Comparing traditional and unmanned aerial vehicles (UAV) assessment methodologies in aquatic weed control research

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Summary Weed control research involves pre and post treatment measurement of various plant attributes to determine treatment efficacy. Aquatic systems are challenging environments presenting specific risks, such as crocodiles, when conducting aquatic weed control trials in tropical Australia. The rapid emergence of technologies such as unmanned aerial vehicles (UAV's) provides the opportunity to remotely collect data via the capture of high-definition imagery; therefore reducing risks whilst conducting research within aquatic systems. UAVs collect data in various parts of the electromagnetic spectrum including visible and infrared (which is particularly relevant to plants due to chlorophyll production). The use of drone-based assessment technology has the potential to augment, if not replace, traditional methods of determining herbicide efficacy. This study compared traditional ground-based (live stems counts and visual damage scores) collected data with remotely sensed UAV (Red Green Blue (RGB) and multispectral images for photogrammetry processing) data to determine whether UAVs could be used to assess the efficacy of field herbicide treatments on the ponded pasture species, Aleman grass (*Echinochloa polystachya*) (Kunth) Hitch.

There was a strong correlation between on-ground and aerial efficacy assessment results for some of the treatments. The correlation was consistent across the higher levels of treatment damage. The use of remotely captured imagery obtained via the UAV proved to be a reliable method for assessing treatment effects over time.

Keywords Aleman grass, Echinochloa polystachya, herbicides, remote sensing.

INTRODUCTION

Aleman grass is a high-impact environmental species in Australia (Van Klinken *et al.* 2018). This ponded pasture species has become invasive in wetland areas of north Queensland, where it often grows alongside Para grass (*Urochloa mutica*) (Forssk.) T.Q. Nguyen, and hymenachne (*Hymenachne amplexicaulis*) (Rudge) Nees, however it has the capacity to colonise even deeper water than either of those species (Hannan-Jones and Weber 2016). Pizzaro (1999) describes it as "a semiaquatic macrophyte that roots in the littoral sediments of water bodies and forms dense meadows with prolific perennial growth". Aleman grass often grows in aquatic situations where access for traditional methods of control and assessment is limited.

We conducted a field trial to identify effective herbicides and application rates for Aleman grass control near Ingham in north Queensland (Lat: 18.70713, Long:146.17411) with results seen in Setter *et al.* (2023). Here, we use the results and analysis of this trial to compare the effectiveness of traditional ground-based herbicide efficacy assessment methods with UAV-based assessments.

DAF has a significant UAV capability and aspects of this were incorporated into this field trial. The UAV component utilised new and innovative remote sensing tools to assess herbicide efficacy. These assessments included capturing high-resolution imagery. Both visible spectrum (RGB) and multispectral imagery were used.

If successful, UAVs could be used both for herbicide application and as an alternative method for assessing herbicide efficacy.

MATERIALS AND METHODS

The site chosen for the four-month field trial was permanently wet and subject to seasonal inundation but still accessible for the on-ground treatments and assessments. The field trial consisted of 45, 5 m x 5 m plots, each allocated a randomised herbicide treatment, plus three control plots. For spray methods and further details refer to Setter *et al* (2023). There was a two-metre buffer between plots. This provided the opportunity for each plot to be assessed individually over the duration of the trial.

For the traditional assessment at each allocated time the number of live stems was assessed using four randomly placed 25 cm x 25 cm quadrats per plot. Live stems were physically counted by two operators. Vegetation colour was individually estimated over the entire plot and was given a ranking of % green, yellow or brown. This method provided both a quantitative and qualitative assessment result.

UAV imagery was obtained using a DJI Phantom 4 Multispectral combined with a DJI D-RTK 2 Mobile Station. The camera sensors are six 1/2 .9" CMOS, including one RGB sensor for visible light imaging and five monochrome sensors for multispectral imaging. Each sensor has 2.08 effective pixels. UAV imagery was processed into orthomosaics using PIX4Dfields software. Plots were digitised into polygons and placed over the orthomosaics in both RGB and multispectral. Three vegetation assessment indices were used to rate the treatment effect: NDVI, GNDVI and LCI. Brief explanations of these follow.

NDVI (Normalised Difference Vegetation Index) is used to quantify vegetation greenness and is useful in understanding vegetation density and assessing changes in plant health. NDVI is calculated from spectrometric data at two specific bands: red and near-infrared. NDVI is calculated as a ratio between the red (R) and near infrared (NIR) values. NDVI = (NIR - R) / (NIR + R).

GNDVI (Green Normalized Difference Vegetation) is an index of plant "greenness" or photosynthetic activity. It is a chlorophyll index used at later stages of development, as it saturates later than NDVI. The GNDVI is more sensitive to the variation of chlorophyll in the crop than the NDVI and has a higher saturation point. GNDVI = (NIR-GREEN) / (NDVI+GREEN). The GNDVI can be used in crops with dense canopies or in more advanced stages of development, while the NDVI is adequate to estimate the vigour of the crop during the initial stages.

LCI (Leaf Chlorophyll Index) is calculated to measure the chlorophyll content in leaves in areas of complete leaf coverage. There are different methods to calculate LCI, often depending on the specific wavelengths used in the analysis. In this case we used ((NIR – Rededge) / (NIR + R)).

The indices values were run in PIX4Dfields zonal statistics software package to determine quantitative values. These values were then analysed using Genstat® Edition 24 (VSNI 2024) to assess statistical significance. ANOVA and Fisher's Protected LSD ($P<0.05$) test were used to determine significant differences between treatments.

The assessment methodology comparison trial gave information on the correlation between field-collected/quantitative effects of herbicides on Aleman grass and UAV remotely sensed qualitative results which were processed into a quantitative value.

RESULTS

As can be seen in Table 1., comparisons between traditional and UAV assessment methods of herbicide efficacy were done. Although the output recorded was different between the traditional and UAV assessment methodology, the results were able to be analysed to show which treatments had the highest mortality effect on Aleman grass plants. A strong correlation between methods at the higher level of damage suggests UAV image acquisition was accurate for plant health determination.

Whilst there was slight variation, all three UAV methods, as well as the traditional ground-based assessment method gave the same result for the most efficacious treatments (shown in bold type, Table 1).

DISCUSSION

Use of UAVs can minimise inherent risks of field work, such as heat effects, drowning, crocodile danger, and general physical injuries. As well as making research data collection safer, UAV use may allow data to be collected at times when traditional data collection methods cannot be used, e.g. flooding, or inability to use roads due to flood impacts. This form of data capture has the advantage of not disturbing the plants being measured (i.e. non-destructive, leaving the system intact) (Gracia-Romero *et al*. 2020) (Hussain *et al*. 2020).

An additional benefit of capturing a wide range of digital data using a rapidly developing technology, is that this digital "snapshot" can be reassessed if or when new techniques and systems become available (Gracia-Romero *et al.* 2020 & Barbedo 2019), as was the case in this study. Treatment efficacy tested in this trial was conducted using 2D RGB and multispectral digital imagery. An inherent aspect of UAV-based photogrammetry is that a 3D point cloud is produced during photogrammetry processing. Though not utilised in this trial, this 3D point cloud can be used to generate a highly accurate Digital Elevation Model (DEM) and a Digital Surface Model (DSM). These 3D outputs support additional processing options including height and volume analysis.

Utilising the learnings from this trial, the most successful herbicides were then tested via a large spray drone capable of aerial herbicide application. This process facilitated a subsequent trial, utilizing the most successful herbicides, where the spray drone applied the treatments in an area where other forms of application were not easily/safely able to be done.

This trial was then assessed in a similar manner to the methods described in this paper. UAVs both conducted the trial and performed the assessment; all from the relative safety of the bank.

Table 1. Comparison of results from traditional and UAV methodology of damage assessment. Means within a column that do not share a letter are significantly different ($P < 0.05$) according to Fisher's LSD test. Untreated plants served as a control treatment.

Traditional method			UAV method			UAV method			UAV method		
% Live stem reduction	Mean		GNDVI	Mean		NDVI	Mean		LCI	Mean	
Control	17.3	a	Nominee High	0.845	a	Nominee High	0.841	a	Pledge Medium	0.3045	a
Verdict Low	20.4	ab	Pledge Medium	0.844	a	Pledge Medium	0.837	a	Nominee High	0.3022	a
Nominee High	34.2	abc	Nominee Low	0.838	a	Control	0.8265	a	Nominee Medium	0.2951	a
Pledge High	38.6	abcd	Control	0.838	a	Nominee Low	0.8252	a	Nominee Low	0.2938	a
Nominee Low	39.3	abcd	Nominee Medium	0.837	a	Nominee Medium	0.8198	a	Pledge High	0.2937	a
Pledge Low	39.5	abcd	Pledge High	0.837	a	Pledge High	0.8165	a	Control	0.2919	a
Pledge Medium	47.2	bcde	Verdict Medium	0.83	ab	Verdict Medium	0.8126	a	Pledge Low	0.2785	ab
Verdict Medium	50.8	cdef	Verdict Low	0.828	ab	Verdict Low	0.8087	a	Verdict Low	0.2737	ab
Nominee Medium	52.3	cdef	Pledge Low	0.827	ab	Pledge Low	0.7997	ab	Verdict Medium	0.2735	ab
Poacher Low	**62.6**	**defg**	**Verdict High**	**0.809**	**bc**	**Verdict High**	**0.7566**	**b**	**Verdict High**	**0.2541**	**bc**
Verdict High	**65.5**	**defg**	**Weedmaster Low**	**0.788**	**cd**	**Weedmaster Low**	**0.6903**	**c**	**Weedmaster Low**	**0.2263**	**cd**
Weedmaster Low	**72.6**	**efgh**	**Poacher Low**	**0.783**	**de**	**Poacher Low**	**0.6713**	**cd**	**Poacher Low**	**0.2209**	**cd**
Poacher Medium	**77.3**	**fgh**	**Poacher Medium**	**0.764**	**ef**	**Weedmaster Mediun**	**0.6271**	**de**	**Weedmaster Mediun**	**0.2007**	**de**
Weedmaster Mediun	**85.2**	**gh**	**Weedmaster Mediun**	**0.764**	**ef**	**Poacher Medium**	**0.621**	**e**	**Poacher High**	**0.198**	**de**
Poacher High	**93.4**	**h**	**Poacher High**	**0.759**	**fg**	**Poacher High**	**0.609**	**ef**	**Poacher Medium**	**0.1978**	**de**
Weedmaster High	**94.2**	**h**	**Weedmaster High**	**0.738**	**g**	**Weedmaster High**	**0.5732**	**f**	**Weedmaster High**	**0.1721**	**e**
LSD	27.2		LSD	0.022		LSD	0.0476		LSD	0.0361	

Worldwide, UAVs are playing an increasingly important role in agriculture (Duan *et al.* 2017) and weed management (Esposito *et al.* 2021) (Roslim *et al.* 2021). DroneDeploy©, one of the largest cloud based drone photogrammetry platforms, reported a 76% year on year increase in active users between 2021 and 2023 (DroneDeploy 2022). UAV remote sensing platforms demonstrate operational advantages including low operation cost, near-real-time data acquisition and high-spatial resolution (Hussain *et al*. 2020).

UAVs have been recognized as excellent tools for assessing plant heath when compared to ground-based in-field measurements (Enciso *et al*. 2019) (Tattaris *et al.* 2016). Across the Queensland Department of Agriculture and Fisheries (DAF), for example, there are now 86 registered UAV pilots performing hundreds of assessment flights covering thousands of hectares each year. A subset of these assessments are used to evaluate the results of agricultural trials conducted to evaluate herbicide, insecticide and fertilizer application (pers. comm. Marcus Bulstrode).

UAVs are able to capture large amounts of data which can exceed the amount of data recorded though on-ground assessments. Having the option to capture a greater proportion of the plant canopy can improve treatment differentiation (Gracia-Romero et al. 2020).

Göktoˇgan *et al*, (2009) found an autonomous rotary wing unmanned air vehicle (RUAV) to be a cost-effective tool for the surveillance and management of aquatic weeds, specifically Alligator weed (*Alternanthera philoxeroides*) and Salvinia (*Salvinia molesta*) in New South Wales. Olson & Anderson (2020) list several pitfalls related to UAV-based remote sensing including data degradation due to lighting conditions, airspace restrictions and inclement weather.

Restrictions around the use of UAV technology in Australia include flight regulations and geographical scale. Flying UAVs in Australia (as with much of the world) is highly regulated. Requirements such as Visual Line of Sight (VLOS) impact on the ability of the equipment to cover large geographical areas. Though existing satellite-based equipment can cover large geographical areas and have long duration data sets, there is a limit to image resolution and the ever-present potential for atmospheric interference. For the trial assessment plot size used in this paper, only UAV-based imagery could have captured data at the required resolution (Ground Sampling Distance (GSD) < 5 cm).

In aquatic systems, and elsewhere UAVs now have the capability to both apply the treatments (herbicide) as well as perform the assessment process. These assessments can be conducted at a greater temporal frequency than ground assessment and use multiple sensors.

Though there are still developments occurring, the technology incorporated in UAV flight platforms is reasonably mature. Big advances are still occurring in UAV digital data processing software. This is one of the reasons that preciously captured data may provide additional scientific results in the future.

Milling (2019), notes that for some time UAVs use for weed control, had been restricted, but records using the UAV as a tool to apply herbicide resulting in 80–90% brownout of giant reed after a single treatment using glyphosate.

One of the biggest advantages of digital UAV data capture that should be stressed is the ability to record the data once then analyse it using multiple different (current and future) indices or systems.

CONCLUSIONS

We conclude that the use of UAVs to assess weed control activities, particularly in aquatic or other inhospitable or inaccessible environments, is undoubtedly the best option in many situations.

There are additional benefits such as time savings, the option to reevaluate the source data and potential future utilisation of the multifaceted data collected.

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