

A Hybrid UAV Ground-Truthing Methodology for Mapping Invasive Plant Species in Australian Rangelands

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Summary Accurate ground truth data underpins the development of robust machine-learning models for unmanned aerial vehicle (UAV) based weed detection. In remote Australian rangelands, however, acquiring such data is constrained by limited mobile connectivity, heterogeneous terrain and the visual similarity of co-occurring invasive species. This paper presents a hybrid field methodology for collecting ground truth data to support UAV-based mapping of Chinese apple (*Ziziphus mauritiana*) and Prickly acacia (*Vachellia nilotica*) weeds across four sites near Bowen, Queensland. Two complementary ground-truthing technologies were evaluated and combined: a low-cost manual method using colour-coded cardboard markers, and an automated, survey-grade real-time kinematic (RTK) Global Navigation Satellite System (GNSS) using a DJI D-RTK 3 Mobile Station. A total of 192 markers were placed across three connectivity-limited sites, while centimetre-level coordinates were logged for ten individuals of each species at the RTK site. The two technologies were not flown and compared at the same site, and this paper is therefore presented as a preliminary, descriptive assessment of their respective feasibility and data yield rather than a controlled comparison of mapping accuracy.

Keywords Artificial intelligence, Chinese apple-*Ziziphus mauritiana*, ground truth, object detection, Prickly acacia- *Vachellia nilotica*, rangelands, remote sensing, RTK GNSS, weed mapping.

INTRODUCTION

Invasive woody weeds pose a sustained threat to the productivity and biodiversity of Australian ecosystems, including rangelands [1-2]. Chinese apple (*Ziziphus mauritiana* Lam.) and Prickly acacia (*Vachellia nilotica*) are two of the most widespread woody invaders in northern Queensland, forming dense thickets that displace native vegetation and reduce grazing capacity [2]. Effective control at

landscape scale depends on accurate, timely information about spatial distribution and density. Traditional ground-based surveys are reliable at plot scale but labour-intensive and difficult to scale across the vast properties typical of northern Australian rangelands. UAVs equipped with high-resolution RGB and multispectral sensors offer a practical alternative for mapping woody weeds at intermediate scales, bridging the gap between ground surveys and satellite imagery [3]. Platforms such as the DJI Matrice 300 RTK with Zenmuse P1 camera and the DJI Mavic 3 Multispectral have demonstrated high utility for environmental mapping [4]. This labour saving is realised once a detection model is trained: a single, localised ground-truthing exercise can then support repeated large-area surveys without further ground visits, so the field effort here is a one-off training investment, not a substitute for that saving.

Acquiring such ground truth data in remote Australian rangelands is non-trivial. The most accurate technologies - survey-grade RTK GNSS (Global Navigation Satellite System) receivers - depend on a continuous correction stream delivered over a mobile network or comparable link [5]. Across much of inland northern Australia this infrastructure is absent or intermittent, making an RTK-only protocol impractical at the regional scale. Less precise alternatives (e.g. handheld GNSS or post-hoc visual interpretation of orthomosaics) introduce positional and species-label noise that is problematic for training pixel-level or object-detection models [6].

This paper presents a preliminary assessment of two ground-truthing technologies for UAV-based weed mapping, addressing the need for practical approaches to collecting species-validated field data in connectivity-limited settings. Two technologies were deployed across four sites near Bowen, northern Queensland: a manual, colour-coded cardboard marker system suitable for internet connectivity-limited sites, and an automated, survey-grade RTK

GNSS using a DJI D-RTK 3 Mobile Station for sites with stable correction signals [5]. Because the two technologies were deployed at different sites rather than compared directly at the same site, this study does not establish their relative mapping accuracy; instead, it asks the narrower question of whether each technology can feasibly produce usable, species-validated ground-truth records under the connectivity conditions for which it is suited, as a first step toward a future controlled comparison.

MATERIALS AND METHODS

Study sites and connectivity assessment: Field work was conducted across four sites in the Bowen region of northern Queensland, an area where Chinesee apple and Prickly acacia tree weeds co-occur within open woodland and grazing landscapes. Three of the sites were inland in topographically complex terrain with limited or no reliable mobile coverage; the fourth was a coastal site with stable mobile coverage and dependable RTK correction signals.

Selection of ground-truthing technology The two technologies differ in accuracy, cost and infrastructure needs. RTK GNSS delivers centimetre level positioning but requires a stable correction-signal stream [5]; the manual marker method delivers unambiguous in-image references at metre-scale accuracy using only field-team labour and a small consumables budget. Sites with reliable RTK signals were assigned the RTK protocol; the three sites with unreliable or absent signals were assigned the marker protocol.

Manual ground truthing using colour-coded markers At the three connectivity-limited sites, a colour-coded cardboard marker system was used to identify individual target plants in subsequent UAV imagery. Each marker was a white rectangular/square cardboard (50 x 40 cm or 30 x 20 cm) with a brightly coloured one-direction arrow painted on it (Fig 1): blue markers were placed adjacent to mature Chinesee apple plants, and pink markers adjacent to Prickly acacia and/or juvenile Chinesee apple plants.



Figure 1. UAV image of Chinesee apple trees at 30m altitude with visible plotted manual markers

Each cardboard was secured with a metal pin within one to two metres of the trunk of the target plant, during a single field campaign immediately prior to UAV flights to minimise weather-related degradation. Across the three marker-based sites, 192 markers were placed in total, spanning both mature and juvenile individuals of the two weed species.

Automated RTK GNSS ground truthing At the fourth, coastal site, a DJI D-RTK 3 Mobile Station was operated in Rover station mode, connecting to correction signals via the mobile network to log centimetre level coordinates at the trunk of each target plant. Ten individuals of each species were surveyed, yielding twenty high-precision points, each recorded as a check point with a fixed convergence count of 5 epochs.

UAV data acquisition Aerial imagery was acquired at all four sites using two UAV platforms: a DJI Matrice 300 RTK with Zenmuse P1 45-megapixel camera for RGB capture, and a DJI Mavic 3 Multispectral for green, red, red edge and near-infrared bands. Each site was flown at 12 m, 30 m and 70 m, using 70% side and 80% forward overlap. The 12 m flights suit fine-scale crown differentiation and juvenile plant detection; 30 m and 70 m give progressively broader coverage for landscape-scale mapping. The same specification was used at all sites, so imagery is directly comparable.

RESULTS

Manual marker dataset Across the three connectivity-limited sites, all 192 markers were placed in a single field campaign without any live data link, confirming the manual protocol can be executed with minimal infrastructure. Because each marker is imaged with its target plant (Figure 1), the ground-truth record is preserved within the orthomosaic itself, independent of any external geospatial layer. The blue and pink markers were clearly distinguishable from ground cover and from each other at 12 m and 30 m, and remained identifiable at 70 m, sufficient for species- and growth-stage-level labelling without ambiguity.

Automated RTK GNSS ground truthing

The spatial layout of all twenty check points is shown in Figure 2, and the full coordinate record - including per-point horizontal and vertical positional precision - is provided in Table 1.



Figure 2. Orthomosaic of the coastal site highlighting RTK-identified chinese apple and prickly acacia trees (white rings).

Table 1 shows two outlier points - prickly acacia P5 (vertical SD 3.37 cm) and Chinese apple C6 (vertical SD 1.75 cm) - most likely associated with brief, localised reductions in correction signal stability. Despite these, the mean horizontal and vertical SD across the 20 points are 1.17 cm and 0.91 cm, respectively, consistent with the manufacturer's stated RTK performance under good correction conditions and well within the precision needed to associate each record with a single plant in 12 m, 30 m and 70 m UAV imagery.

Table 1. Full record of the 20 RTK GNSS checks points logged at the coastal site using a DJI D-RTK 3 Mobile Station.

Point ID	Latitude (°)	Longitude (°)	Altitude (m)	H-SD (m)	V-SD (m)
Prickly 1	-20.108405	148.250229	66.65	0.0085	0.0036
Prickly 2	-20.108198	148.250479	66.05	0.006	0.0041
Prickly 3	-20.107852	148.250439	65.04	0.0068	0.0054
Prickly 4	-20.107718	148.25029	65.05	0.0124	0.0046
Prickly 5	-20.107634	148.250262	64.88	0.0185	0.0337
Prickly 6	-20.107354	148.250344	63.92	0.0084	0.0055
Prickly 7	-20.107203	148.250421	63.33	0.0062	0.0034
Prickly 8	-20.10713	148.250547	63.42	0.0064	0.0081
Prickly 9	-20.107044	148.250523	63.16	0.0086	0.0054
Prickly 10	-20.107084	148.250285	63.48	0.0096	0.0081
Chinese 1	-20.107165	148.250284	63.52	0.0126	0.0097
Chinese 2	-20.107288	148.250199	63.84	0.0066	0.0075
Chinese 3	-20.107582	148.250076	64.79	0.0215	0.0044
Chinese 4	-20.107847	148.250076	65.32	0.0147	0.0152
Chinese 5	-20.108018	148.249955	65.65	0.0259	0.0077
Chinese 6	-20.107826	148.249667	65.17	0.0132	0.0175
Chinese 7	-20.107651	148.24962	64.65	0.01	0.0076
Chinese 8	-20.107587	148.249679	64.38	0.0112	0.0126
Chinese 9	-20.107451	148.249634	64.15	0.0191	0.0138
Chinese 10	-20.107331	148.249648	63.81	0.0074	0.0036
Mean	-	-	-	0.0117	0.0091

Combined hybrid dataset The final ground-truth dataset is the union of the manual and automated records: 192 marker records plus 20 RTK records, for a total of 212 species-validated entries.

DISCUSSION

At the connectivity-limited sites, an RTK-only protocol would have meant accepting an unreliable correction stream or deploying alternative infrastructure [6]; at the coastal site, a marker-only protocol would have under-used the available signal and forfeited RTK's higher-precision benchmark [8]. The work presented here was designed to address a specific operational constraint of weed mapping in northern Australia: the simultaneous need for spatially precise, species-validated training data in the absence of mobile and correction-signal infrastructure across many of the landscape areas where the field work reported here were undertaken. As a preliminary, non-comparative assessment, the following observations can be drawn.

First, the manual colour-coded marker method is a practical, low-cost solution for connectivity-limited sites. With 192 markers deployed across three sites without any live data link, the protocol produced a dense, visually unambiguous ground-truth layer preserved in the UAV imagery itself rather than as a separate geospatial file [8], eliminating drift between independently logged GNSS positions and orthomosaic geometry. Distinct marker colours – of which a third were for juvenile Chinese apple (Figure 2) – also support stage-specific analyses that may be difficult to recover from RTK points alone [8].

Second, automated RTK GNSS ground truthing remains the most precise approach where available; the 20-point coastal dataset in Table 1 and Figure 2 indicates consistent high accuracy, although a sample this size at one site cannot characterise performance region-wide. RTK's main limitation is dependence on mobile reception for the correction stream; growing LEO satellite internet availability (e.g. Starlink) offers a future pathway for remote sites, though accuracy would still degrade with distance from the reference base station. The manual protocol can thus be regarded as RTK's connectivity-limited counterpart.

Third, treating the two technologies as complementary and selecting between them site-by-site is what made it possible to obtain ground-truth records at all four sites - a hypothesis, for future testing, that maybe generalise to other rangeland programs operating across mixed-connectivity terrain.

Several limitations should be acknowledged in this preliminary work. First, the manual-marker and RTK protocols were applied at different sites, so this study cannot directly compare their positional accuracy or detection completeness; a stronger design, planned for future work, would deploy both at one well-connected site - including a UAV flight with the

correction link deliberately disabled - so the two can be compared against a common reference. Second, "ground truthing" is used here to mean establishing species-validated reference locations for future image annotation and model training, not an independent accuracy assessment of UAV-derived maps against those reference points, which remains necessary before either protocol can be considered validated for that purpose. Third, the RTK dataset comprises only 20 points from one coastal site- too small a sample for broader claims about RTK performance here, and colour-coded markers are themselves an established technique [6] rather than a novel contribution

As such, the study's contribution is limited to demonstrating the feasibility of RTK-assisted identification of Chinese apple and prickly acacia, together with landscape mapping.

CONCLUSION

This preliminary study shows that a low-cost, colour-coded marker method and an automated RTK GNSS method can each produce species-validated ground-truth records suited to the connectivity conditions under which they were deployed: 192 marker records across three sites near Bowen, and 20 centimetre-level RTK points at one well-connected site. Because the two methods were applied at different sites rather than against a common reference, this study does not establish which is more accurate or complete, and the marker method itself is not a novel technique; the contribution here is a feasibility record, not a validated comparison. The recommended next step is a controlled trial at one well-connected site - flying matched UAV missions with the correction link active and disabled, with markers and RTK points placed side by side. That will allow accuracy and detection completeness to be compared directly, alongside testing LEO satellite internet (e.g. Starlink) as a correction-signal carrier for remote sites.

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