo point images from pre-weed treatment in 21/03/2022 and post-weed treatment in 15/06/2022 at Viv Cox following drone weed treatment on 20/04/2022.

Site variations may impact effectiveness of weed treatment, including vegetation density which may impact access and distribution of weeds across site, such as either in large targetable clumps or thinly dispersed between native vegetation. Effectiveness is also dependent on herbicide concentration and application rate.

Weed treatment costs from the project are listed in Table 5.

Manual weed treatment	$1,782.46/Ha
Drone weed treatment	$1,405.32/Ha

Table 5 Manual and drone weed treatment costs per hectare.

6. Monitoring

Comparing drone and manual monitoring is more complex than the above components, as there is a big range of potential monitoring analysis from drone data collection and multiple potential manual methods for monitoring. Therefore, this project is limited to comparing cost and effectiveness of the approaches implemented, and additional detail on other drone monitoring analysis options is discussed in the Best Practice Guidelines.

Case Study Analysis Results – Monitoring

Monitoring Effectiveness and Cost

Monitoring effectiveness has been categorised for the matrix as ‘Successful’ (successful data collection under prescribed method) or ‘Unsuccessful’ (unsuccessful data collection). Manual monitoring included vegetation assessment, germination assessment, and photo monitoring point assessments. Drone monitoring included repeated and ground-truthed orthomosaic assessment. Monitoring by both drone and manual methods were successful at all three sites (Table 6). For detailed monitoring results please refer to the Project Final Report.

	Effectiveness Categorisation
Ross Road	
Manual	Successful
Drone	Successful
Viv Cox	
Manual	Successful
Drone	Successful
Big Dune	
Manual	Successful
Drone	Successful

Table 6 Effectiveness categorisation of monitoring by drone and manual methods at the three project sites.

Monitoring costs from the project are listed in Table 7 showing cost per event for manual monitoring (vegetation, germination, and photo point), and drone monitoring (including orthomosaic data capture and processing). For both manual and drone monitoring there are many additional analysis options which would increase costs.

Manual monitoring	$3,666.20/event
Drone monitoring	$1,034.88/event

Table 7 Manual and drone monitoring costs per monitoring event.

7. Cost Effectiveness Matrix

The cost effectiveness matrix combines the effectiveness results and costs for the project listed above in the decision support tool matrix, resulting in one of three ratings (1) no clear decision, situational assessment required, (2) keep using manual approach, or (3) adopt drone technology. This project has shown that it can be more cost effective to adopt drone technology for riparian and wetland restoration (Table 8).

	Effectiveness	Cost	Cost effectiveness rating
Revegetation			Revegetation: Adopt drone technology
Manual	Low	$2,105.52 /Ha	
Drone	Low	$1,568.00 /Ha	
Weed Treatment			Weed Treatment: Adopt drone technology
Manual	High	$1,782.46 /Ha	
Drone	High	$1,405.32 /Ha	
Monitoring			Monitoring: Adopt drone technology
Manual	Successful	$3,666.20 /event	
Drone	Successful	$1,034.88 /event	

Table 8 Cost effectiveness matrix with results from the project.

8. References

Esposito, M., Crimaldi, M., Cirillo, V., Sarghini, F., & Maggio, A. (2021). Drone and sensor technology for sustainable weed management: A review. *Chemical and Biological Technologies in Agriculture*, *8*(1), 1-11.

QLD Government (2017) Guide to determining terrestrial habitat quality, A toolkit for assessing land based offsets under the Queensland Environmental Offsets Policy, Version 1.2

Räsänen, P. (2007). Routine measurement of health-related quality of life in assessing cost-effectiveness in secondary health care.

Robinson, J. M., Harrison, P. A., Mavoa, S., & Breed, M. F. (2022). Existing and emerging uses of drones in restoration ecology. *Methods in Ecology and Evolution*.

9. Appendix A

This is a template for user-based assessment to allow for changing costs, effectiveness, or additional components, adapted from the decision-making tree in Rasanen 2007.

	Effectiveness	Cost	Cost effectiveness rating
Revegetation			
Manual			
Drone			
Weed Treatment			
Manual			
Drone			
Monitoring			
Manual			
Drone			

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