Mapping *Pseudoraphis spinescens* using remotely sensed imagery

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Arthur Rylah Institute for Environmental Research,
Department of Environment, Land, Water and Planning

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Front cover photo: *P. spinescens* sward on Steamer Plain (Adrian Kitchingman).

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Summary

Pseudoraphis spinescens is a key semi-aquatic grass species of the Barmah Forest, Victoria, Australia. It is known to form large floating mats and swards but a decline in coverage has been noted over many years, attributed to altered flooding regimes and grazing by stock.

To assess the coverage and changes of *P. spinescens* extent an on-ground mapping exercise was conducted in 2013/14. While useful maps were produced, the field component was time-consuming, costly and associated with some field based Safety and Wellbeing risks. Therefore, interest was expressed in the feasibility of remotely mapping *P. spinescens* as an alternative.

This project aimed to assess the feasibility of using remotely sensed imagery to map *P. spinescens* and provide recommendations for any future efforts. Satellite WorldView-2 and aerial (airplane) imagery was sourced to cover selected wetlands in the Barmah Forest. Imagery was captured in December 2016 to try and detect *P. spinescens* at its most identifiable growth stage, however floods hadn't fully receded leaving large areas still inundated (including many *P. spinescens* swards). Unmanned Aerial Vehicle (UAV) imagery was captured for Little Rushy Swamp and a section of steamer plain in April 2017 to assess its suitability of assessment. Although there wasn't time available to process the UAV imagery, it was found to be suitable for analysis. The capture of UAV imagery is also relatively flexible which could give greater potential for more accurate timing of capture.

Despite the lack of visible *P. spinescens* in many wetlands, classifications were still attempted using unsupervised (no training data used) methods to test the feasibility of the approach on broad vegetation types. Classification of all wetlands combined were compared to classifications of a wetland (Little Rushy Swamp) individually. The classifications were generalised to different degrees to simplify the maps and also attempt to remove erroneous classification of trees. To help determine and verify classified regions limited ground observations were conducted.

Individual wetland classifications were found to be more accurate than all wetlands classifications. While some areas in the all wetlands classification had some areas correctly identified other areas were inverted to those classes determined in the individual wetland classifications. A contributing factor to this appears to be the possible different life stages of *P. spinescens* over the Barmah Forest due to varied rates of receding flood waters in different wetlands. A summary comparison with the previously mapped extents of *P. spinescens*, in 2013/14 indicated that there is a fair amount of uncertainty in the classifications especially where *P. spinescens* be mixed with other species.

While this project was not a successful exercise in accurately mapping *P. spinescens* a number of key lessons were learnt for any future efforts to remotely map *P. spinescens*. Recommendations include: more care in the timing of the imagery capture is needed to attempt to reduce water cover and to have *P. spinescens* at the most identifiable stage from other species; uncertainty in the timing of imagery capture may require a versatile imagery capture platform capability of relatively short notice deployment, such as UAVs; wetlands be processed individually; conduct suitable ground-truthing with an adequate number and spread of sample points; possibly reducing the number of wetlands to study. With the gaps and improvements identified in this report, it is hoped that any future remote sensing efforts of *P. spinescens* will be more successful in delivering a product useful for monitoring and management decisions.

1 Introduction

Pseudoraphis spinescens (R.Br.) Vickery (commonly known as Moira grass or Spiny mud grass) is a semi-aquatic grass that forms large floating mats and eventually swards after floodwaters recede. It was once common on the treeless plains and wetlands of Barmah Forest, Victoria, Australia and is considered a keystone species and part of a number of vegetation communities in need of conservation (Colloff *et al* 2014). The reduction in extent of *P. spinescens* has been largely attributed to the regulation of the Murray River in the mid-1930s, which changed flood regimes, as well as grazing pressure from rabbits, cattle and horses since the 1880s (Chesterfield 1986).

In an effort to measure the extent changes of *P. spinescens*, the mapping of its coverage over Barmah Forest's floodplains was conducted in 2013-14 (Vivian *et al* 2015). The mapping process aimed to spatially quantify extents of various degrees of coverage of *P. spinescens*, from dominant monotypic swards to sparsely scattered individuals in among other vegetation. While the maps produced provide insight into *P. spinescens* coverage, the mapping process was largely manual and on-ground. This can be very time-consuming, access-dependant and have some Safety and Wellbeing risks associated with remote field access. Therefore, the use of remotely sensed data was considered as an alternative for future mapping of *P. spinescens* coverage.

Remotely sensed imagery is a method of measuring electromagnetic radiation emissions or reflectance of an object (Mather 1999). Sunlight is the most common source of radiation. Detectors, usually mounted on satellites or aircraft, collect measurements of parts (bands) of the electromagnetic spectrum and digitally transform them into an image. The nature in which various objects emit or reflect different amounts of radiation across the electromagnetic spectrum gives these objects spectral signatures. Given the right resolution and combination of spectral band data, it is possible to use these signatures to locate objects in a given space. The act of identifying these signatures and generalising them for mapping purposes is called classification. To ensure classifications are adequately representing their underlying character training or ground-truthing samples are usually collected. The commonly used airborne platforms make remote sensing a useful technique for collecting spectral data over large areas.

Vegetation is one of the more common subjects of remote sensing. The biochemical and biophysical properties of different plants exhibit different spectral properties (Adam *et al* 2010), especially across the infra-red and red spectral bands. Wetland vegetation has been recognised as one of the more challenging groups to detect (Adam *et al* 2010, Lane *et al* 2014) because boundaries between vegetation communities are often difficult to identify and because the reflectance properties of wetland vegetation are often similar and combined with the reflectance spectra of the underlying soil, hydrologic regime and atmospheric vapours (Adam *et al* 2010).

Recent availability of multispectral data from the high resolution WorldView satellites has allowed more comprehensive mapping of wetlands (Lane *et al* 2014, Whiteside and Bartolo 2015). DigitalGlobe's WorldView-2 and 3 satellites provide up to 8 spectral bands of imagery at less than a metre resolution. The availability of WorldView-2 data and the large expanse of the wetlands that potentially contain *P. spinescens* made WorldView-2 imagery an ideal candidate for remotely mapping *P. spinescens*. However, despite the high sub metre resolution of WorldView-2 imagery, there were still question marks regarding its suitability for the often patchy nature of *P. spinescens* swards. To explore this, aerial imagery at a much higher resolution would be able to detect smaller patches.

The aim of this project is to explore and compare the suitability of satellite and aerial photography for mapping *P. spinescens* in the floodplains of Barmah Forest, Victoria, Australia. The use of high resolution multiband WorldView-2 satellite imagery and traditional high resolution aerial 4 band photography will be acquired and processed to create vegetation classifications focusing on *P. spinescens* extents. Confidence in the final products and their suitability for quantifying *P. spinescens* extents will be discussed. Recommendations for any future remote sensing efforts to map *P. spinescens* will also be outlined and discussed.

2 Methods & Results

2.1 Identification of area of interest and timing of data capture

Regions of interest were investigated and defined by Keith Ward and Lisa Duncan of the GBCMA and were given three levels of priority: Required, Desired and Opportunistic (Figure 1). The regions of interest covered previously mapped areas of P. spinescens (Vivian et al 2015). The time of data capture was set to late spring or early summer, when it was hoped the wetlands would have drained of most surface water. At that time, *P. spinescens* would be at its peak growth, which would make it identifiable in the landscape. The timing also hoped to capture *P. spinescens* swathes before they were heavily grazed after receding of waters.

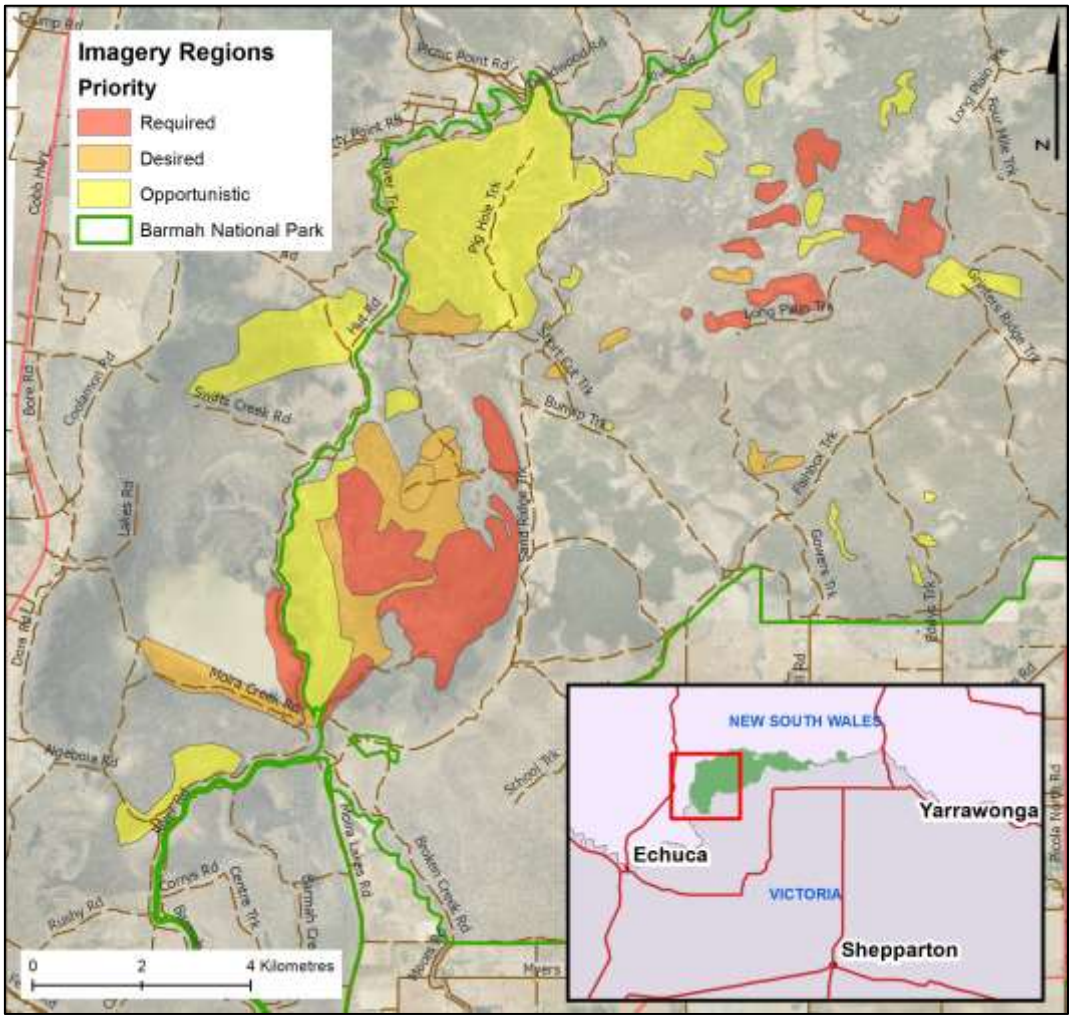


Figure 1. Regions specified for imagery capture priority

2.2 Imagery

Two types of imagery were captured for this investigation. Satellite imagery was captured to access multiple spectral band of information, and photographic aerial imagery was collected for high resolution investigation. Both imagery captures were coordinated through the Coordinated Imagery Program (CIP) section of DELWP. CIP is tasked with coordinating imagery collection tenders and quality assurance for DELWP, as well as other clients, with the aim to reduce redundant collections and share/spread costs where applicable. For this project, CIP dealt with the tender process for the collection of aerial photography and coordinated the collection of satellite data from the designated provider.

2.2.1 Satellite imagery

While numerous satellite products were available, the decision was made early on to acquire imagery from the WorldView-2 satellite. The WorldView-2 satellite is owned by DigitialGlobe and provides high resolution imagery in eight multispectral bands (Table 1). The panchromatic band is at 50cm resolution, while other bands are at 2m resolution. Technical details are in Appendix C.

Table 1: Spectral Bands available in the WorldView-2 satellite

Band	Spectral Range
Pan	450-800 nm
Coastal	400-450 nm
Visible Blue	450-510 nm
Visible Green	510-580 nm
Yellow	585-625 nm
Visible Red	630-690 nm
Red Edge	705-745 nm
Near Infrared 1	770-895 nm
Near Infrared 2	860-1040 nm

The supplied satellite imagery covered all Required and Desired regions and was captured on 11 December 2016 (Figure 2). Six image products of different band combinations were delivered (Table 2).

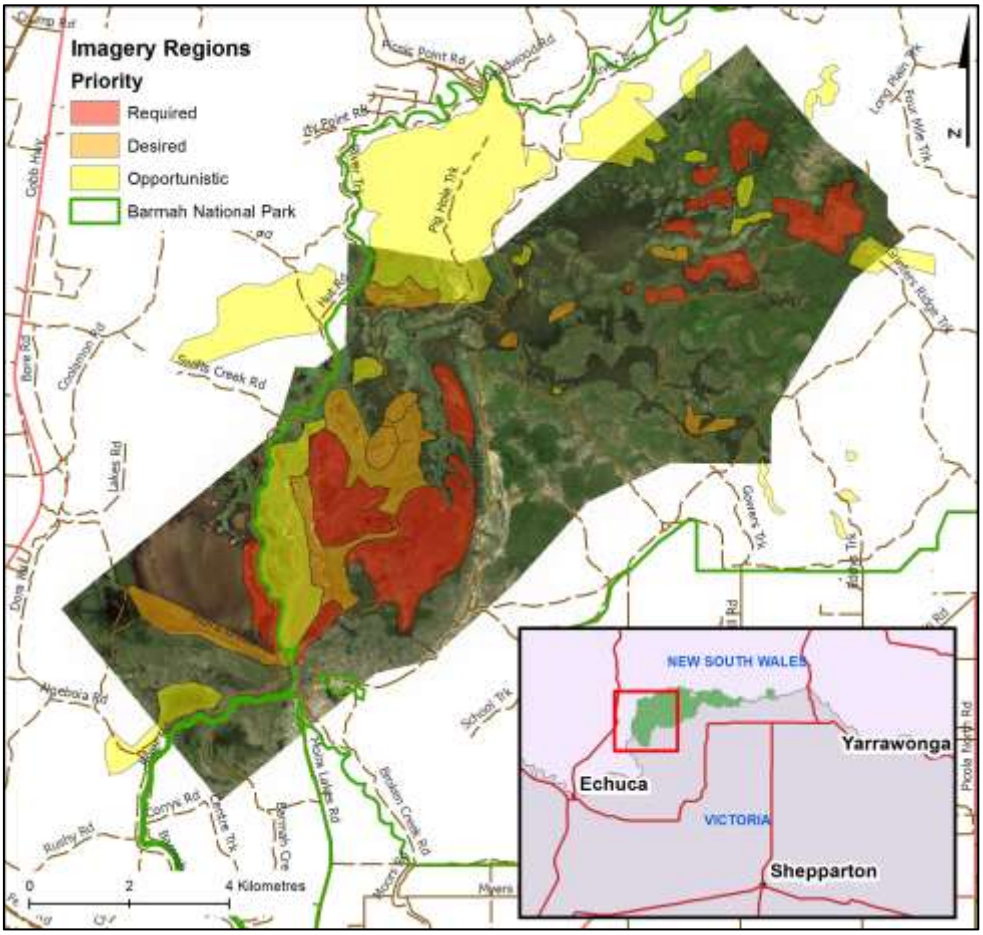


Figure 2: Extent of satellite imagery

Table 2: Satellite images and band combinations supplied

Image Name	Bands included
Natural Colour (NC)	visible red, visible green and visible blue
False Colour (FC)	Near Infrared band 1, visible red and visible green
Enhanced Natural Colour (ENC)	visible red, visible green + Near Infrared band 1, and visible blue
N2ReY	Near Infrared band 2, red edge and yellow
N2YC	Near Infrared band 2, yellow and coastal
YGC	yellow, visible green and coastal

2.2.2 Aerial photography

Aerial photography was acquired to provide high resolution imagery at ~10cm resolution to allow refinement of mapped products from this project. It was supplied in 4 spectral bands – Infrared, Red, Green and Blue. Technical details and metadata supplied with the imagery are in Appendix C. The aerial imagery covered Required and Desired regions and was captured on 13 December 2016 (Figure 3).

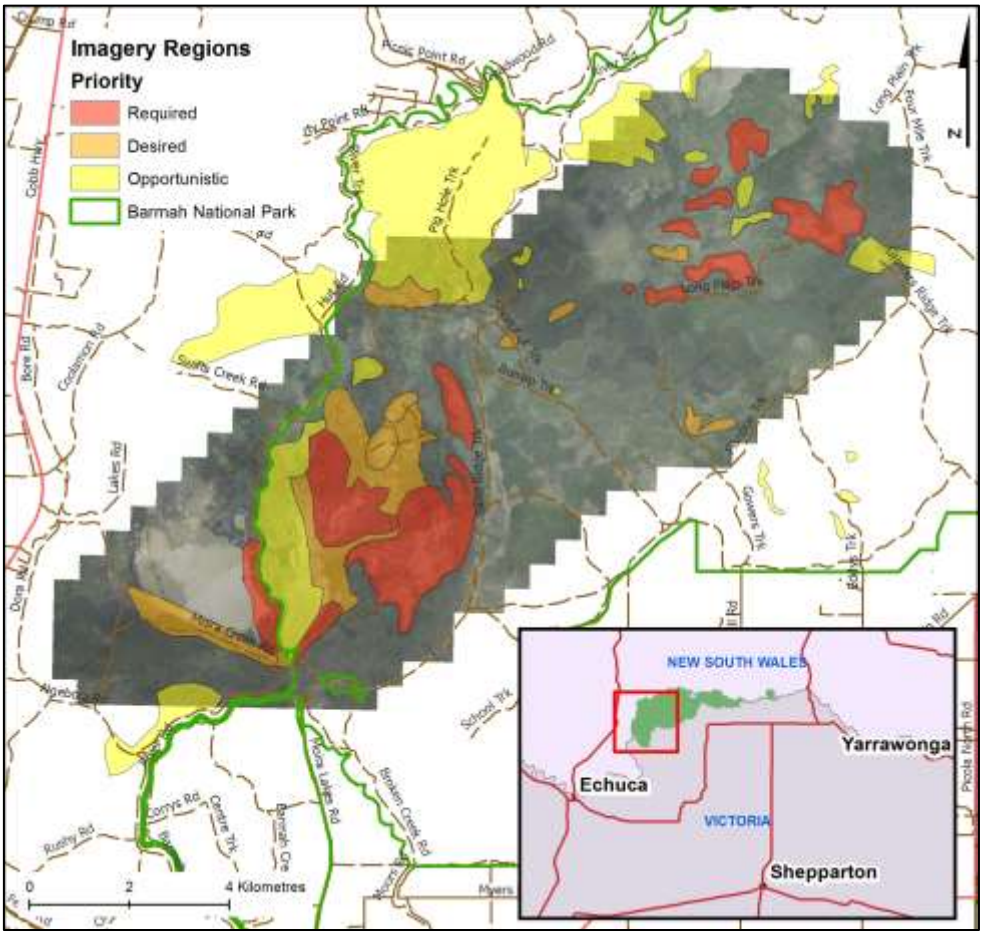


Figure 3: Extent of aerial imagery

The images had quality control issues flagged by the CIP. The low angle of capture in some areas caused problems when mosaicked, resulting in a lack of seamlessness between scene boundaries in some areas (Figure 4). The supplier attempted to re-mosaic the images and achieved some improvement, though the problem still existed.

Figure 4: Aerial imagery discrepancies: (A) Low angle of capture distortion; (B) lack of seamlessness in mosaicing

2.2.3 Unmanned aerial vehicle photography

On 9 June 2017, unmanned aerial vehicle (UAV) photography was collected to examine its feasibility for mapping *P. spinescens*. The acquisition and capture was coordinated through University of Melbourne's Unmanned Aircraft Systems Integration Platform. Although the imagery was not able to be processed in time for this report, the supplied imagery was suitable for mapping *P. spinescens*. Two regions were captured: a western section of Steamer Plain and Little Rushy Swamp (Figure 5). With a resolution of around 6.5cm, the imagery has the potential to produce very refined maps and help clarify vegetation features for classification. There was some noticeable mosaicking distortion, but the majority of the coverage was relatively seamless. Little Rushy Swamp had the more noticeable mosaicking issues (Figure 5), but this could be attributed to the less than optimal sun angle conditions creating greater amounts of shadowing.

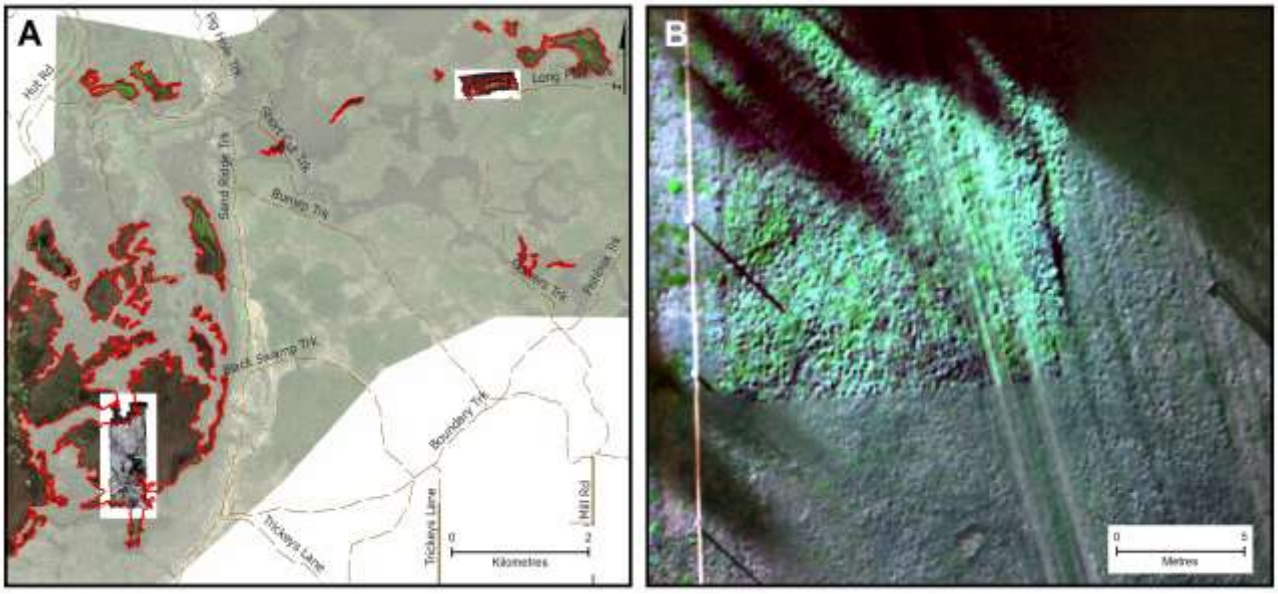


Figure 5: A: Locations of UAV imagery captured (bordered white) against the focal wetlands (red); B: A noticeable area of mosaicking distortion in Little Rushy Swamp

2.3 Field Observations

Field observations were made on 19 and 20 April 2017 to verify some locations of *P. spinescens* and note other species of vegetation which may add to confusion in the classification. In total, 48 observation points with photographs were collected and overlayed onto mapped imagery to help classification training (Figure 6). Unfortunately, 15 of the ground observations were located in areas covered by water in the imagery. The field observations identified a problem with discerning some areas of *Ludwigia peploides* (Water Primrose) and *P. spinescens*. It also became evident that compared to *L. peploides*, *P. spinescens* had a much less clear spectral signature in the imagery. This is contrary to what was thought for the time of the year the imagery was captured.

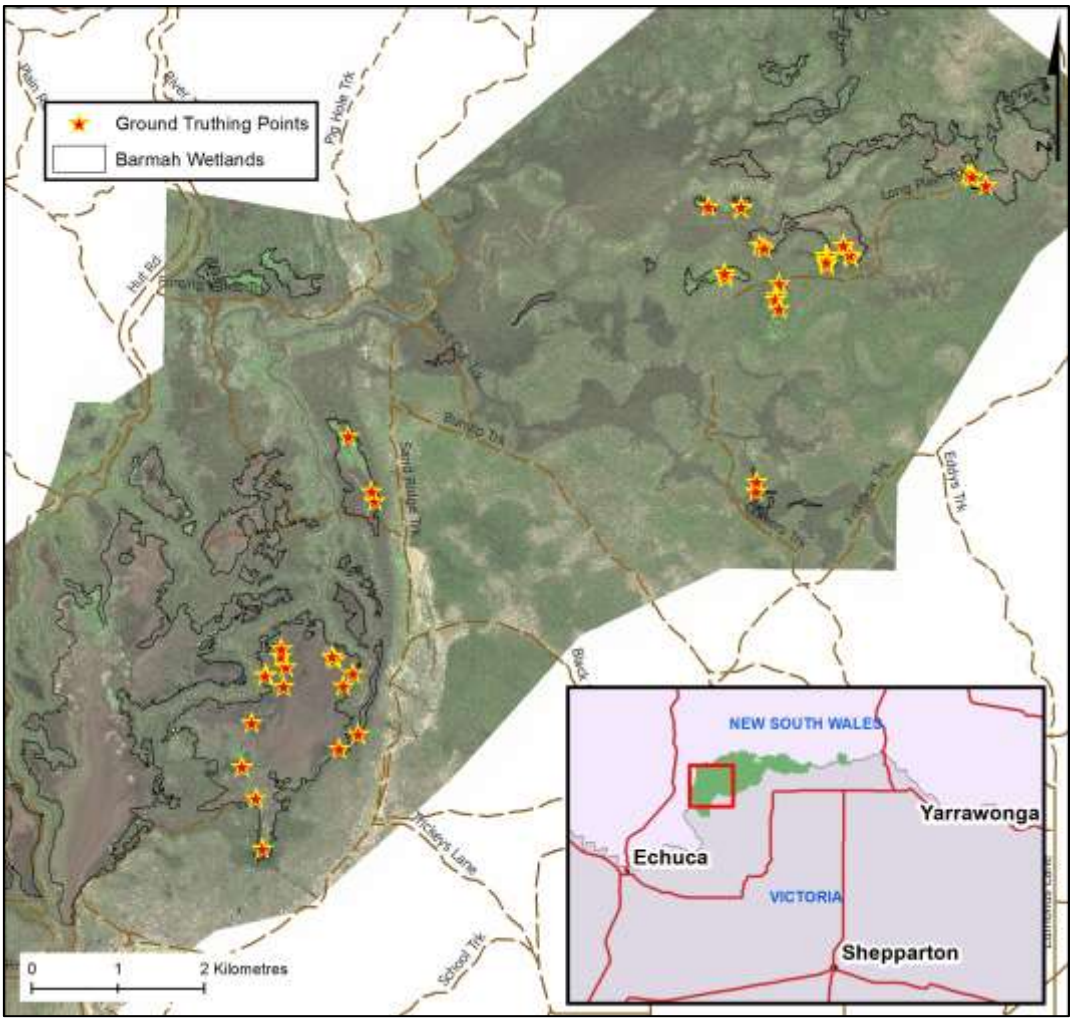


Figure 6: Ground-truthing locations

2.4 Imagery classification process (identifying *P. spinescens* regions)

After the delivery of the satellite and aerial imagery it became evident that large areas of the study region were still inundated with water, including many of the key *P. spinescens* areas (Figure 7). This severely limited the ability to classify regions of *P. spinescens* across the whole study area. It was also noted that due to different levels of drainage over the region, visible *P. spinescens* was at a range of vegetative stages. The large degree of water coverage over previously mapped *P. spinescens* swards (Category 1 in Vivian *et al* 2015) also severely restricted the usefulness of the aerial imagery captured (Table 3). As a result, satellite imagery was used to test broad scale classifications, while the use of aerial imagery was confined to Little Rushy Swamp, which had the lowest water coverage (Table 3) and was ground-truthed. All imagery processing and classification were conducted using ArcGIS 10.3.1 with Spatial Analyst extension.

Table 3: Water coverage of wetlands during imagery capture

Wetland	Water Coverage	Water coverage of previously mapped Category 1* *P. spinescens*
Bucks Lake	80.4%	
Budgee Creek	49.4%	78.2%
Duck Hole Plain	20.8%	
Formans Plain	61.1%	72.1%
Gowers 2	1.2%	
Gowers 3	24.8%	35.3%
Gowers 4	76.2%	59.0%
Harbours Lake	62.8%	52.0%
Hut Lake	52.6%	81.9%
Island Lagoon	9.8%	2.0%
Ladys Lake	74.6%	93.4%
Little Rushy Swamp	2.1%	0.9%
McDonalds Waterhole	84.3%	
Moira Lake	60.7%	
Rat Swamp	34.5%	1.0%
Reedy Swamp	41.2%	78.3%
Steamer Plain	52.7%	19.1%
Top Lake	77.9%	
War Plain	47.0%	52.0%

* Category 1 areas mapped between 2012 and 2014 are defined as "Distinct patch, or sward, of P. spinescens, with a relatively clear boundary. P. spinescens is the dominant (often only) species in the patch" (Vivian et al 2015)

Figure 7: Photos of key *P. spinescens* sites on 11th of December 2017 when satellite imagery was captured. Little had changed on the 13th of December when aerial photography was captured (bright green ground cover vegetation is *L. peploides*). (A) Harbours Lake; (B) Hut Lake; (C) Top Lake and (D) Steamer Plain. (Images from on-site time-lapse cameras supplied by Keith Ward - GBCMA)

2.4.1 Pre-processing

The pre-processing of imagery involved various exploratory stages aiming to find suitable bands or combinations thereof to help adequately identify *P. spinescens* swards. To reduce the amount of redundant data being processed, a manual boundary for individual wetlands was created (Figure 8) and then used to clip the imagery. Water cover was clearly evident, so areas of water were removed from the imagery using infrared bands.

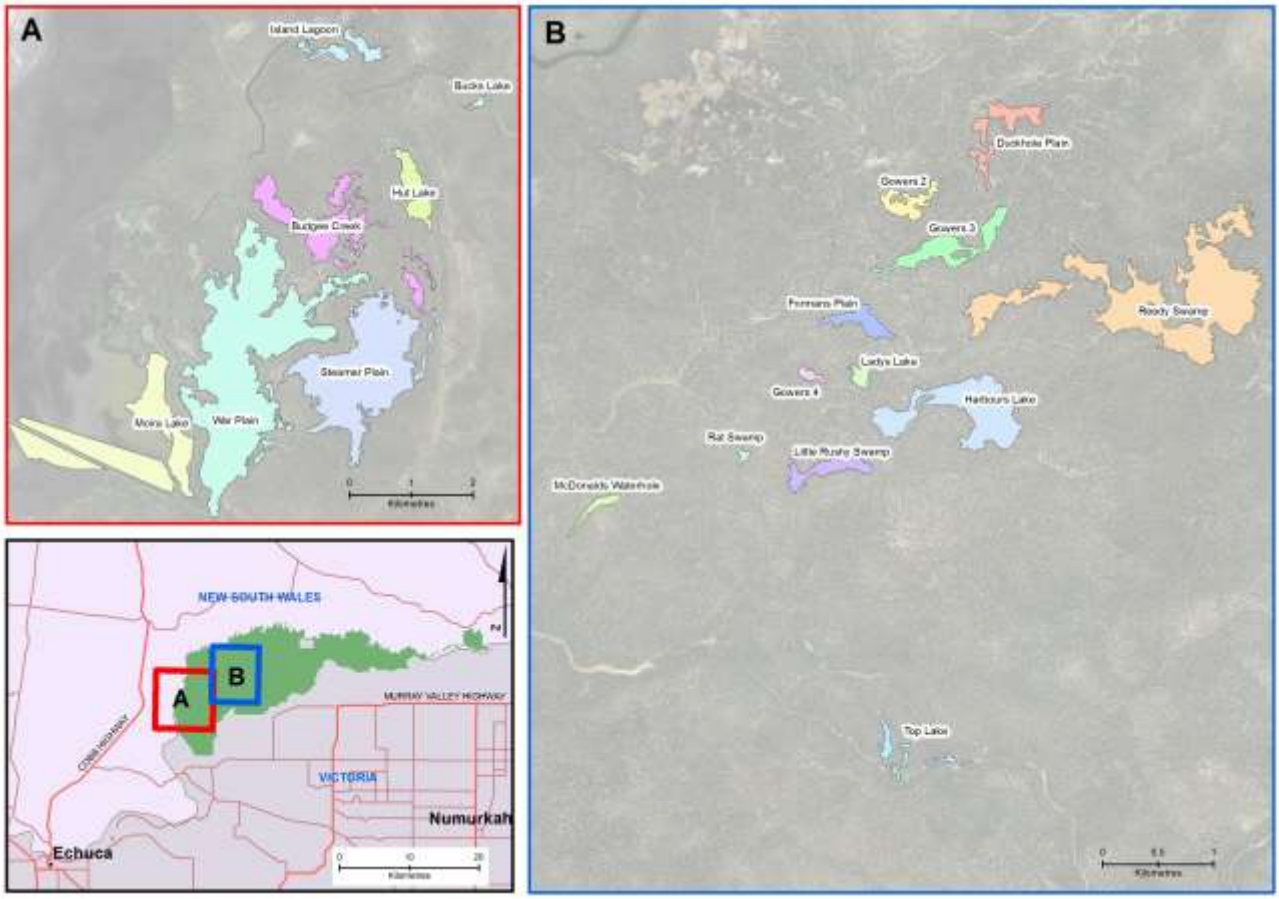


Figure 8: Digitised wetland boundaries

After exploring various band combinations, the spectral bands common in vegetation classification were selected where available. NIR2 and red bands were selected for both satellite and aerial imagery, while the satellite imagery also had the addition of the red-edge band. The visible blue band, which can be useful for discerning between vegetation and bare ground, was also selected for both imagery datasets. These bands were then put through a principal components analysis (PCA) to produce principal components (PCs). These were examined for relevance to the classification process (Figure 9). For satellite and aerial imagery, both across all wetlands and for Little Rushy Swamp, the first three PCs were used and stretched to spread their pixel values across an equal range over all PCs.

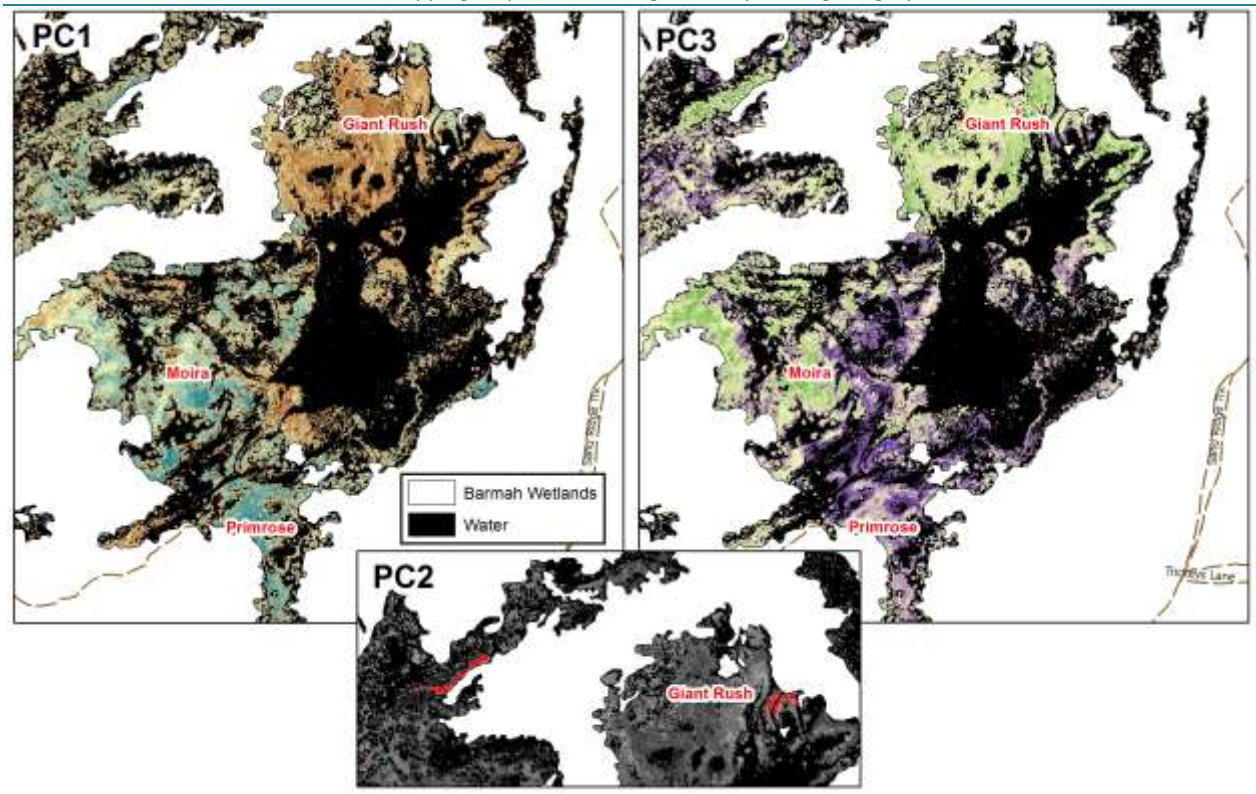


Figure 9: Principal components used in the classification process of all wetlands. The three key broad scale vegetation types which had to be discerned are marked for Steamer Plain. PC1 identifies giant rush; PC2 identifies bare ground or heavily senesced vegetation (red); PC3 identifies primrose.

2.4.2 Classification

2.4.2.1 Unsupervised classification

As *P. spinescens* spectral signatures were varied in the imagery supplied, the decision was made to conduct an unsupervised classification using the Iterative Self-Organizing Data Analysis Technique (ISODATA) algorithm. The unsupervised classification was conducted in several stages. As the unsupervised classification process uses a predefined class count for the ISODATA algorithm, a number of class (cluster) counts was examined to find adequate representations of vegetation types without producing an overly complex mosaic of classes. The starting class count was set at 10. Then, using the dendrogram (Figure 10) produced in the ISODATA process, several classes were merged to produce six classes (Table 4).

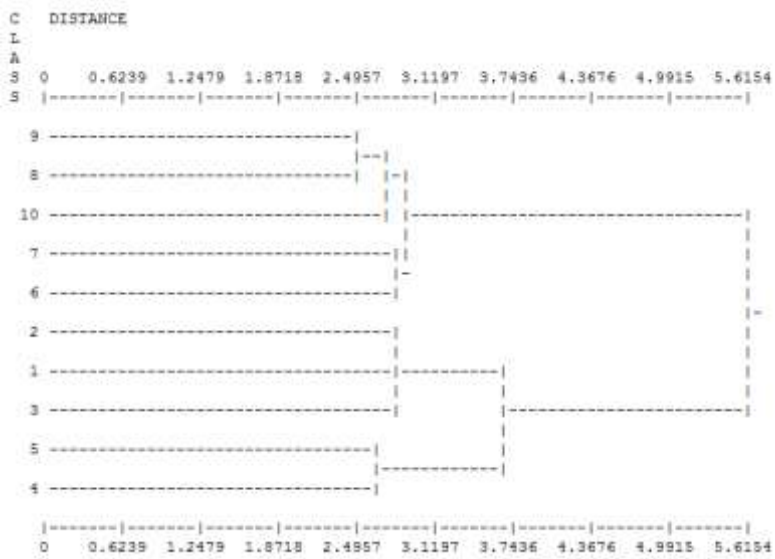


Figure 10: Dendrogram showing class distance (i.e. similarity) from ISODATA clustering for the Little Rushy Swamp PC layers

Table 4: Final classes derived from imagery

Base Classes	Description
1. Possible *moira grass*	Potential coverage of *P. spinescens*
2. Possible transitional *moira grass* mix	Edges of potential *P. spinescens* swards or potential *P. spinescens* mixed with other vegetation
3. Possible primrose	Potential coverage of *L. peploides*
4. Possible transitional primrose mix	Edges of potential *L. peploides* swards or potential primrose mixed with other vegetation
5. Possible giant rush	Potential coverage of *Juncus ingens*
6. Bare ground or senesced vegetation	Potential bare ground or coverage of heavily senesced vegetation

The PCs were then put through a Maximum Likelihood Classification (MLC) process, which used the merged ISODATA cluster signatures. The result is a base classified layer and a confidence layer. The confidence layer indicates the degree to which a pixel's value deviates from the class mean to which it is assigned. The suitability of the classes defined in the ISODATA stage will largely govern the resulting confidence values.

2.4.2.2 Final classification refinements

The base classified layers are notably complex, with many small regions classified. This gives a false impression of the accuracy of the underlying imagery, which had some noted limitations (e.g. trees, shadows and the imagery collection timing problem). To cater for this, the base layer is generalised to two levels. One removed small regions (<2500m^2) and merged them with the larger surrounding areas. The other was a much broader generalisation (blending of regions <250000m^2) with the aim of broadly removing the trees within the wetlands investigated. The final classified layers are listed in Table 5.

Table 5: Names of final classified layers

Source Imagery Data	Final Layer Name	Description
Satellite	allwetlands16_sat_25C*	Classification of all wetlands with all regions >2,500m^2
Satellite	allwetlands16_sat_250K*	Classification of all wetlands with all regions >250,000m^2
Satellite	littlerushy16_sat_25C	Classification of Little Rushy Swamp with all regions >2,500m^2
Satellite	littlerushy16_sat_250K	Classification of Little Rushy Swamp with all regions >250,000m^2
Aerial	littlerushy16_aerial_25C	Classification of Little Rushy Swamp with all regions >2,500m^2
Aerial	littlerushy16_aerial_250K	Classification of Little Rushy Swamp with all regions >250,000m^2

** Not supplied due to inaccuracies discussed*

The final classifications aim to give a generalised indication of the location of *P. spinescens* and its extent. It must be cautioned that due to the lack of a clear signal to identify *P. spinescens* and lack of comprehensive ground observations, there may be many cases of false positive *P. spinescens* identification (as well as in other classes). Trees proved to be difficult to handle in the classifications and are evident on the edges as well as in the wetlands (Figure 11). They did not have a unique spectral signal, so individual trees are often

a mix of all classes. This makes them noticeable in the least generalised classifications (25Cs). The broad generalisations (250Ks) removed or reduced in size some of the trees located within the wetlands, but fringing trees are still often present, especially where there are no other dominant vegetation classes nearby to merge into.

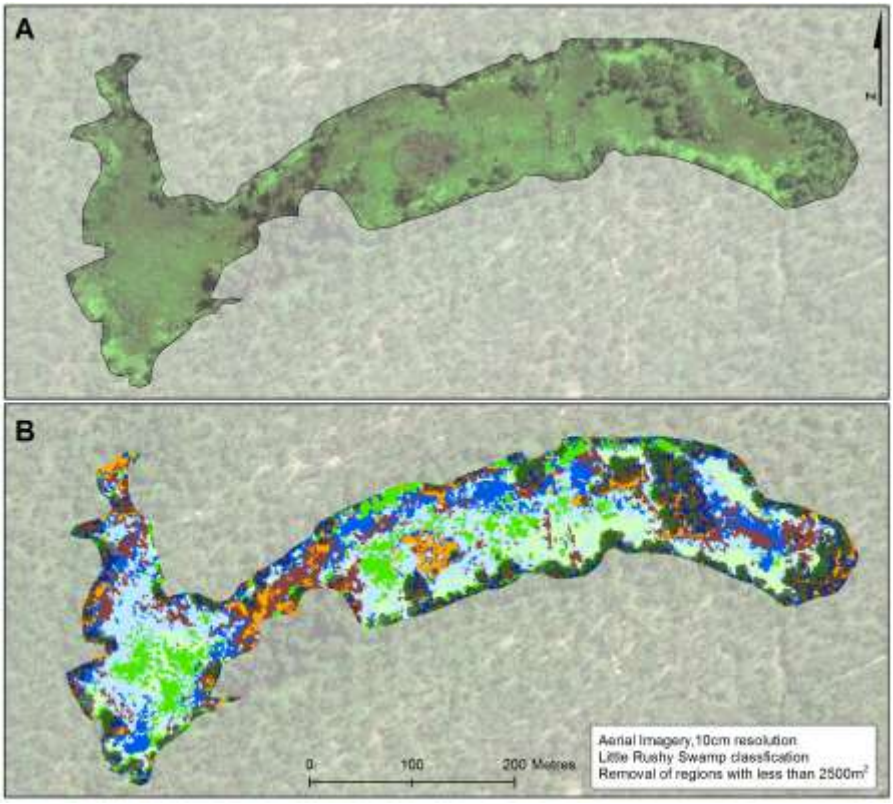


Figure 11: Tree inclusion in wetland boundaries and plains (A), and in a classified image (B: darker regions)

2.5 Final Classified Images

The final classifications aim to give a generalised indication of the location of *P. spinescens* and its extent. The purpose of the classified layer will determine which degree of generalisation is suitable to use. Broad scale maps will benefit the most generalised layers to indicate potential areas of *P. spinescens*. The finer scale generalisation would be suitable for more focused maps, where on-ground assessments may take place. As cautioned previously, due to the lack of a clear spectral signal to identify *P. spinescens* there may be many cases of false positive *P. spinescens* identification. False positives are also noted in other classes. Figures of the final classifications are located in Appendix A. Assessment of classification accuracy is relatively cursory and based on the limited ground-truthing conducted.

2.5.1 Satellite imagery

The satellite imagery was used for both a wide scale (all-wetlands) classification as well as an individual Little Rushy Swamp classification. The all-wetlands classification shows the effects of the large degree of water coverage over the region at the time of the imagery capture (Appendix A). Areas on Steamer Plain appear to classify well, with large areas of *P. spinescens* identified in areas traditionally occupied by *P. spinescens*. Other lower wetlands, such as Hut Lake, also seem to classify well, though at the time most *P. spinescens* was submerged. Classification problems appear to occur in wetlands further north, with Little Rushy Swamp being a clear example. Areas classified for *P. spinescens* and *L. peploides* appear swapped in Little Rushy Swamp when comparing the all wetlands classification and the independent Little Rushy Swamp classification (Figure 12). The resulting confidence layer from the all wetland MLC process indicates confidence in pixel class allocations to be fairly even across all the wetlands. On the other hand, the confidence layer for the Little Rushy Swamp classification indicates more focused areas of low confidence

(Appendix A). These areas were probably not adequately captured in the ISODATA clustering or lost when merging ISODATA classes.

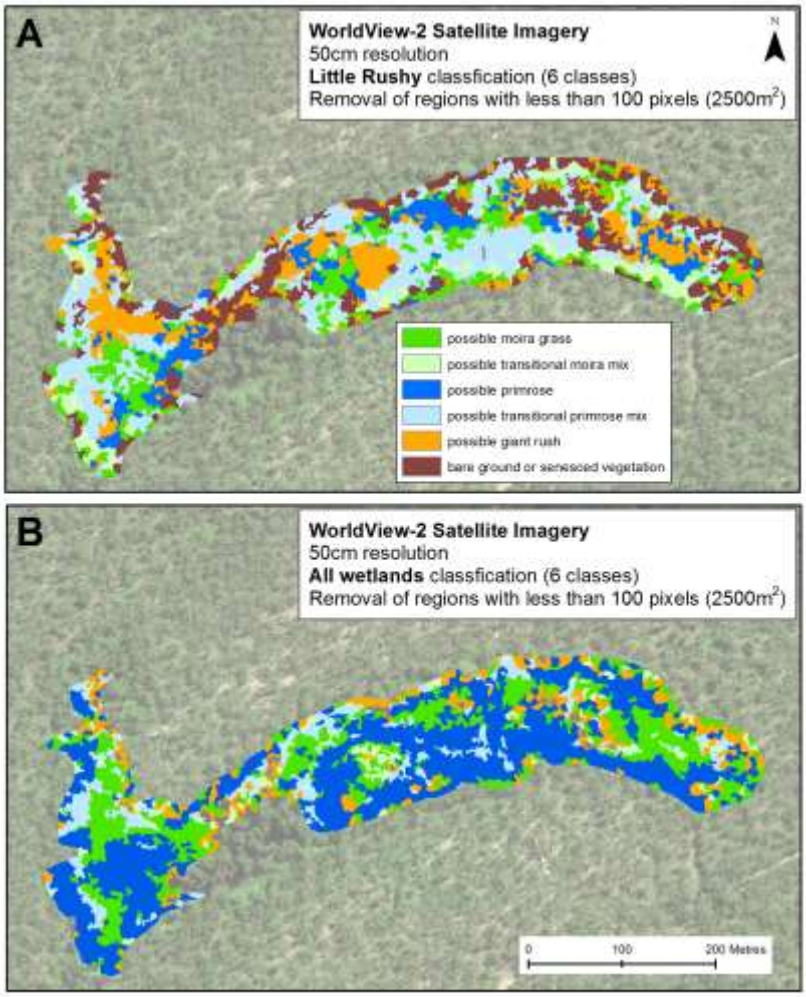


Figure 12: Comparing the individual classification of a wetland (A) to the misclassification in the 'all wetlands' (B) processed data

2.5.2 Aerial imagery

The aerial imagery was only used for a classification of Little Rushy Swamp. Ground-truthing was conducted, but it was not comprehensive enough to produce a quantitative classification. However, the final layer has sufficient details to give an on-ground indication of the likelihood of *P. spinescens* being present (Appendix A). The confidence layer from the aerial imagery MLC has a relative even spread of confidence values when compared to the satellite imagery confidence layers. The few regions where low confidence values are clustered are not where *P. spinescens* is present, which raises the confidence in the *P. spinescens* mapping aspect of the aerial imagery.

2.6 Comparison with previous mapping

A broad comparison was made with previously mapped areas of *P. spinescens* in 2013-14 (Vivian *et al* 2015) only for Little Rushy Swamp and Steamer Plain, as they had suitable amount of confidence in their capture of larger *P. spinescens* swards. Only previously mapped areas that overlapped with defined boundaries of the focus wetlands were used. The previously mapped areas were attributed with four categories denoting the relative coverage of *P. spinescens* (Vivian *et al* 2015). For this comparison, only Category 1 (dominant *P. spinescens* coverage) was used, since only dominant coverages would be clearly evident in the imagery. Due to the noted uncertainty around the classified layers accuracy, the more generalised allwetlands16_sat_250K and littlerushy16_aerial_250K classified layers was used in comparisons.

The overlay of previously mapped Category 1 *P. spinescens* gave mixed results (Figure 13), probably reflecting the uncertainty in the new classifications as opposed to errors in the previous mapping. Of the two focal wetlands, Steamer Plain had the greatest proportion of previously mapped *P. spinescens* intersecting with the possible *P. spinescens* class. However, it should be noted that Steamer Plain had almost 20% of its previously mapped *P. spinescens* covered by water. A relatively high percentage of Steamer Plain's previously mapped *P. spinescens* was also included in the possible *L. peploides* class.

Little Rushy Swamp showed more previously mapped *P. spinescens* being included in the transitional classes for both *P. spinescens* and *L. peploides*, with almost a third more included in the *L. peploides* transitional class. A smaller but similar percentage of previously mapped *P. spinescens* was included in the possible *P. spinescens* or *L. peploides* classes.

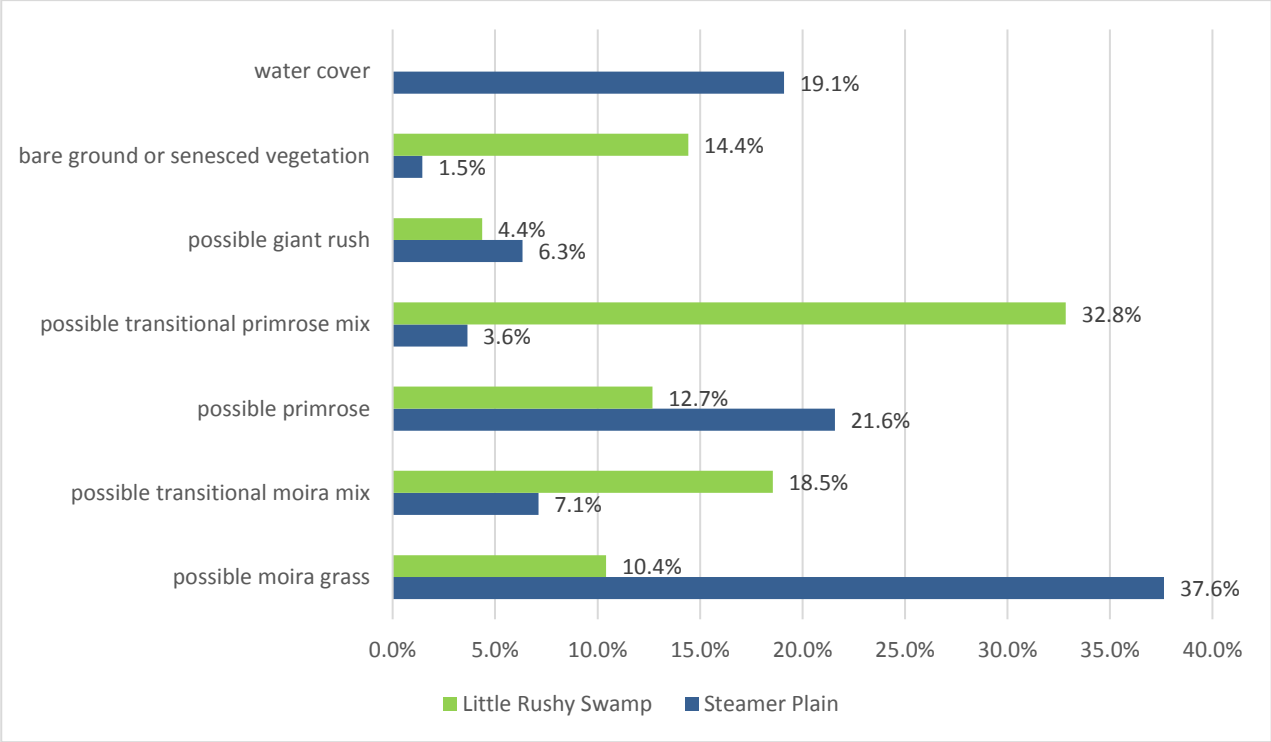


Figure 13: Percentage of Category 1 previously mapped *P. spinescens* (Vivian *et al* 2015) covered by new classes (described in Table 4)

4 Discussion

The remote mapping of *P. spinescens* via satellite and aerial imagery in this project produced mixed results but highlighted key criteria for any further remote mapping efforts. Both satellite and aerial imagery showed a great amount of detail, suitable for classifying dominant vegetation types including *P. spinescens*. Classifications of very broad vegetation types were made and generalised to different degrees to examine the high and low resolution abilities of the mapping. Classifications across all wetlands and an individual wetland were also conducted to test the feasibility of both approaches. The final classifications were suitable for identifying potential areas of *P. spinescens*, but a number issues discussed prevented a quantitative extent of *P. spinescens*.

The WorldView-2 satellite imagery proved the most versatile compared to the aerial imagery due to the great number of spectral bands captured, the capture of the whole area in one pass and the reduced degree of tree shadows. The aerial imagery suffered from a number of issues which affected the quality of classifications. Largely, the variable angle of capture caused inconsistencies in the image, with some areas more affected by tree coverage and tree shadows. In addition, a lack of seamlessness across tiles cases greatly increased classification complexity. However, the much greater resolution (5x) of the aerial imagery makes it a viable option for more quantitative assessments as long as the supplied imagery caters adequately for the tree shadow and seamless issues.

While the supplied satellite and aerial imagery were adequate for *P. spinescens* identification, more fundamental problems arose, namely the seasonal timing of the imagery capture. Unfortunately, due to a prolonged flooding season, the imagery from both platforms was captured when there was still a great deal of water coverage across the focus regions. The water cover was also found to have substantially covered previously mapped dominant *P. spinescens* areas (Vivian *et al* 2015), which confounded efforts to both identify *P. spinescens* swards and to get a complete coverage estimate. Only Little Rushy Swamp was virtually free from water cover, which allowed it to be used to assess classification performance.

The water cover of the wetlands was not the only seasonal timing issue. It was also quickly noted that *P. spinescens* was at different life history stages across the study area, since the drainage of water varied throughout. The different life stages allowed *P. spinescens* to be more distinct from other dominant vegetation in some areas compared to others. However, there was still a fair degree of classification uncertainly around the transitional or mixed vegetation areas. More care will be needed when selecting the timing of capture to ensure *P. spinescens* is the most identifiable from other nearby dominant species. The range of *P. spinescens* life stages at a single time may also require imagery captures of individual wetlands to be staggered over a period of time.

Only dominant vegetation types are visible in both the aerial and satellite imagery. The mapping of sparse or even mixed *P. spinescens* coverage was not possible with any confidence. Classification of only dominant features though aerial imagery resolution give potential for more refined mapping, though classification confidence is still limited to generally monotypic vegetation coverages. *P. spinescens* did not appear to have any clear signatures in the various spectral bands supplied. In some cases, the combination of principal components appeared to identify *P. spinescens* via the elimination of other more identifiable species. This creates a more complex classification process (i.e. the variation in spectral bands included), which needs to be explored further in any future *P. spinescens* mapping.

Options for supervised and unsupervised classification methods were assessed. Due to the lack of a clear *P. spinescens* signature, the decision was made to use an unsupervised method. This would let natural spectral clusters in the imagery define potential classes. The key issue is attributing the final classes to vegetation types and gauging the consistency of the vegetation mix within classes. It is very difficult to discern the components of mixed vegetation areas. Since the proportions of the vegetation components can vary within short areas, it is difficult to attribute a confident spectral signature. In the case of the classification efforts for this report, the areas between dominant vegetation types were termed 'transition zones' to indicate that they should be given a higher degree of uncertainty as to the consistency of the

contents. Ultimately in the future, a more structured supervised classification approach would be preferred with the inclusion of an adequate amount of on-ground training data.

Trees confounded some classifications by displaying numerous spectral signatures. The lack of a clear signature prevented trees from being filtered and produced false positives in classes, skewing attempts for area estimations. The tree line also defines the boundary of wetlands and plains to varying degrees. It became evident that a clear boundary for each wetland or plain was essential for the classification process and providing a somewhat standardised whole area from which to gauge changes in coverage of *P. spinescens* over time. LIDAR provides information which allows trees to be filtered from the imagery, giving a cleaner platform for classifications.

Most important to the success of any later remote mapping efforts will be a comprehensive ground-truthing protocol. With the variability in the spectral signature of *P. spinescens* in different wetlands, ground-truthing will help both increase confidence in the classifications and give the ability to generate a confusion (or error) matrix. Ground-truthing would be best after a preliminary classification. This will enable the targeting of some areas which may be giving confusing or unusual spectral signals. As each wetland of interest will have to be classified individually, the ground-truthing will also need to be conducted in each wetland separately. Ground-truthing should consist of point coordinates, photographs and an adequate description of the vegetation proportions within a defined radius. Even if mapping is only targeting *P. spinescens*, observation points will have to be located in a variety of vegetation types to help reduce false positive classifications of *P. spinescens.* Transition zones of the *P. spinescens* swards should also be targeted. Large wetlands with multiple *P. spinescens* swards should have ground-truthing points located in a range of swards across the wetland's range. If a supervised classification of wetlands is a possibility, enough data needs to be collected for separated training and accuracy assessment points.

Overall, there is good potential for a remote mapping assessment of *P. spinescens* swards. Satellite and aerial imagery provide a relative fast way of gathering spectral data, but both have limitations. Eight-band imagery via the WorldView-2 satellite is comprehensive and seamless, but lacks resolution when compared to aerial imagery. However, aerial imagery collected for this project was only four bands and suffered from mosaicking issues, which could have hindered classifications of some individual wetlands. To avoid tree shadows, aerial imagery runs may need to be taken over several days. The option of collecting multiband (>4) imagery via UAV provides an appealing option for high resolution mapping.

UAV imagery collection is the most intensive option, but could provide the most accurate option in terms of assessing *P. spinescens* coverage. Compared to the other imagery collection methods, UAV imagery collection is time consuming, but more spatially targeted. The amount of time involved in capturing images may require a reduction of wetlands being assessed. Organising UAV imagery capture is relatively quick (as long as permits are in place), which is suited to the potential moving temporal window for capturing *P. spinescens* at its optimal growth stages. Imagery capture could also be conducted over multiple days, ensuring optimal sun angles and picture quality. Days of even light can be targeted with preference for cloud free sunny days but also overcast days if necessary. Days with patchy cloud are best avoided. The acquisition of multiband imagery with more than the four bands of aerial imagery is of particular interest, as it provides more opportunity for *P. spinescens* identification and mapping. While there can be mosaicking issues, seamless mosaicking is an issue for any form of remote sensing where captured images do not fully cover the study area. However, UAV imagery capture involves more images requiring mosaicking for a given area as compared to aerial imagery.

Planning for any future remote mapping of *P. spinescens* will require a decision to be made on the level of resolution needed to make suitable management. The increasing amount of effort to collect progressively higher resolution imagery will have a reciprocal increase in the required budget for both image collection and ground-truthing. Table 6 outlines some of the key criteria to consider for the different imagery collection platforms. The need to process individual wetlands also increases the time required for the imagery processing and classification. Budgetary limitations may necessitate the choice of a few 'sentinel' wetlands, which can represent the health of *P. spinescens* coverage overall. If budgets are adequate, satellite imagery could capture imagery to assess all wetlands broadly, while UAV imagery could provide

detailed and quantifiable imagery for the key wetlands. Again, there would be increases in the ground-truthing and processing requirements.

Table 6: Basic criteria to consider when selecting remote sensing platform

Criteria	WorldView-2 Satellite	Aerial Photography	UAV
Timeliness of imagery acquisition	Data collected over several days (depending on cloud cover)	Data collected over one day	Data collected over multiple days
Flexability of acquisition	Window is set around two weeks before capture	Window is set several weeks in advance but competing tasks could delay date of acquisition	Window can be set close to acquisition time as long as required permits are in place. Potential for short notice rescheduling
Scope of acquisition	All wetlands in one image	All wetlands in multiple images	Limited number of wetlands per day
Number of spectral bands collected	8	4	7
Resolution of data	50cm	~10cm	~6.5cm
Seamlessness of final product	seamless	mosaicked	mosaicked
Cost	~$5K*	~$7K - $20K*	NA but involves physically flying UAVs in the field

** Figures from range of costs from tender process.*

Key Recommendations

- Time the imagery captures for best identification of *P. spinescens* (possibly a staggered approach to capture individual wetlands at different times)
- Preferably capture imagery when there is no water cover or *P. spinescens* is consistently exposed above water
- Capture imagery during noon hours to reduce tree shadowing and on non-patchy cloud days
- Use versatile imagery capture platform such as UAVs to conduct timely imagery captures and provide multiband imagery
- Select 'sentinel' wetlands
- Process wetlands individually
- Develop suitable ground observation protocol with adequate number of sample points per wetland
- Source LIDAR data to create more accurate wetlands boundaries and remove trees from imagery

Conclusion

The feasibility of assessing *P. spinescens* coverage via remotely sense data is achievable. However, certain imagery specifications and timing of imagery capture will ultimately determine how accurate or useful the final mapped *P. spinescens* coverage will be. Ground-truthing is vitally important because it can hone the accuracy of mapping processes and give an indication of the broad error contained in the final mapped products. Budgetary constraints will largely determine the scope of mapping efforts and the number of wetlands to be assessed. As the resolution of the acquired imagery increases, so do the time requirements and costs. While the imagery captured for this project did not allow for a comprehensive map of *P. spinescens* extents, it did demonstrate the processes required to map *P. spinescens* remotely. With the gaps and improvements identified in this report, it is hoped that any future remote sensing efforts of *P. spinescens* will be more successful in delivering a product useful for monitoring and management decisions.

References

Adam, E., Mutanga, O. and Rugege, D. (2010) Multispectral and hyperspectral remoe sensing for identification and mapping of wetland vegetation: a review. *Wetlands Ecology and Management* **18**, 281-296.

Chesterfield, E.A. (1986) Changes in the vegetation of the river red gum forest at Barmah, Victoria. *Australian Forestry* **49** (1), 4-15.

Colloff, M.J., Ward, K.A. and Roberts, J.(2014) Ecology and conservation of floodplain grassy wetlands in the southern Murray-Darling Basin, Australia. *Aquatic Conservation: Marine and Freshwater Ecosystems* **24**, 238-255.

Lane, C.R., Liu, H., Autrey, B.C., Anenkhonov, O.A., Chepinoga, V.V. and Wu, Q. (2014) Improved wetland classification using eight-band high resolution satellite imagery and a hybrid approach. *Remote Sensing* **6**, 12187-12216.

Mather, P.M. (1999) *Computer Processing of Remotely-Sensed Images*, 2nd edn. john Wiley and Sons Ltd, London, UK.

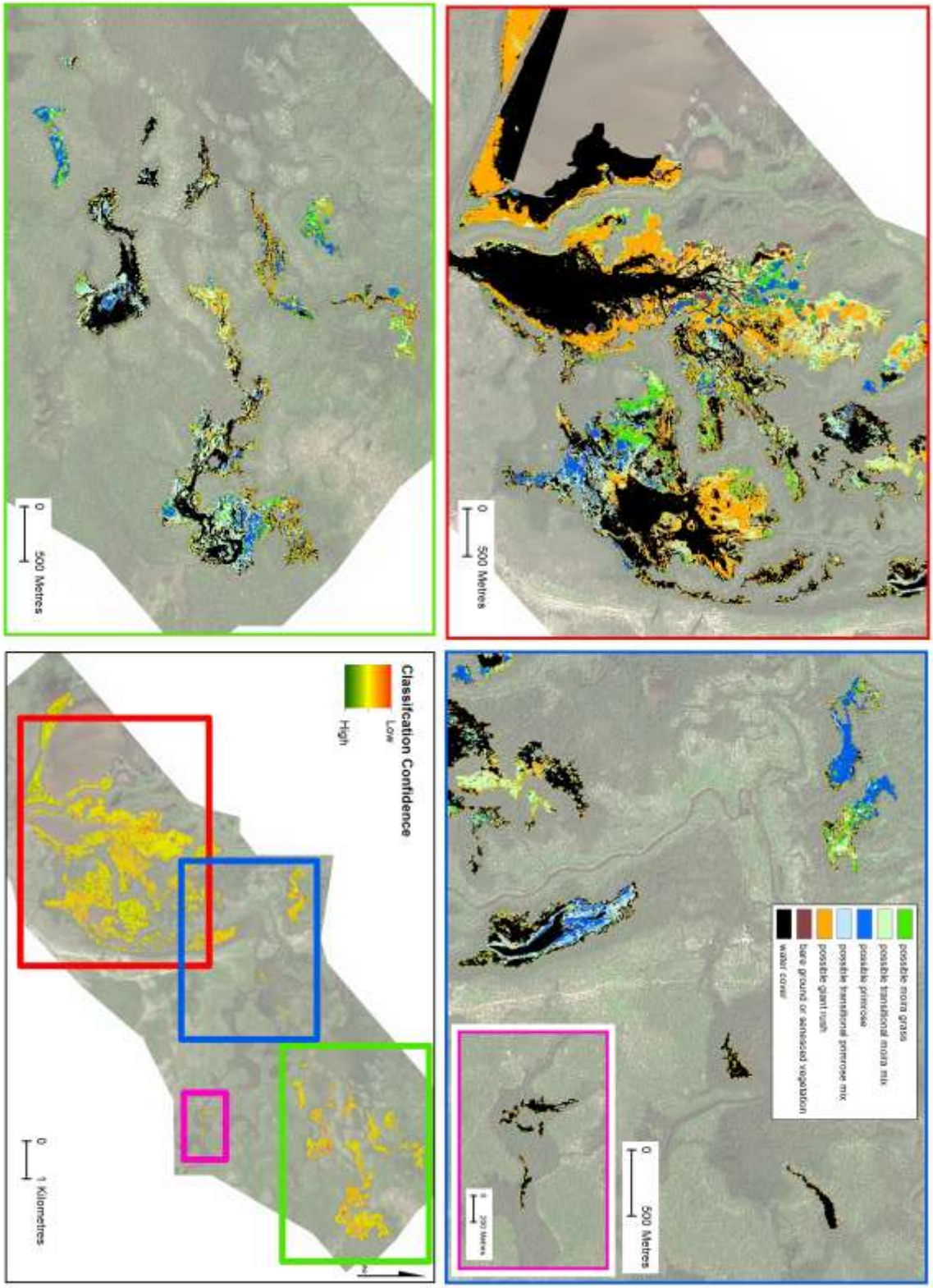
Vivian, L.M., Ward, K.A., Marshall, D.J. and Godfree, R.C. (2015) Pseudoraphis spinescens (Poaceae) grasslands at Barmah Forest, Victoria, Australia: current distribution and imaplications for floodplain conservation. *Australian Journal of Botany* **63**, 526-540.

Whiteside, T.G. and Bartolo, R.E. (2015) Mapping aquatic vegetation in a tropical wetland using high spatial resolution multispectral satellite imagery. *Remote Sensing* **7**, 11664-11694.

Appendix A Final Classification Maps

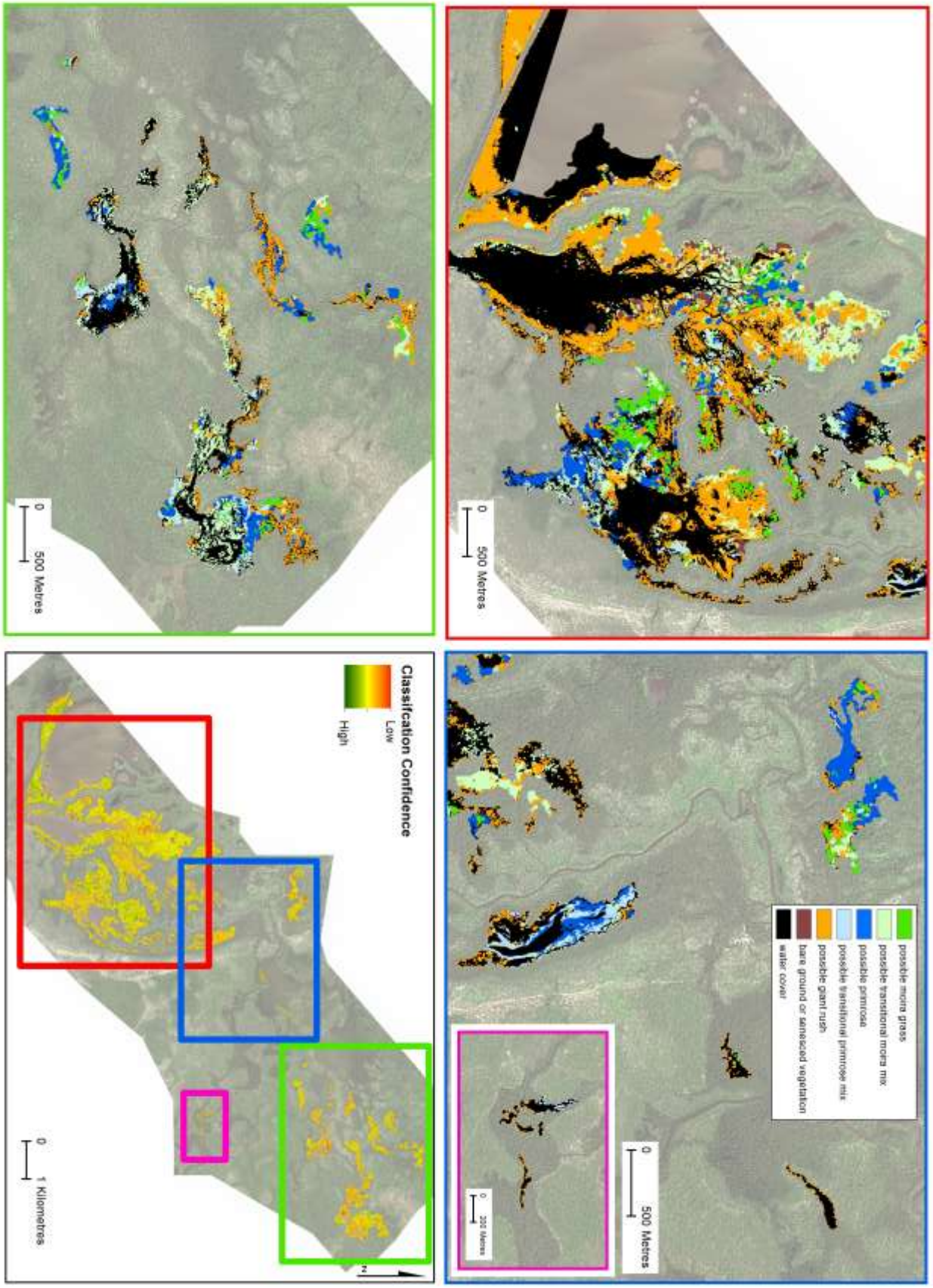
All wetlands; satellite imagery; 50cm resolution; removal of areas < 2500m^2 (allwetlands16_sat_25C)

The classifications in the 'all wetland' layers can be misleading with noted errors.

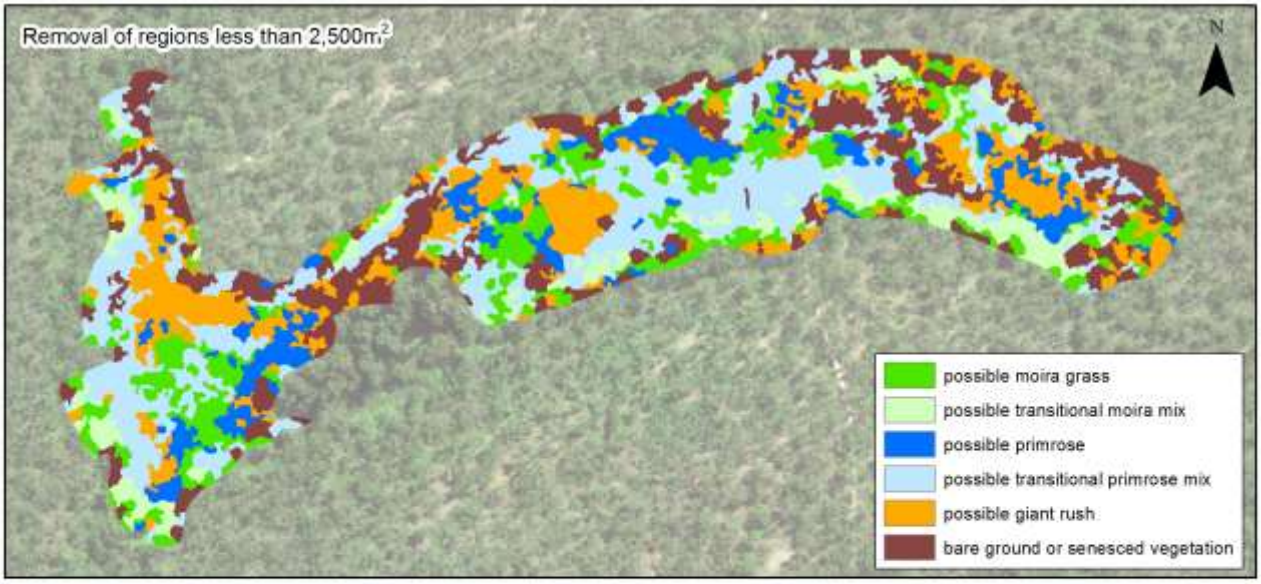


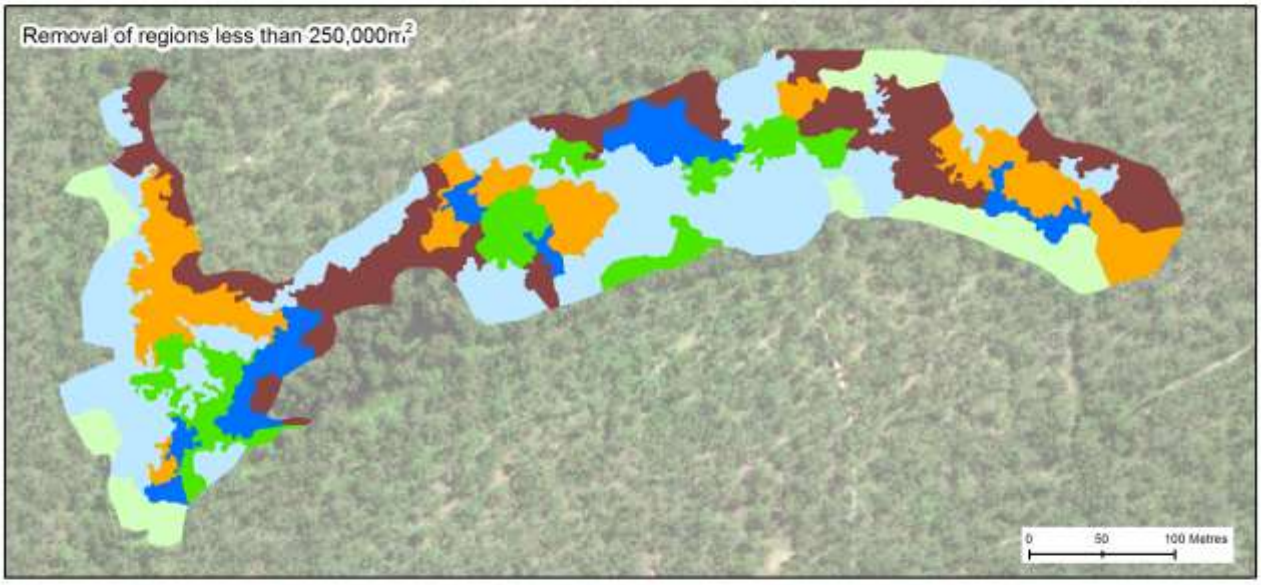
All wetlands; satellite imagery; 50cm resolution; removal of areas < 250,000m^2 (allwetlands16_sat_250K)

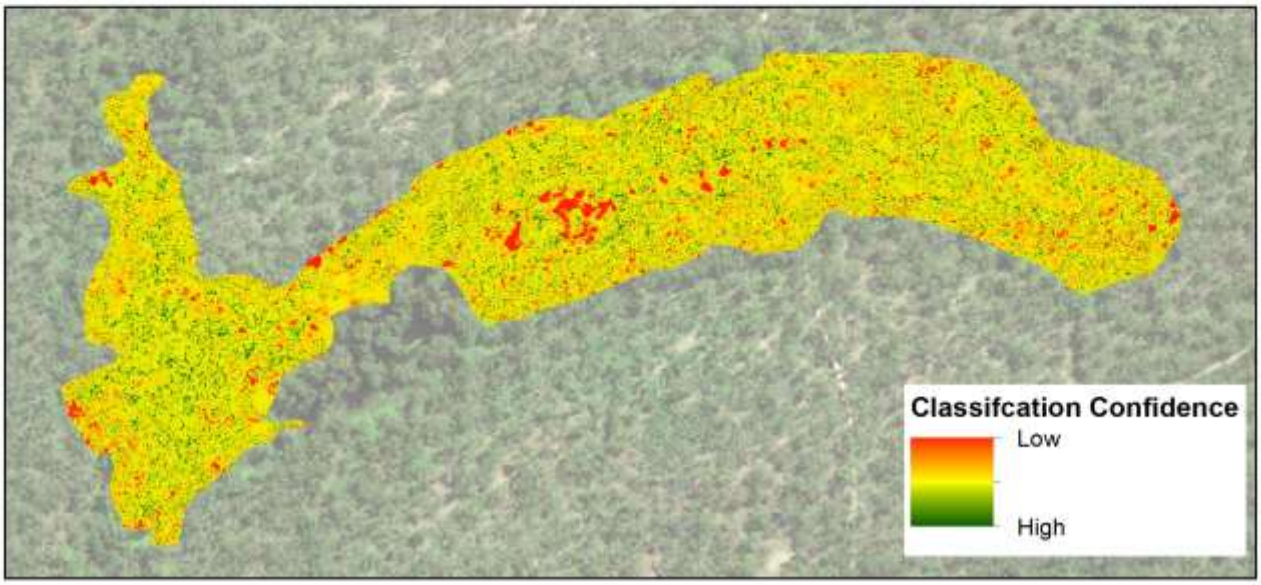
The classifications in the 'all wetland' layers can be misleading with noted errors.



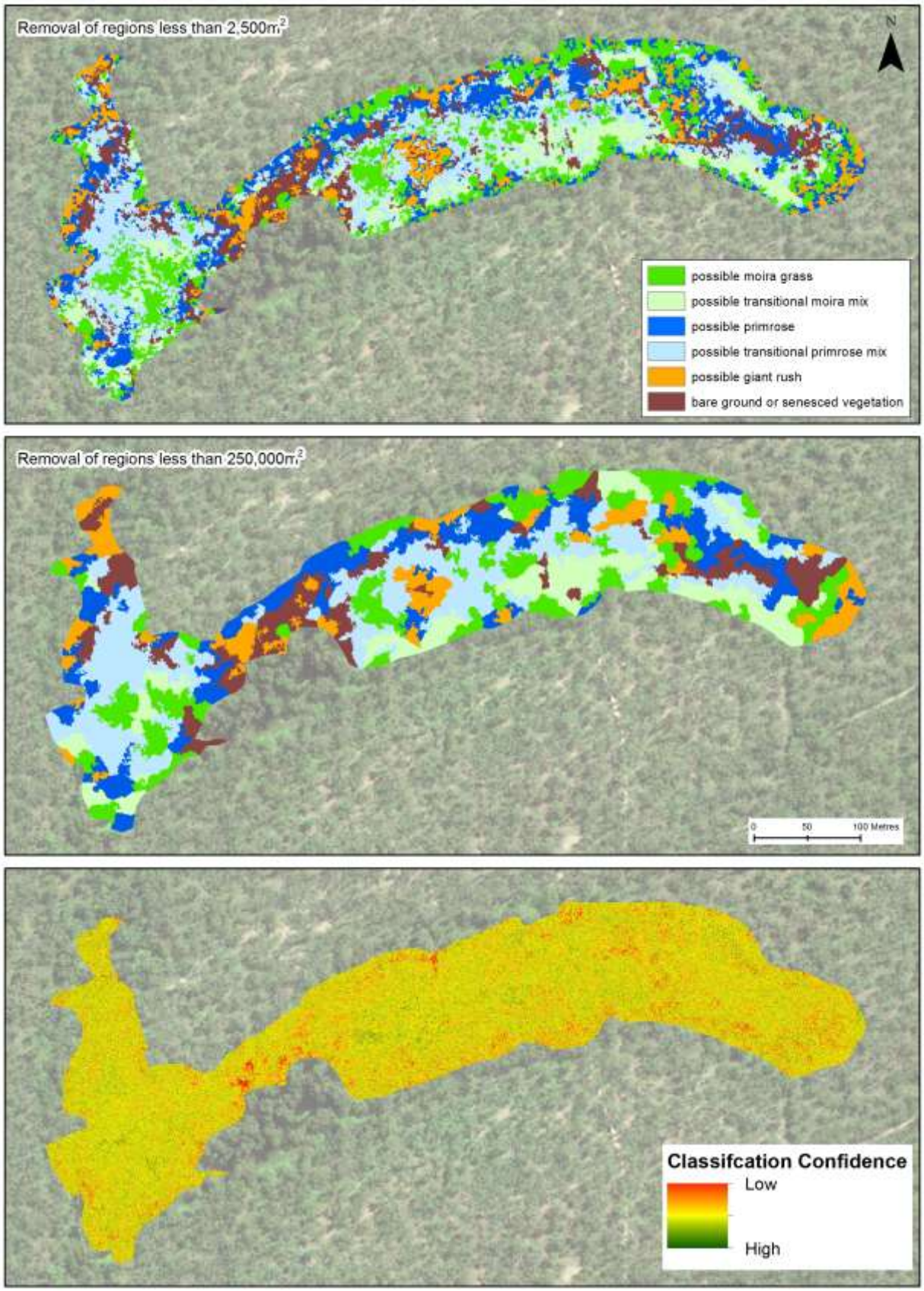
Little Rushy Swamp; satellite imagery; 50cm resolution (littlerushy16_sat_25C & littlerushy16_sat_250K)



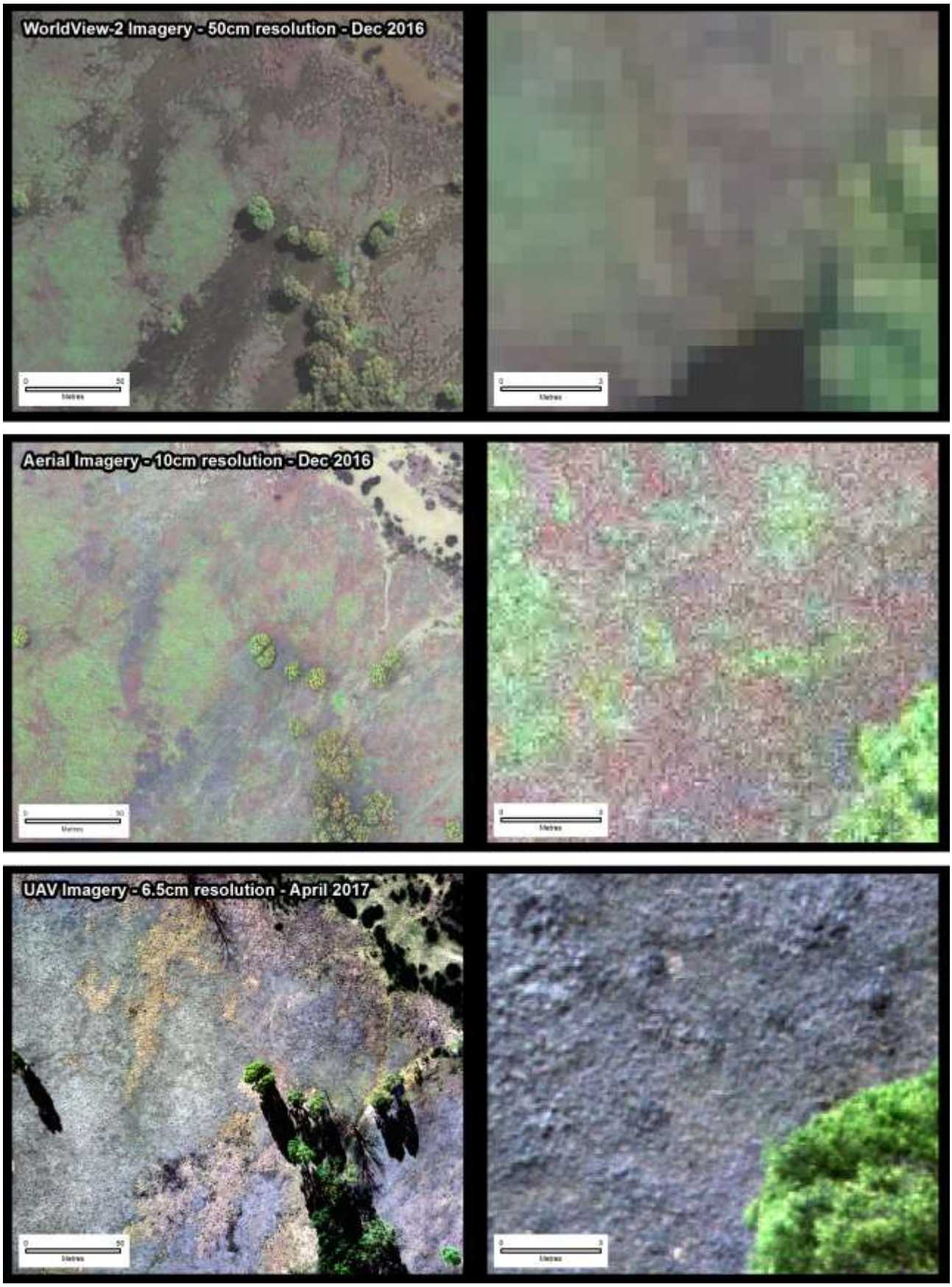




Little Rushy Swamp; aerial imagery; 10cm resolution (littlerushy16_sat_25C & littlerushy16_sat_250K)



Appendix B Comparison of imagery resolutions



Appendix C Supplied imagery technical documentation

PHOTOMAPPING
precise spatial solutions

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ABN 30 005 552 876
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PO Box 369
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Victoria, Australia
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Fax +61 3 9326 6476
ps@photomapping.com.au

Photomapping Project #5775

DEWLP
Barmah - Millewa - Moira Grasslands
Digital Photography Acquisition

Project Summary

Barmah Millewa Moira Grasslands imagery was captured by Photomapping Services using our Leica ADS80 SH81 on the **13th December 2016.** The data was captured in order to provide orthorectified multispectral imagery products.

1. Data supplied:

1.1 Orthorectified imagery tiles in GeoTIFF and ECW format – RGBN. Tile size is 500m x 500m

"eXXXXnYYYYY_YYYYmmmDD_product_RES_projection"
where:
eXXXXnYYYYY is the lower left coordinate of the tile
YYYYmmmDD is the year, month and day of capture
product indicates the type of data supplied
RES is the data resolution in pixel size cm.
Projection represents the coordinate system.
e.g. e3110n60185_2016dec13_air_rgbi_15cm_mga55

1.2 Orthorectified mosaic imagery in ECW format – RGB and CIR.

"location_YYYYmmmDD_product_RES_projection"
where:

location is the name of the area
YYYYmmmDD is the year, month and day of the start of capture
product indicates the type of data supplied
RES is the data resolution in pixel size cm.
Projection represents the coordinate system.
e.g. barmah-millewa-moira-grasslands_2016dec13_air_vis_15cm_mga55

** All supplied products with accompanying world (.tfw, .eww), header (.ers) and tab (.tab) files.*

2. Metadata

Project

Project Number	5775
Acquisition Date	13/12/2016
Device Name	ADS100 - SH100
IMU / GPS	Leica IPAS20 CUS6
Flying Height (AMSL)	4400' FT AMSL
No. of Runs	6
Swath Width	2000m
Flight Direction	45 - 225 degrees
Flight Time (Local)	14:31 - 15:12
Pixel Size	10cm
Weather Conditions	Clear
Horizontal Datum	GDA94
Vertical Datum	AHD
Map Projection	MGA Zone 55
Forward Overlap	100%
Side Overlap	30%
Control	Control from existing project
Aerial Positioning Method	Basestation(s): Echuca
Vertical Accuracy	+/-0.50m
Horizontal Accuracy	+/-0.50m

2.2 Orthorectified Imagery

Description of mosaicing and Colour balancing	XPro, ERDAS Imagine
Output File Type	TIFF TFW ERS TAB ECW EWW
Output Tile Size	500m
Compression Rate	8-bit
Spatial Metadata	Source footprints, tile index and mosaic footprints in shapefile format
Tile Index File Formats	Shapefile
Overall Mosaic – Resolution & File Type(s)	ECW: compression 9:1

2 of 4

PHOTOMAPPING

www.photomapping.com.au

3. Data Accuracy

Airborne survey position was collected by the on-board Leica IPAS20 CUS6 system. This collected data was then post-processed using the Echuca base station.

3.1 Triangulation Results

	Control Points Residuals (m)		Tie Points σ (m)	
	RMS	Max.	RMS	Max.
X	0.000	0.000	0.098	0.289
Y	0.000	0.000	0.104	0.316
Z	0.000	0.000	0.214	0.584

4. Additional Services

Photomapping Services are the mapping and airborne imagery specialists with a focus on delivering spatial solutions including: Photogrammetry, Aerial Photography and Digital Imagery, LiDAR Airborne Laser Scanning, GIS Data Capture, Revision and Management and Cartography and Custom Map Production.

For further information contact:

Peter Saunders
Photomapping Services

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GEOIMAGE
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Job No.	18555
Client	Dept of Environment Land Water and Planning
Area of interest	Barmah Millewa, VIC

Data type	WorldView-2
Datum	GDA94
Projection	MGA55

Orthorectification and Pan-sharpening of WorldView-2 Imagery Barmah Millewa, VIC

Raw Data:

- Fresh capture Ortho-Ready Standard Level 2A WorldView-2 imagery
- 50cm resolution panchromatic, 2m resolution 8-band multispectral
- 1 swathe, 100sqkm, acquired 11 December 2016

Processing:

- Raw TIFs imported into PCI Geomatica and compiled
- Systematically orthorectified the panchromatic and multispectral swathes separately using rational polynomial coefficients (RPCs) without XY control and the Shuttle Radar Topography Mission (SRTM) DEM resampled to 5m for Z control
- Pan-sharpened the orthorectified multispectral image using the orthorectified panchromatic image in PCI Geomatica
- Pan-sharpened data exported to ER Mapper BIL format
- Contrast enhanced, ECW format images of the pan-sharpened data prepared in ER Mapper
  - Natural Colour (NC) – visible red, visible green and visible blue in RGB
  - False Colour (FC) – NIR band 1, visible red and visible green in RGB
  - Enhanced Natural Colour (ENC) – visible red, visible green + NIR band 1, and visible blue in RGB
  - N2ReY – NIR band 2, red edge and yellow in RGB
  - N2YC - NIR band 2, yellow and coastal in RGB
  - YGC – yellow, visible green and coastal in RGB
- Opacity layers added to ECW format enhancements

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ABN 91 603 077 185

WorldView-2 acquired 11 December 2016
Enhanced Natural Colour

Products Supplied:

/Unenhanced_ERMapperBIL

- UnSigned16BitInteger 8-band Multispectral image in ER Mapper BIL format (*BarmahMillewa_WV2_2m_11Dec2016_8band_MGA55.ers*)
- UnSigned16BitInteger Panchromatic image in ER Mapper BIL format (*BarmahMillewa_WV2_50cm_11Dec2016_Pan_MGA55.ers*)
- UnSigned16BitInteger 8-band Pan-sharpened Multispectral image ER Mapper BIL format (*BarmahMillewa_WV2_50cm_11Dec2016_ps8band_MGA55.ers*)

/Enhancements

- Arc-compatible, low compression (1:1), ECW format enhancements (*BarmahMillewa_WV2_50cm_11Dec2016_ENC_x1.ecw etc.)*

/RAW_Imagery

- Raw Ortho-Ready Standard Level 2A WorldView-2 imagery as delivered by DigitalGlobe *(Please note that this data is not orthorectified.)* (*16DEC11002131-P2AS_R1C1-055992757010_01_P001.tif etc.)*

/Metadata

- *18555_Readme.pdf*
- DigitalGlobe EULA (*WW0023A_Internal_Use_License_Ver2-24-15.pdf*)
- Metadata for these captures (*16DEC11002131-M2AS-055992757010_01_P001.IMD etc.)*

Image Details:

WorldView-2 Multispectral Image acquired 11 December 2016:
Top Left Coordinate = 311142.00mE, 6031472.00mN
Cell Size = 2.00m
Number of Lines = 7681
Number of Pixels = 8363
Projection = MGA55
Datum = GDA94

WorldView-2 Panchromatic Image acquired 11 December 2016:
Top Left Coordinate = 311142.50mE, 6031470.50mN
Cell Size = 0.50m
Number of Lines = 30723
Number of Pixels = 33449
Projection = MGA55
Datum = GDA94

WorldView-2 Pan-sharpened Multispectral Image acquired 11 December 2016:
Top Left Coordinate = 311142.50mE, 6031470.50mN
Cell Size = 0.50m
Number of Lines = 30721
Number of Pixels = 33449
Projection = MGA55
Datum = GDA94

Appendix D TLM Metadata

Metadata field	Description
MDBA project ID	
TLM icon site	Barmah-Millewa Forest
Project title	Exploration of the feasibility to remotely sense and map moira grass using aerial and satellite imagery
Service provider	Arthur Rylah Institute
Version number	Final
Theme	UVEG
Monitoring start date	11/12/2016
Monitoring end date	9/7/2017
Format	pdf document, Excel spreadsheet, GIS data
Creative Commons licence	Attribution 4.0 International (CC BY 4.0) as default

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