GOVERNMENT OF WESTERN AUSTRALIA

Department of **Biodiversity, Conservation and Attractions**

Using Remote Piloted Aircraft (RPA) to collect ground information for image analysis – 2020 edition

Version: 1.5 Last Updated: 23/12/2020	Approved by: Katherine Zdunic
Custodian: Remote Sensing & Spatial Analysis	Review date: 23/12/2020

Version number	Date approved DD/MM/YYYY	Approved by	Brief Description
1.3	01/09/2020	John Mosaj	
1.4	23/12/2020	Katherine Zdunic	

Biodiversity and Conservation Science

Using Remote Piloted Aircraft (RPA) to collect ground information for image analysis – 2020 edition

A technical guide for different environments in Western Australia

December 2020

GOVERNMENT OF WESTERN AUSTRALIA

Department of Biodiversity, Conservation and Attractions

Department of Biodiversity, Conservation and Attractions
Locked Bag 104
Bentley Delivery Centre WA 6983
Phone: (08) 9219 9000
Fax: (08) 9334 0498

www.dbca.wa.gov.au

© Department of Biodiversity, Conservation and Attractions on behalf of the State of Western Australia 2020
December 2020

This work is copyright. You may download, display, print and reproduce this material in unaltered form (retaining this notice) for your personal, non-commercial use or use within your organisation. Apart from any use as permitted under the *Copyright Act 1968*, all other rights are reserved. Requests and enquiries concerning reproduction and rights should be addressed to the Department of Biodiversity, Conservation and Attractions.

ISSN [ISSN] (print)
ISSN [ISSN] (online)
ISBN [ISBN] (print)
ISBN [ISBN] (online)

This report/document/publication was prepared by Remote Sensing & Spatial Analysis Program, Biodiversity Conservation Science.

Questions regarding the use of this material should be directed to:
Program Leader
Remote Sensing & Spatial Analysis Program
Department of Biodiversity, Conservation and Attractions
Locked Bag 104
Bentley Delivery Centre WA 6983
Phone: 92199584
Email: Katherine.Zdunic@dbca.wa.gov.au

The recommended reference for this publication is:
Department Biodiversity, Conservation and Attractions, 2020, *Using Remote Piloted Aircraft (RPA) to collect ground information for image analysis – 2020 edition*, Department of Biodiversity, Conservation and Attractions, Perth.

This document is available in alternative formats on request.

Contents

Appendices

Figures

1 Introduction

At the Department of Biodiversity, Conservation and Attractions (DBCA) the collection of field data is essential for many research, conservation and monitoring programs. The advent of reliable, small and affordable remote piloted aircrafts (RPAs), commonly known as drones, has revolutionized the collection of field information by improving the safety, accessibility and amount of quantitative information that can be captured in the field. An example of this is in the spinifex fuel monitoring and fire rates of spread projects (Rampant, Zdunic, and Burrows 2019) where two people would sample a single 100m transect at 1 metre intervals for vegetation cover and height. In the same time it took for the transact capture one RPA operator was able to capture a 100mx100m area at an image resolution of a few millimeters. The imagery was then processed post fieldwork for vegetation height, volume, cover and species.

Satellite imagery has been used at DBCA to map and monitor land and seascapes since the early 1990’s (G. A. Behn, Wallace, and Hick 1990; G. Behn and Campbell 1992; G. Behn et al. 2000; Barber et al. 2007; Zdunic and Behn 2009; R van Dongen 2013; Brundrett et al. 2019; Strydom et al. 2020). Ground information is essential to develop, calibrate and validate satellite imagery; ensuring the imagery products derived relate to the environment accurately and provide useful measures for land managers. Data collection via RPA’s can efficiently help bridge the gap between on-ground sampling and satellite observations and can yield more efficient time in the field; balanced by increased processing in the office. RPA’s also provide the ability to monitor at fine scales small areas through repeat captures and image analysis.

This guide has been created to bring together the learnings and techniques developed by the Remote Sensing & Spatial Analysis (RSSA) Program in Biodiversity and Conservation Science in developing RPA imagery capture methods and processing. The guide provides the variations in small RPA capture and processing required in different landscapes of Western Australia. These landscapes include the karri forest; jarrah and marri forest, mangroves, coastal shrublands, vegetated wetlands and spinifex grasslands. The guide specifically, and only, covers the capture of continuous overlapping still photography for the creation of larger high-resolution orthomosaic photography and 3D point clouds for further vegetation assessment.

Glossary

Orthomosaic: detailed, accurate photograph derived representation of an area, created out of many photographs that have been stitched together and geometrically corrected so that it is as accurate as a map.

3D point cloud: a collection of data points where each point represents a surface or object in space i.e. it has an X, Y and Z value.

Structure from motion (SfM): is a term used describing how three-dimensional data (i.e. 3D point clouds) is produced from two dimensional overlapping images taken from different locations using photogrammetry.

2 RPA capture and minimum equipment requirements

The requirements for RPA use for DBCA applications are outlined below and are current as of May 2020. Some requirements are set by the Civil Aviation Safety Authority (CASA), and others by DBCA.

- Abide by all the CASA RPA regulations.
- DBCA requires all operators (employees and contractors) to have acquired a full CASA certified Remote Pilot License (RePL) regardless of the weight of the RPA (*Note: this rule is stricter than the CASA ruling*).
- Ensure the RPA is registered with CASA (https://www.casa.gov.au/knowyourdrone/registration-and-accreditation).
- Have a current notification of intention to fly with CASA. If flying in the 'excluded' category this can be done online at https://forms.casa.gov.au/public/launch.aspx?portal=1&id=%7b1b396e81-f96a-433c-b377-05e5aa11cba2%7d&Form=RPAS
- See the CASA website for details if flying in the 'excluded' category, as it is not covered in this document.
- Lodge a flight plan with the region and/or district manager and the aviation operations officer (air-operations-plans@dbca.wa.gov.au), see appendix 1 for an example form. At this stage, the region or district manager will also specify limitations for the areas you can fly that are often not mapped on apps like "Open sky". For example, exclusion zones in our DBCA marine parks are not listed so this instruction will only come from the region or district mangers or marine park coordinators.

Remote Sensing & Spatial Analysis (RSSA) program minimum equipment requirements applied in this document.

- Recommended RPA's for this purpose are the DJI Phantom 4 pro or the DJI Matrice 200/210 with the Zenmuse X4s camera. The DJI Inspire with the Zenmuse X4s camera would also be adequate and in calm conditions the DJI Mavic 2 pro (20mp camera) should be adequate but not yet proven.
- Other multi-rotor RPA's and fixed wing RPA's have not been tested and non-DJI RPA's will not operate with the software that is currently being used in RSSA.
- A recent model tablet:
  - Apple iPad (preferably the mini for convenience) and DJI software. An iPad should be dedicated to the RPA to keep the system secure and operational.
    - DJI GO 4 app: is used to fly the RPA separate from planning and flying missions and is required to update firmware and general drone use.

        - DJI Ground Station Pro (GSP) is required used to pre program RPA flights to capture areas of imagery.
    - Android tablets and apps are available to use with DJI RPA's however these have been found to be less robust than the Apple iPad and GSP software combination.
- Software to undertake field survey
    - For Apple iPad: DJI Ground Station Pro (DJI GSpro) is a free, reliable and proven app for capturing the survey data required. There is a paid extension (~$80) for importing ESRI shape files and KML files of field plots is required.
    - For Android: Lichti software (https://flylitchi.com/; cost to download from an app store)
    - Airmate or Runway by ozrunways: for assisting with planning your flight under CASA regulations and provides other aeronautical information such as radio frequencies etc.
    - Open sky to assist with planning and determining if you can fly in an area or what to look out for.
- Agisoft Metashape software to undertake photogrammetric processing of digital images (perpetual licence costs ~$4500). This can be used to stitch the digital images together into a seamless image with geographic coordinates commonly known as an orthomosaic.

Optional

It is also good practice to have an aeronautical radio and have completed aeronautical radio operator certificate (usually as part of RePL training).

3 What ground measures can be obtained?

Ground measures that can be derived from overlapping nadir photography captured by RPA and processed to orthomosaic level can include:

- Cover: the areas of green vegetation, bare ground, and non-photosynthetic vegetation to provide percentage areas of cover.
- Structure: 3D data can be derived from the overlapping photographs enabling height and volume calculations; applications in vegetation require different processing parameters to buildings.
- Monitoring: change in extent and height of vegetation ranging from individual plants to coups/stands.
- Species identification (limited): the identification of species through image analysis is heavily dependent on the visual contrast between present species/genera and field information.
- Capture at equal distance intervals

Figure 1 displays the general requirements and flying specifications for the ground measures of cover, structure, monitoring and species identification. These are described in more detail in the Image Capture section.

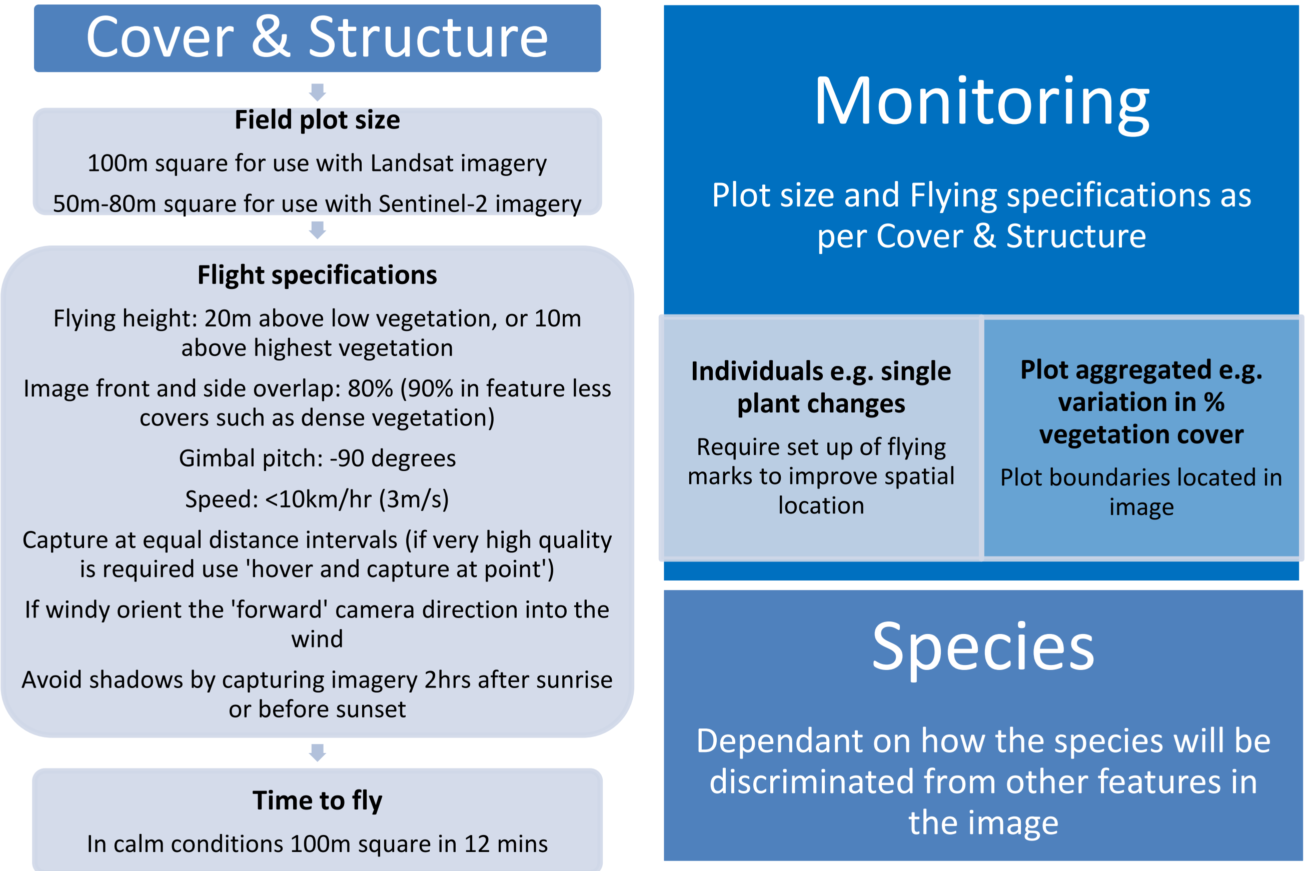


Figure 1: Flowchart of field plot size flying specifications for obtaining different ground measures.

4 RPA models

There are many models of RPA available and there are likely many that are suitable for this purpose. We have chosen the DJI brand due to reliability; availability; market leader; back-up and parts available; value for money and compatibility with our software and workflow.

Current (May 2020) recommended models are:

- DJI Phantom 4 pro v2: Best value for money, ease of use and portability
- DJI Matrice 200/210 with Zenmuse X4s camera: expensive, very stable but heavy, less portable and requires extra level of CASA approvals (greater than 2kg).
- DJI Mavic pro 2 (model with 20mp camera): affordable, very portable and light but susceptible to breezes and lack of landing legs makes it very difficult for take-off and landing in the field and on boats.

The DJI Inspire with Zenmuse x4s camera, like the Matrice 200/210 but is more suited to videographers, and therefore is not good value for money for our purposes.

These RPA's need to be paired with a tablet, high capacity minimum 32GB microSD for onboard imagery storage; microSD card adaptor and portable hard drive to copy and store imagery.

5 Image Capture

5.1 Planning

The planning of field sites considers the ground measure required, accessibility, terrain, tide, time per plot, the resources available (e.g. batteries, number of RPA pilots). Field sites are planned to be homogeneous in order to provide a consistent measure to compare to satellite imagery (Kuhnell et al. 1998; Behn et al. 2001). Homogeneous areas have a consistent patterning of vegetation across them, consistent soil colour, a uniform fuel age and are sufficiently large to enable colocation with a three by three pixel sample of Landsat satellite imagery (which has a 30m pixel size). This requires a plot size of 100m by 100m. Having a larger plot size than the three by three pixels is important as at the edges of the plot there will be fewer overlapping images and a reliable orthomosaic will not be able to be produced. If Sentinel 2 satellite imagery (pixel size 10-20m) is being used, then the plot size can be reduced to a 50-80m square.

The required image resolution (mm pixels to cm pixels) is affected by the flying height and so height planning will need to be considered according to terrain and the ground measure required. For example, species identification may require higher image resolution than a cover measure (Figure 2, Figure 3).

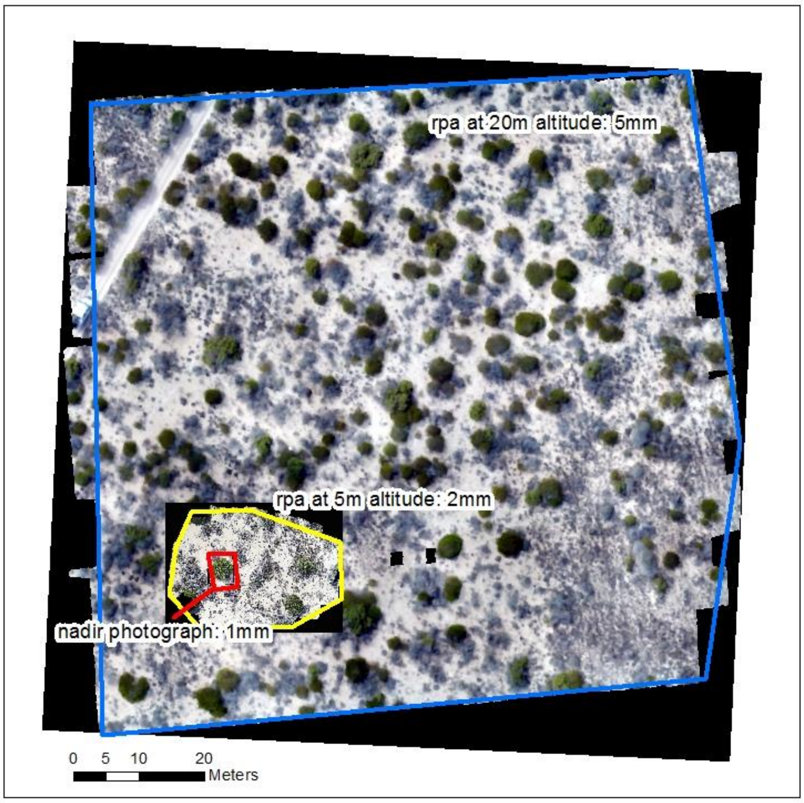


Figure 2: Capture footprints for nadir imagery (red) and RPA imagery at 5 (yellow) and 20 m (blue) altitudes.

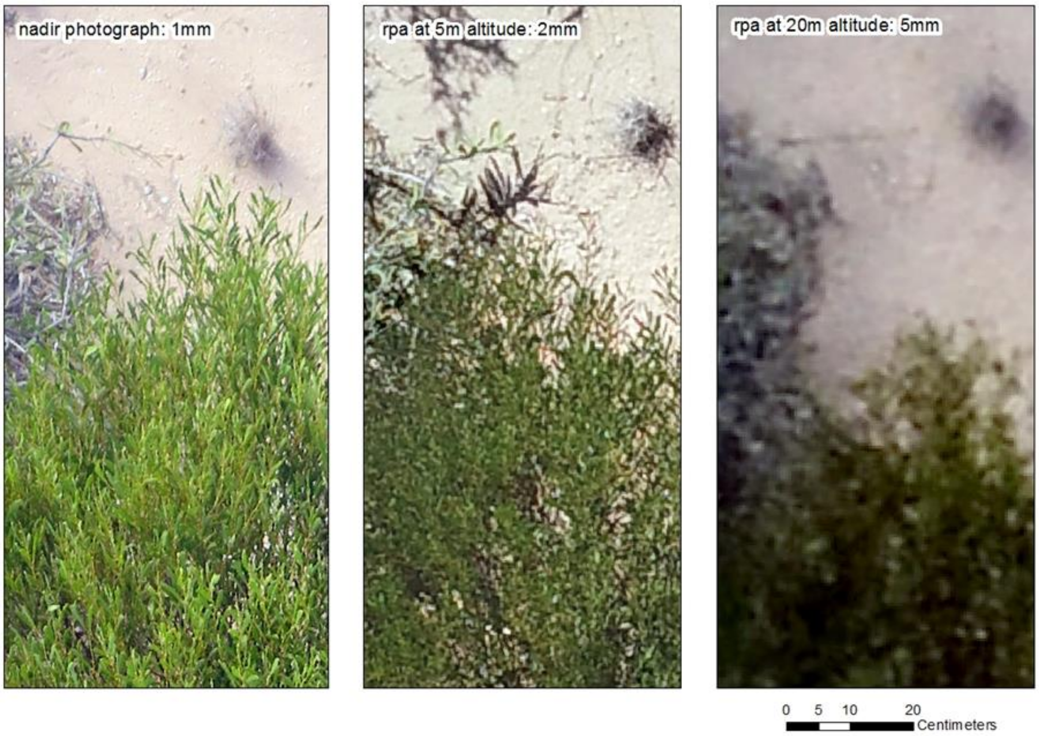


Figure 3: A comparison of imagery from nadir photography (1 mm resolution), RPA at 5 m altitude (2 mm) and RPA at 20 m altitude (5 mm).

Another aspect of terrain to consider is where you as the RPA operator will be in the landscape your launch site; are you up high with a good view or where you will fly or the same level as your sites or lower if you are flying from a boat at low tide. Line of sight from your position in the landscape as a rule is 500m from the controller, determining the take-off/landing position and buffering this location by 500m can give you a guide to where you can fly to in the landscape. Figure 4 is an example of a field map used to plan RPA capture of mangroves in the Pilbara using the launch sites to determine which sites that can be captured by one of multiple operators. Plans like these can maximise time in the field particularly when coordinating multiple RPA operators.

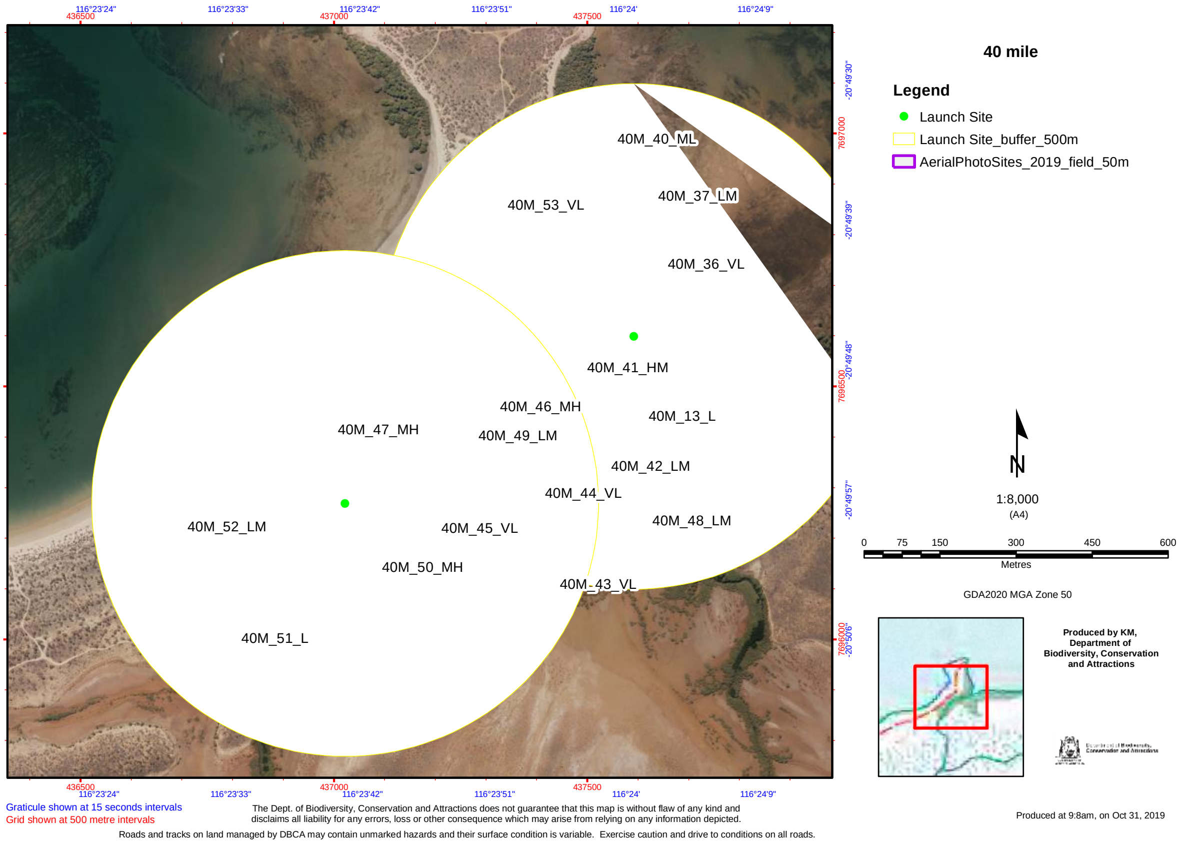


Figure 4: Field trip map for planning site capture with suggested locations for launching the RPA and the flighting distance limits (within a 500m line of sight buffer). With multiple RPA operators this can help plan who will fly each site when in the field.

Weather, tides, and day length may all play major part in the planning of the mission. Avoid days of winds higher than 25km/hr as gusts may cause erratic flight behaviour. Operating later or early in the day can produce long shadows and poor imagery for point cloud production, and so the two hours after sunrise and before sunset should be avoided. Western Australian is big state and the sun will be higher in the sky the further north you go. Apps like sun calc can help you plan for a sun angle. Water on the ground (e.g. when capturing mangroves) can cause reflections and provide a false ground level if trying to assess vegetation height. RPA photos do not detect green cover through water well so a high tide or mid tide can also obscure green vegetation reducing the % cover for that site.

While flying in hot conditions has not proven to be overly difficult or reduce battery life the RPA batteries will not charge in temperatures over 28^{o} C so planning has to include having enough batteries for the entire day if operating in those conditions. Where possible a spare RPA is useful in case of equipment failure the field trip can continue. It is also prudent to carry spare propellers as the RPA should not be flown with damaged propellers.

To improve image position for individual plant identification and monitoring the establishment of ground marks is required. This involves placing 4 targets on the ground easily visible by the RPA and recording the centre of their position using a GPS or preferably DGPS. The ground marks are often two contrasting colours in a checker pattern (Figure 5), these can be made or purchased. Establishing the ground marks will ensure the processed orthomosaic can be accurately rectified to the ground and therefore directly compared to other datasets in further spatial analysis and repeat RPA captures.

Figure 5: Example of a ground mark configuration, a 30cm by 30cm square is sufficient.

Software for planning and undertaking the field work needs to be updated and functioning where there is Wi-Fi available before the RPA flight/s are undertaken so you can upload your sites and cache the background imagery at a high resolution. The functions of commonly used RPA apps are described below:

DJI Go: provides the standard flight software for DJI RPA’s

- used for updating RPA firmware
- setting camera specifications and safety settings
- flying; take-off and landing
- capturing ad-lib whole of site photos and video
- capturing oblique photographs

DJI ground station pro: office and field mission (flight) planning software

- Used for planning missions/sites, including assessment of battery usage and time required for field trips
- Purchase an upgrade to upload ESRI shapefiles and KML files (~$80)

- Reliable flying (no fly aways); flexible; powerful; reliable for data collection; has always produced a good result.
- Issues: this software only works on iPad and occasionally does not capture an image

Litchi

- Works on android
- Flight planning needs to be carried out in the online Litchi flight planner (https://flylitchi.com/hub). This system works well but is not flexible. Flight plans cannot be made or modified in the field.

5.2 Flying specifications

All flights need to be following CASA regulations and ensure that DBCA approvals are in place and if necessary further CASA approval. Guidelines for flying heights, time-of-day and temperatures are detailed in the Planning section.

High winds can affect the stability of the RPA, clarity of image capture and safety (Duffy et al. 2018). Flying in winds greater than 35km/hr (approx. 19 knots) is outside the operating conditions of the DJI RPA’s and could lead to loss of the RPA. Winds over 20 km/hr will require a higher level of skill when operating/landing between trees and will lead to significantly more battery usage. Wind will also impact the quality of imagery and the ability of the processing software to co-locate vegetation features on neighbouring photos while will then complicate the processing of the imagery and ultimately produce a lower quality product. Some (typically taller and flexible) vegetation is more prone to wind effects than others (like spinifex and low shrubs).

An example of typical image capture settings is shown in the list below. These are likely to vary slightly for different ground measures and environments.

- Forward overlap 80%
- Side overlap 60%, in dense vegetation forward and side overlaps need to be higher
- Gimbal pitch -90 degrees
- Height 20m for low vegetaion, or 10 m above highest vegetation (will produce a 5mm pixel)
- Speed <10km/hr (3m/s)
- Hover and capture (capture at equal distance intervals will reduce battery use, but some compromise on image sharpness)
- Hover at end of flight to enable flying the RPA onto the next field plot rather than back to base
- If windy orient “forward” direction into wind (camera orientation)
- To lower the processing impact of shadow a good rule of thumb is to avoid capturing imagery during the first and last 2 hours of daylight.

- For take-off and landing a clear flat area is required. A mat or solid surface makes this much easier in the field. An advantage of RPA models with legs is the ability to ‘catch’ the RPA.

For dense vegetation such as forest/mangroves a higher overlap of up to 90% is recommended as the feature recognition software required for orthorectification will struggle with dense featureless vegetation. Foliage movement due to wind will also add to this issue of not being able to locate common features between images.

When preparing to fly the field plots the software will generate a set of waypoints where the RPA will pause and take the nadir photograph. For the 100m by 100m plot there should be around 100 waypoints. The number of waypoints will vary according to the flying height and overlap specified. A general rule of thumb: if you must fly higher due to steep slope and/or vegetation then you’ll need to increase the forward and side overlap to achieve the required photos for the same area.

A typical 100x100m site will take about 10 minutes, but this will increase with; height, wind and distance from site. If using the “stop to take photos” vs the take photos while moving will also increase the time per site. On a typical day we have noticed no movement blur due to the RPA movement, but have due to wind.

An issue with RPA capture in remote areas is battery storage, travel and charging as the volatile batteries cannot be stored in aircraft holds or charged in a vehicle due to the danger of fire. This reduces the amount of field sites that can be captured with a single RPA and the requirement for power generation at the field base. You are also limited to how many batteries you can travel by plane with.

6 Processing

6.1 Imagery processing

6.1.1 Single images

These images may capture entire sites, either from up at height or in oblique to display the position in the landscape, it general we do not apply any processing to these images.

6.1.2 Orthomosaics

Currently the Remote Sensing and Spatial Analysis program are using Agisoft Metashape Professional (https://www.agisoft.com/) to import RPA photos and create orthomosaics.

This is a sophisticated application and requires training and background knowledge to operate it efficiently. There are comprehensive tutorials available through the Agisoft website, appendix 2 contains an example setups and trouble shooting. Broadly the process is step by step within Agisoft Metashape software by following each step in the ‘Workflow’ menu. Typically, 80-150 photographs per 100m by 100m site are processed which requires a high end desktop computer with a good graphics card or a lot of waiting time.

There are vendors providing a processing service to undertake orthomosaic and produce height layers. An example of one is Maps made easy https://www.mapsmadeeasy.com/.

Post-processing software shortcuts:

- Agisoft Metashape
  - georeferencing (putting in ground locations) and mosaicking photography to make orthomosaics.
  - produces dense point clouds for enabling 3D processing.
  - has the capability produce a digital elevation model (DEM) and canopy height model (CHM), and in some situations these models will be adequate for purposes.
  - After each site is aligned a standard batch process can be created to automatically run through the remaining steps for multiple sites at a time. This batch process can be saved and reused for other projects or sites.
- Rapidlasso LAStools
  - developed to process large Lidar data sets and is very efficient for processing point cloud data. It gives more options for cleaning ad processing problematic point cloud data when Metashape produces a less than adequate product.

6.1.3 Height layers

The first steps in the creation of height information from the RPA photography are generated in the same process creating the orthomosaic (6.1.2). The point-clouds are created as part of the orthomosaic creation, these may be exported from Metashape. High density classified point clouds and digital terrain models (DTM's) and digital surface models (DSM's) may also be created in and exported from Metashape for further analysis in other software. The point clouds can be exported in .las files and the DSM's and DTM's in common raster formats which can be viewed in ArcGIS or QGIS.

While the point cloud and derived DSM and DTM may be an accurate product generated by Metashape, some more complex vegetation types, or when a higher level of accuracy is required, then other software is used to clean and process the point cloud data. Rapidlasso LAStools is powerful, but not very user-friendly, software developed for high level, high efficiency processing of point cloud data. Developed originally for processing huge files of LiDAR data it lends itself very well to batch processing photogrammetrically derived point cloud data.

For further processing of height information, a set of raster products can be created for further height analysis e.g. slope, aspect and hydrology. Raster products (ArcGIS grid or TIF formats) at a suitable resolution for your work will process more simply and rapidly than vector or point cloud data.

6.2 Ground measure derivation

6.2.1 Cover

Total vegetation cover has been successfully derived from RPA data using both spectral (RGB) and height data. This has been achieved in simple vegetation structure habitats such as spinifex, mangroves and open shrublands but is yet to be proven in more complex vegetation communities.

In spinifex grassland on dry red soils a green band/red band ratio can produce accurate results of vegetation cover (Rampant, Zdunic, and Burrows 2019). An accurately derived canopy height model can also assist in identifying vegetation cover, typically in flat terrain, significantly increasing the accuracy.

For mangroves, MATLAB and formulas developed for ground cover by (Macfarlane 2011) can be used to determine the green vegetation cover automatically. This process is quick and simple but required the orthomosaic created in Metashape to be first clipped to the site boundary then saved into a high quality jpeg. To extract the green part of the ground cover Macfarlane script uses six different algorithms: LAB1, LAB2, GLA, BCV1, BCV2 and Rosin. Typically, GLA and LAB2 were the best at determine the % of cover however in sparse mangroves either BCV1, BCV2 or Rosin would give better result. Factors that affecting the best representation of green cover in the image were; soil or mud colour as this could vary from white to greys to reds; or if there was water in the image. The process can give you a summary of all algorithm representations over cover for each image as well as a large image which is handy to compare with the original site orthophoto (Figure 6). Each image needs to be visually checked which can be time consuming and when the results are close, particularly under 5% as it can be difficult to know which is the right representation.

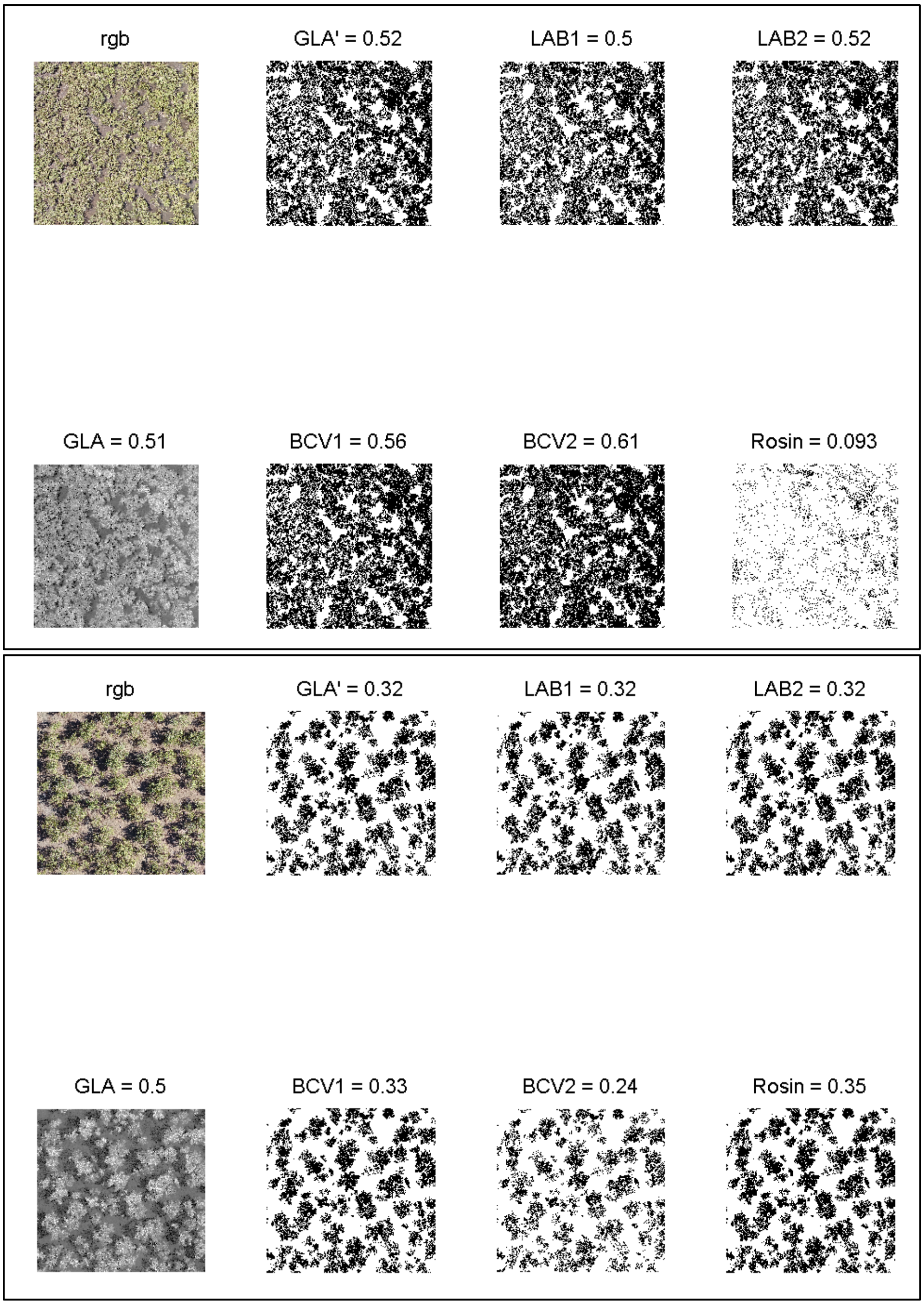


Figure 6: Algorithm representations of cover for each image and the original site orthophoto.

High resolution imagery can be classified into green vegetation, cured and bare ground. The example in Figure 7 shows classifications from nadir imagery, however the same techniques can be applied to RPA imagery. The processing and classification in the figure below were carried out eCognition. This example is from van Dongen et al. 2019.

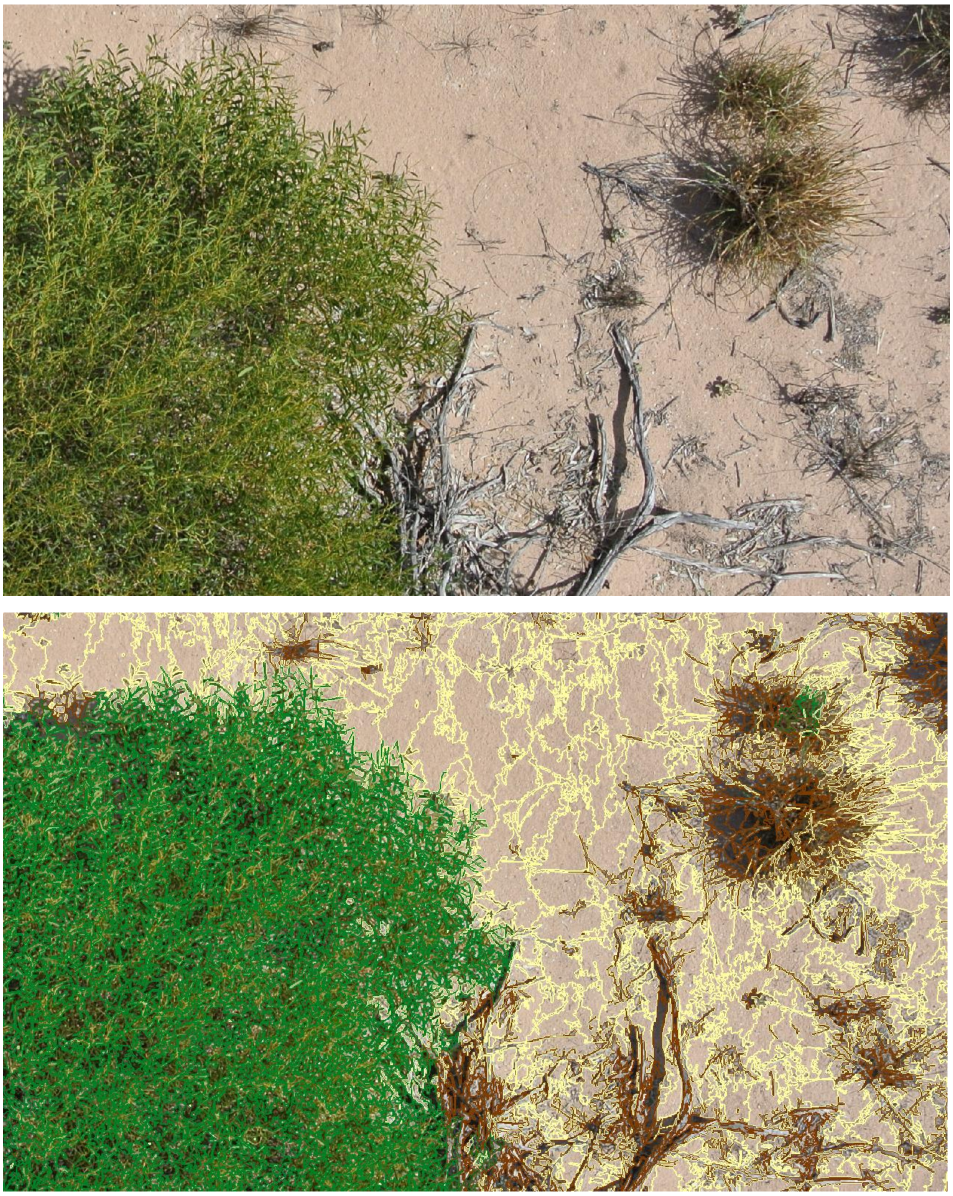


Figure 7: High resolution image (a), and the image with segments classified into green vegetation (green), cured vegetation (brown) and bare ground.

6.2.2 Structure

Canopy height models (actual height of the vegetation above ground level) and other ground surface attributes may be created in the LAStools software or the ArcGIS Spatial Analyst extension. For large data sets programming LAStools and running it batch mode utilises most of the computer's multiprocessing capability and will typically process data up to ten times faster than ArcGIS (with spatial analyst) for large data sets on a high end desktop computer.

6.2.3 Monitoring

RPA data can be used to monitor small scale changes in vegetation cover and species composition. Work such as this is being carried out on Dirk Hartog Island. Relatively small 10 by 10 m plots are being captured by RPA at 2 mm resolution (Figure 8).

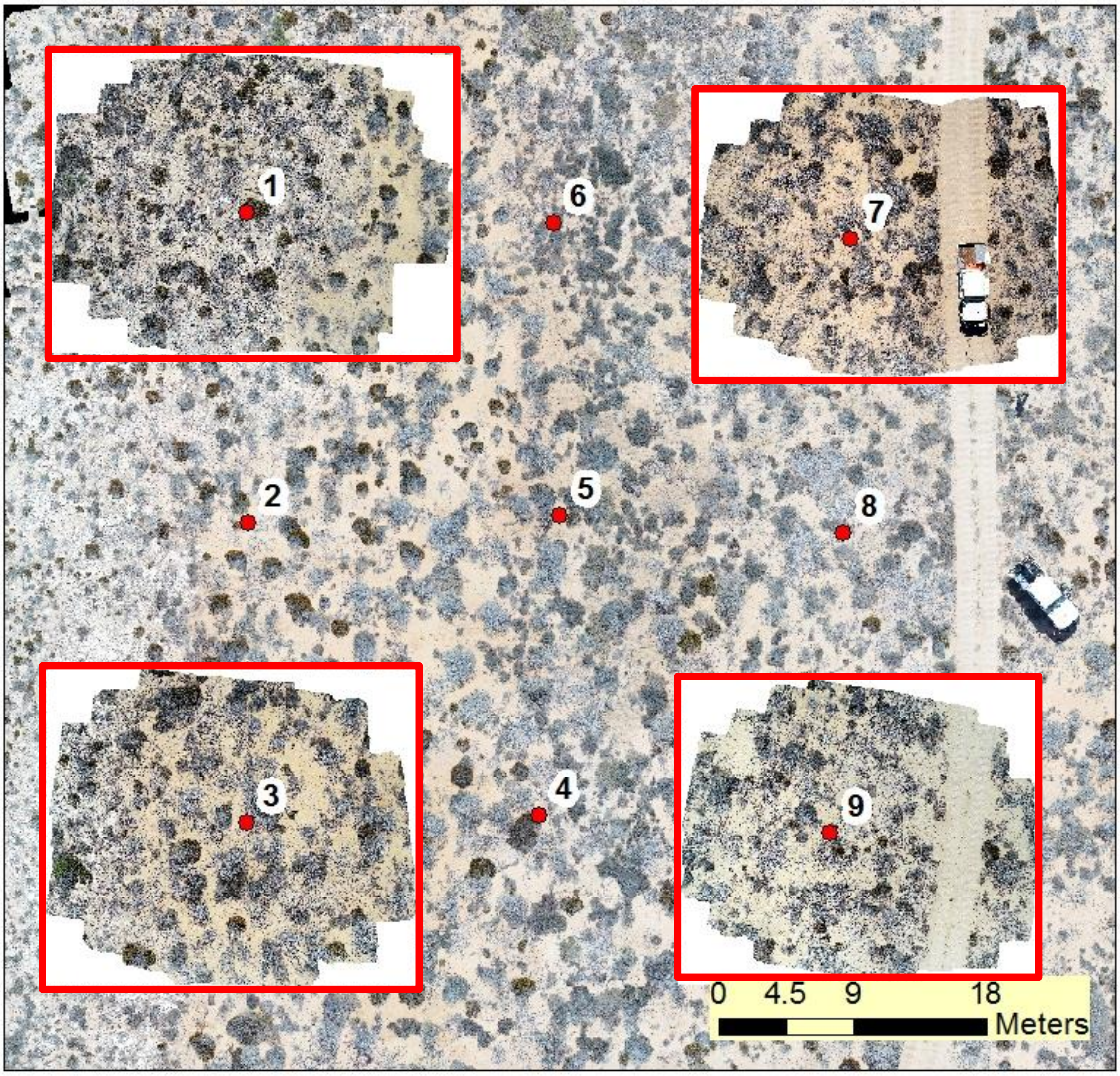


Figure 8: Configuration of RPA image captures at monitoring sites on DHI (red boxes).

That data is now being used to measure small changes in vegetation cover extent. The change in canopy of an *A. ligulata* from 2018 to 2019 is shown in Figure 9. The mean diameter increases from 2.025 m to 2.245 m (10%).

Figure 9: Canopy measurements of an A. ligulata from 2018 and 2019.

6.2.4 Species identification

By collecting GPS points of individual plants within the RPA image it is possible to test to see whether individual species can be separated based on their spectral values and height. Work such as this was carried out over exclusion plots on Dirk Hartog Island (Figure 10). This work is currently ongoing however preliminary accuracies ranged from 46.8 to 60.3 %.

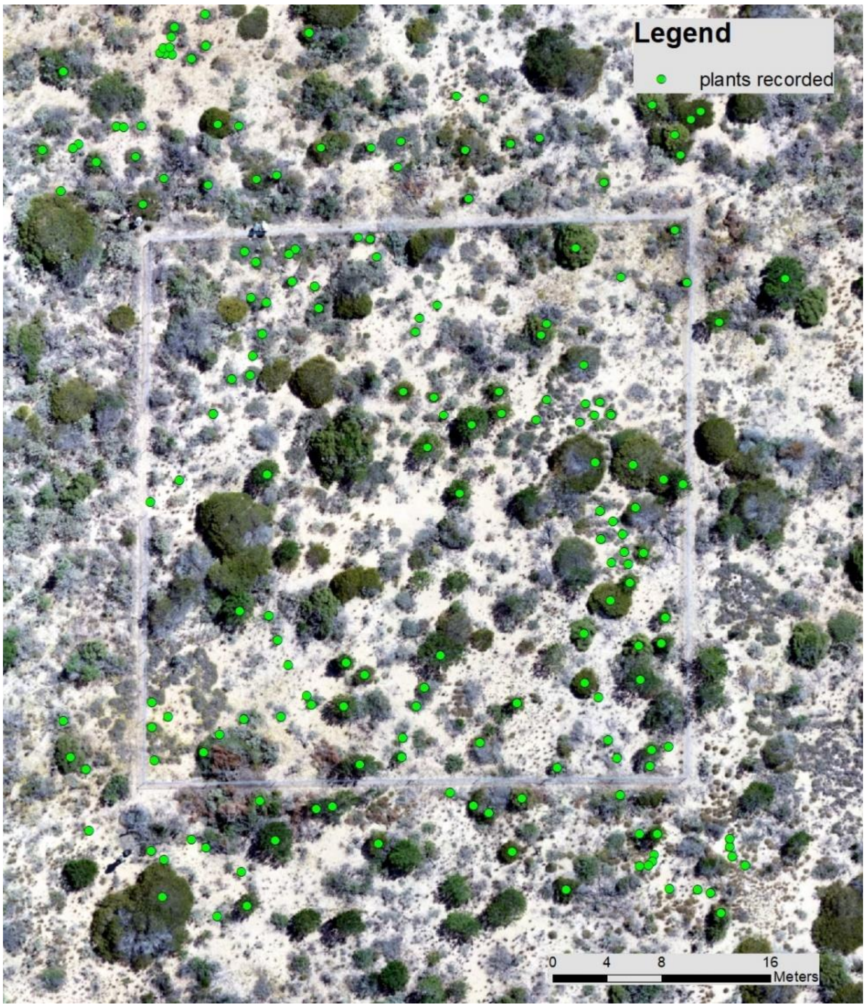


Figure 10: RPA photo mosaic and plant locations example.

References

Barber, Paul, Graeme Behn, Drew Haswell, Frank Honey, Andrew Malcolm, Christine Stone, Bernie Dell, and Giles Hardy. 2007. "The Use of Remote Sensing Technologies to Investigate Severe Woodland Decline in Western Australia." In *Proceedings of the MEDECOS XI Conference*, 11–12. Perth, Western Australia. http://researchrepository.murdoch.edu.au/id/eprint/7104/1/severe_woodland_decline.pdf.

Behn, G. A., J. F. Wallace, and P. T. Hick. 1990. "The Use of Airborne Multispectral Scanner Data for the Detection and Mapping of Insect Damage in the Jarrah Forest." CSIRO. Z:\DOCUMENTATION\Reports_Papers\RS_Library.Data\PDF\Behn et al Pests in Jarrah report-4105788928/Behn et al Pests in Jarrah report.pdf.

Behn, G., and N. Campbell. 1992. "Dieback Assessment, Using Multispectral Data over the Stirling Range National Park, W A." https://publications.csiro.au/rpr/pub?list=SEA&pid=procite:fd1d4f17-3d77-4bf9-bc5f-545283ef556e&sb=RECENT&expert=false&n=1&rpp=25&page=1&tr=1&q=n%20campbell%3B%20g%20behn&dr=all.

Behn, G, F McKinnell, P Caccetta, and T Vernes. 2000. "Mapping Forest Cover, Kimberley Region of Western Australia." *Australian Forestry* 64 (2): 80–87.

Brundrett, Mark, Ricky van Dongen, Bart Huntley, Natasha Tay, and Vanda Longman. 2019. "A Monitoring Toolkit for Banksia Woodlands: Comparison of Different Scale Methods to Measure Recovery of Vegetation after Fire." *Remote Sensing in Ecology and Conservation* 5 (1): 33–54. https://doi.org/10.1002/rse2.88.

Dongen, R van. 2013. "Vegetation Condition Monitoring Using High Temporal Frequency Landsat Imagery: Three Case Studies in Western Australia." Perth: Curtin University.

Dongen, Richard van, Bart Huntley, Greg Keighery, and Mark Brundrett. 2019. "Monitoring Vegetation Recovery in the Early Stages of the Dirk Hartog Island Restoration Programme Using High Temporal Frequency Landsat Imagery." *Ecological Management & Restoration*, 12. https://doi.org/10.1111/emr.12386.

Macfarlane, Craig. 2011. "Classification Method of Mixed Pixels Does Not Affect Canopy Metrics from Digital Images of Forest Overstorey." *Agricultural and Forest Meteorology* 151 (7): 833–40. https://doi.org/10.1016/j.agrformet.2011.01.019.

Rampant, Paul, Katherine Zdunic, and Neil Burrows. 2019. "UAS and Landsat Imagery to Determine Fuel Condition for Fire Behaviour Prediction on Spinifex Hummock Grasslands of Arid Australia." *International Journal of Remote Sensing* 40 (24): 9126–39.

Strydom, Simone, Kathy Murray, Shaun Wilson, Bart Huntley, Michael Rule, Michael Heithaus, Cindy Bessey, et al. 2020. "Too Hot to Handle: Unprecedented Seagrass Death Driven by Marine Heatwave in a World Heritage Area." *Global Change Biology* 26 (6): 14. https://doi.org/10.1111/gcb.15065.

Zdunic, Katherine, and Graeme Behn. 2009. "Exploiting Time Sequences of Satellite Imagery to Monitor Landscape Aspects." In . http://spatial.adelaide.edu.au/SSC2009/papers/Wilson.pdf.

Appendices

Appendix 1

Aircraft Operations Plan example

Part B – Aircraft Operations Plan

All aviation activities within Parks and Wildlife are governed by ***Policy Statement 66 – Aviation in the Department of Environment and Conservation***.

An AOP is NOT REQUIRED providing:

- the aircraft operator has been contracted through formal tendering processes and is used within scope of contract; or
- the operation is conducted according to a Parks and Wildlife approved Safety Management Plan and associated AOP; or
- the aircraft operation has an AOP that was initially approved as part of multiple aircraft operations for the same activity.

AOP Identifier (AOP ID)

AOP ID	**BSC-SRMP-28/02/2020**

Operator's license number (ARN)
1068063 (K Murray) **1068827 (K Zdunic)**

2: Client/Branch/Division	**Contact name**

Remote Sensing & Spatial Analysis, Biodiversity & Conservation Science	Kathy Murray

3: Project Supervisor	
Supervisor Dr Steeg Hoeksema	Position Senior Environmental Officer, Rivers and Estuaries
Division BCS	Branch/section/region: Rivers and Estuaries Science
4: Mission	
Mission Name	Alexandrium algal bloom survey
Dates of Operation	2th -30th March 2020
Mission Objective	Obtain high resolution imagery of Alexandrium algal bloom in the Swan and Canning Rivers
Area/location of proposed aerial activity	Numerous sites within Swan River Marine Park Waters including Matilda Bay, Swan River, Perth

5: RPA being used	
RPA type	Multirotor < 2kg
Manufacturer and model	DJI, Mavic 2 Pro
Year of manufacture	Mavic 2 Pro -2019
Total flight hours	2.31 Hrs
Primary intended use	Photography and videography

6: RPA records

Flight log record	YES	Accumulated time	2.51 Hrs
Battery log record	YES		
Maintenance preflight checks	YES		
Service history	YES		
Record of all information Where?	YES With Katherine Zdunic, DBCA, Kensington		

7: RPA Operation with CASA			
Do you have a CASA Remotely Piloted Aircraft License (RePL)	YES	Name Kathy Murray Katherine Zdunic	Number 1068063 1068827
Total flying time (hours) of operator	12.02 Hrs (KM) 7.5 Hrs (KZ)		
Hours operating the RPA being used for this mission	0.4 Hrs on this model (KM) 2 Hrs on this model (KZ)		
If required, has the ReOC been lodged and approved?	Not required Date: (Copy attached YES / NO)		
Has approval from CASA (At least 5 days prior to mission) *This includes RPA's under 2kg*	YES Date: 29/3/2017 & 18/6/2019 CASA Notification ID: 27985 (KM), 28523 (KZ) Copy attached YES		

8: Air Operations Plan		
Lodged by Kathy Murray	Email to	air-operations-plans@dbca.wa.gov.au
AOP approval by	Jason Omodei	JOmodei
Date of approval	3/3/2020	
Comments		

9: Air Operations		
LOS	YES	
OLOS	NO	
Autonomous	YES	
Day	YES	
Night	NO	
Weight	<2.0kg	
Launch and recovery site Coords/georef	Multiple see attached map. NOTE all sites are outside of restricted zone of airport and outside warning zones of helipads, however operators will be vigilant.	
Security	YES	
Safety	YES	
Signage	YES where in proximity with public	

10: Wildlife interaction approvals

From	N/A	Date	
Comments			

11: Insurance cover			
Cover by	RiskCover		
Amount of cover	public liability policy up to $M600 workers compensation policy up to $M300.		
Comments			

12: Notification Confirmation		
Regional Manager		
District Manager	Mark Cugley	
Comments	Noting sensitive native and migratory bird population at Pelican Point Marine Park, flight operations are to minimise disturbance in this area and be above 120m.	

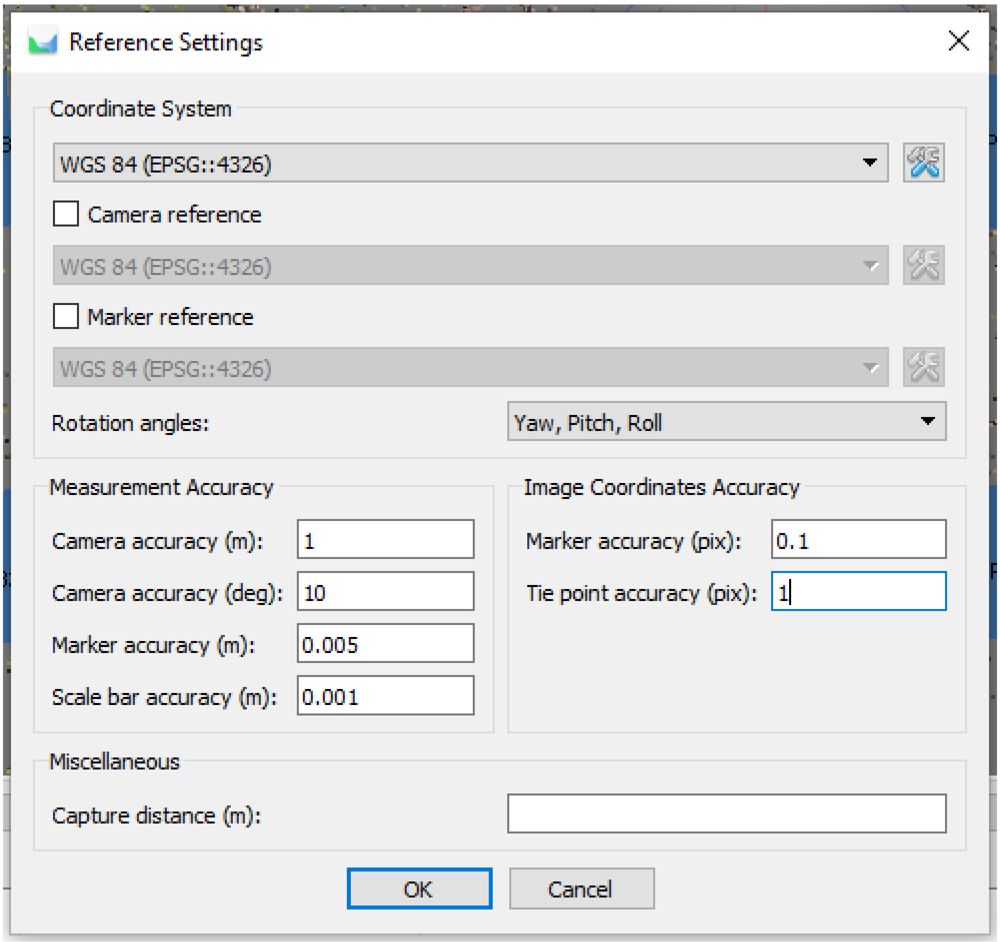
Appendix 2

Agisoft processing documentation

[\\kens-gis-001\Z\DEC\MangroveMonitoring\Working\Northern_Kimberley\FieldTrips\FieldTrip_201906\FieldData\Photos\Processed\](\\kens-gis-001\Z\DEC\MangroveMonitoring\Working\Northern_Kimberley\FieldTrips\FieldTrip_201906\FieldData\Photos\Processed\)Draft - how to batch process AgiSoft.docx

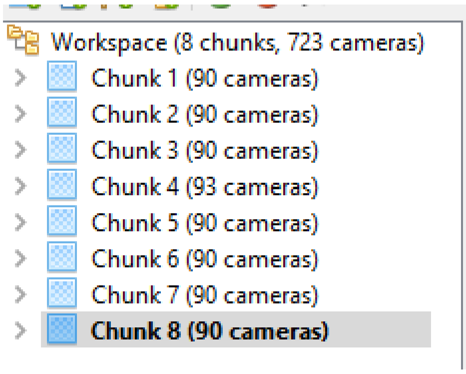
Ellen D'Cruz and Kathy Murray
Last updated 03-09-2019

Optimise camera alignment



Individual Sites

Add all photos you want to batch process as separate chunks. This works well for Z-L sites. For M-H sites you may need to align the photos in each plot separately and then merge to create one chunk (skip to Merge Chunks section).

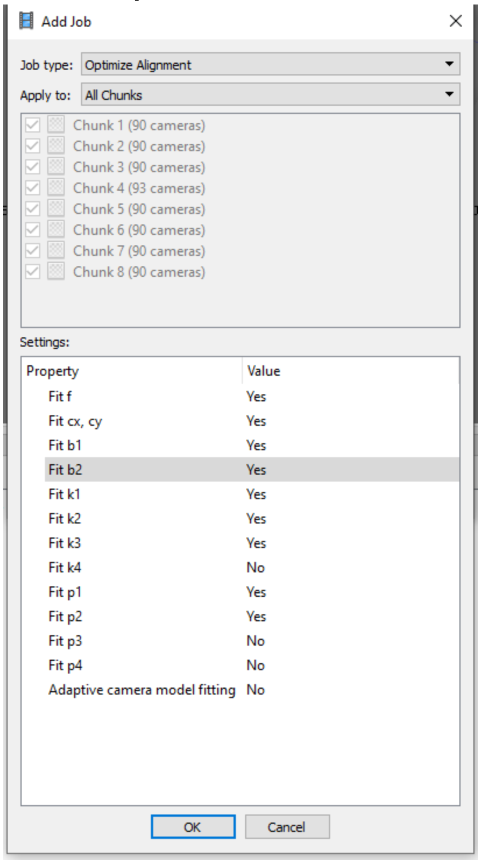


We found it easier to align the photos and set the bounding box manually first. Otherwise this might become an issue where the bounding box cuts off parts of the image at the end.

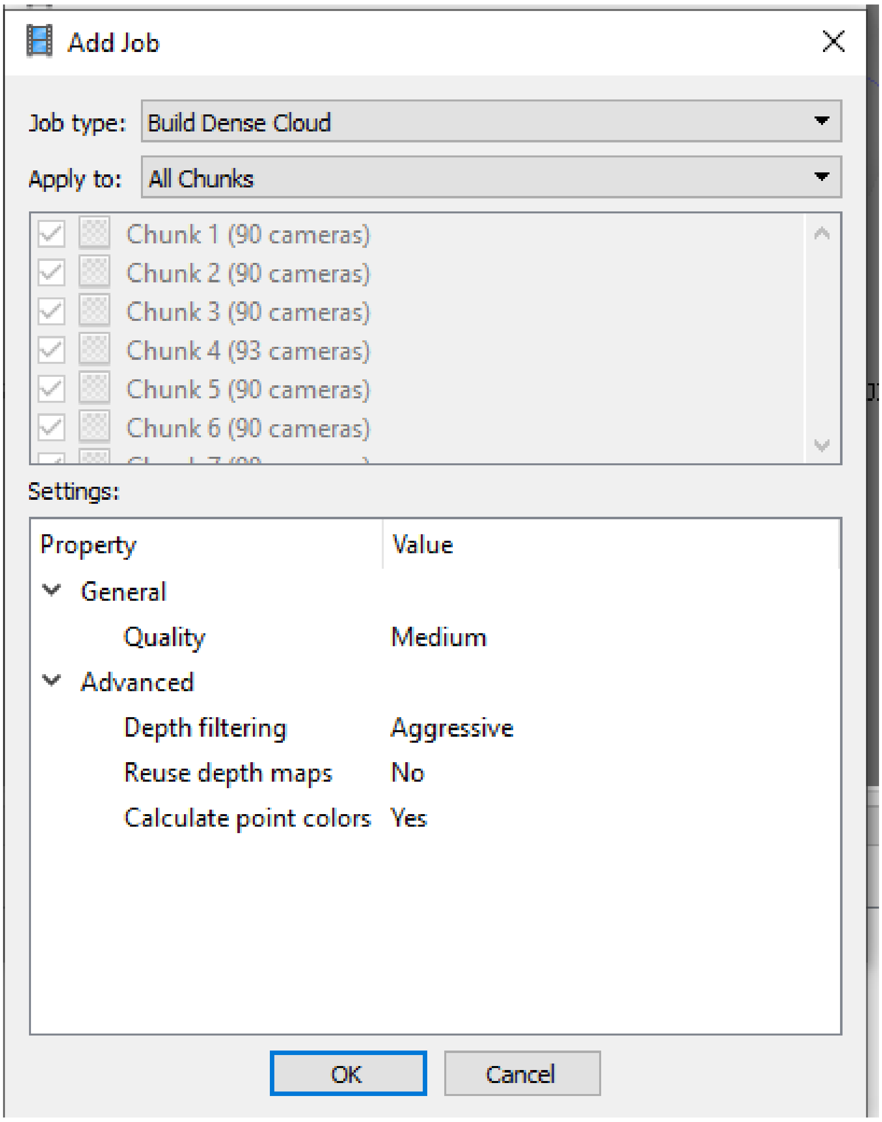
Workflow > Batch Process

Add a step.

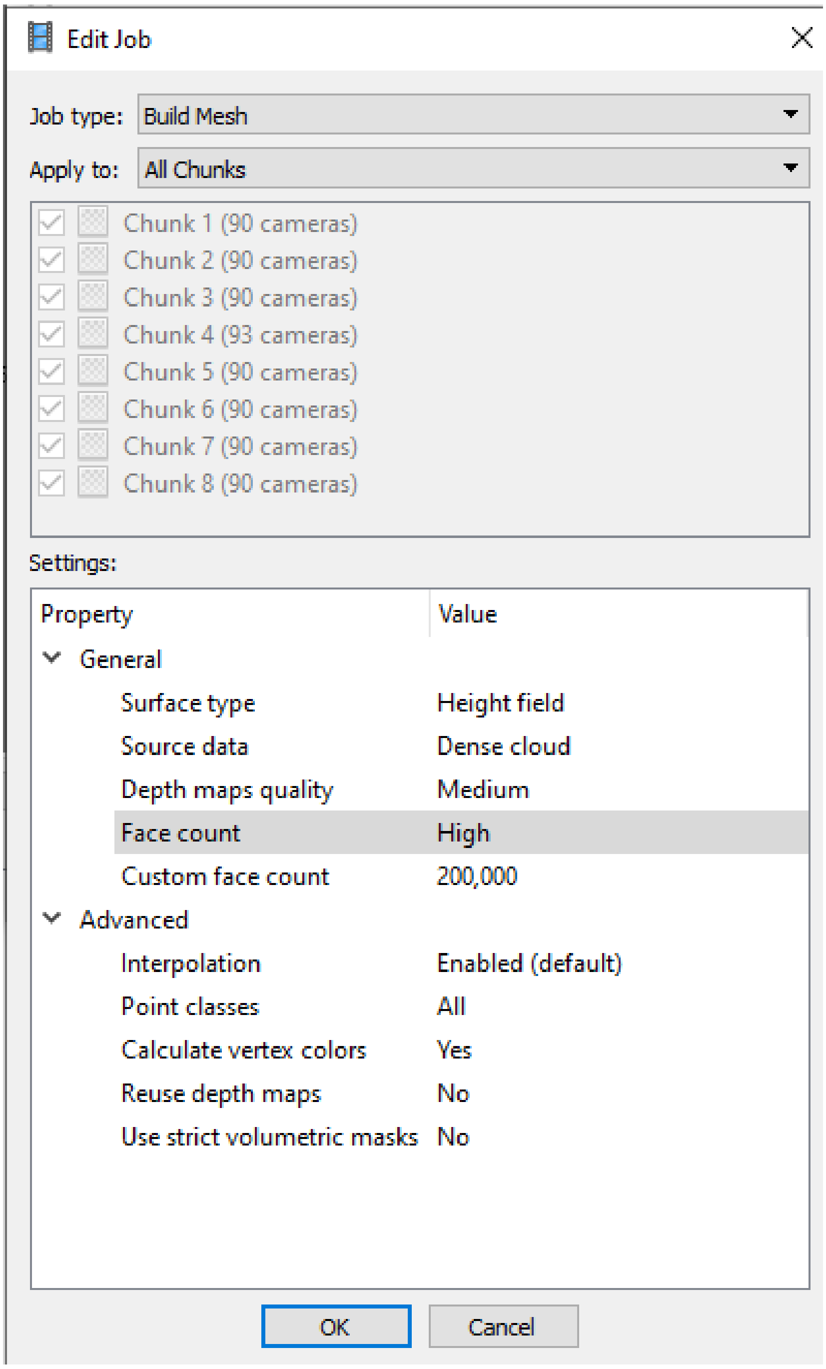
1. Optimise Camera alignment



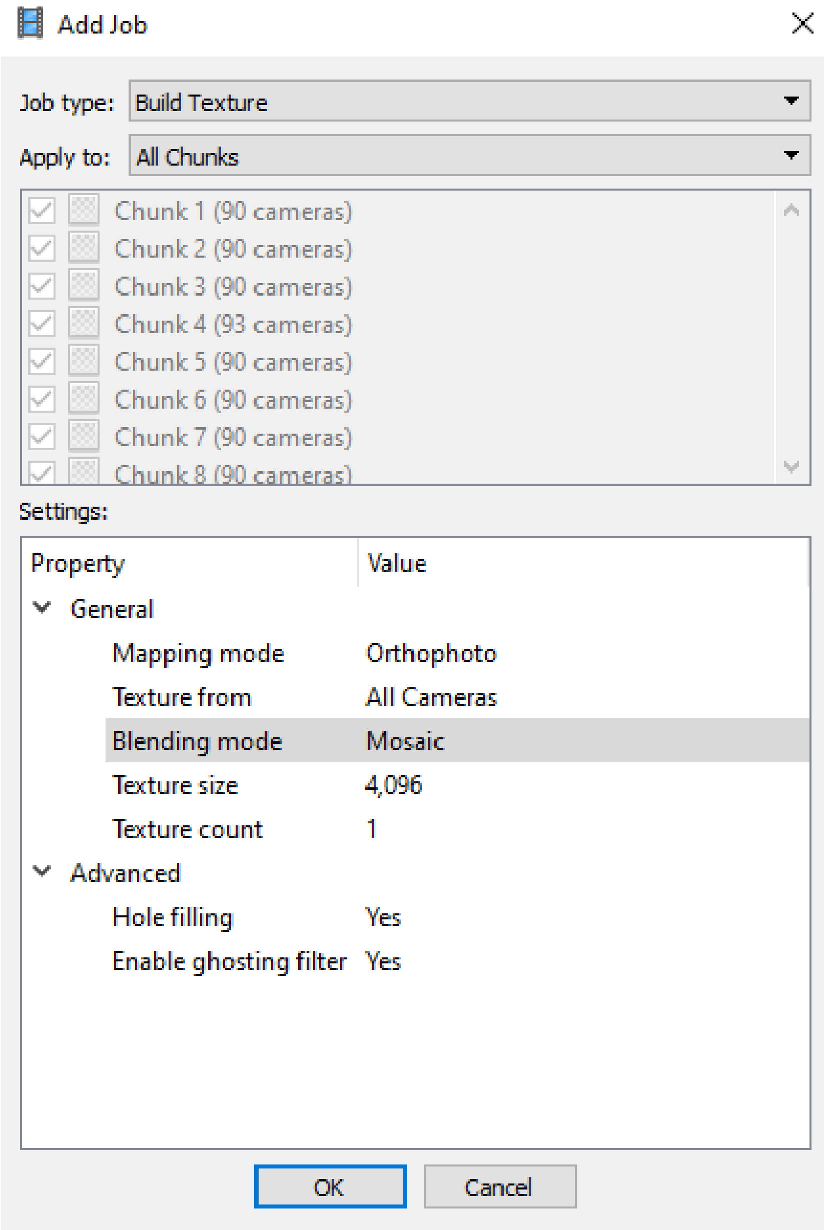
2. Build Dense Cloud



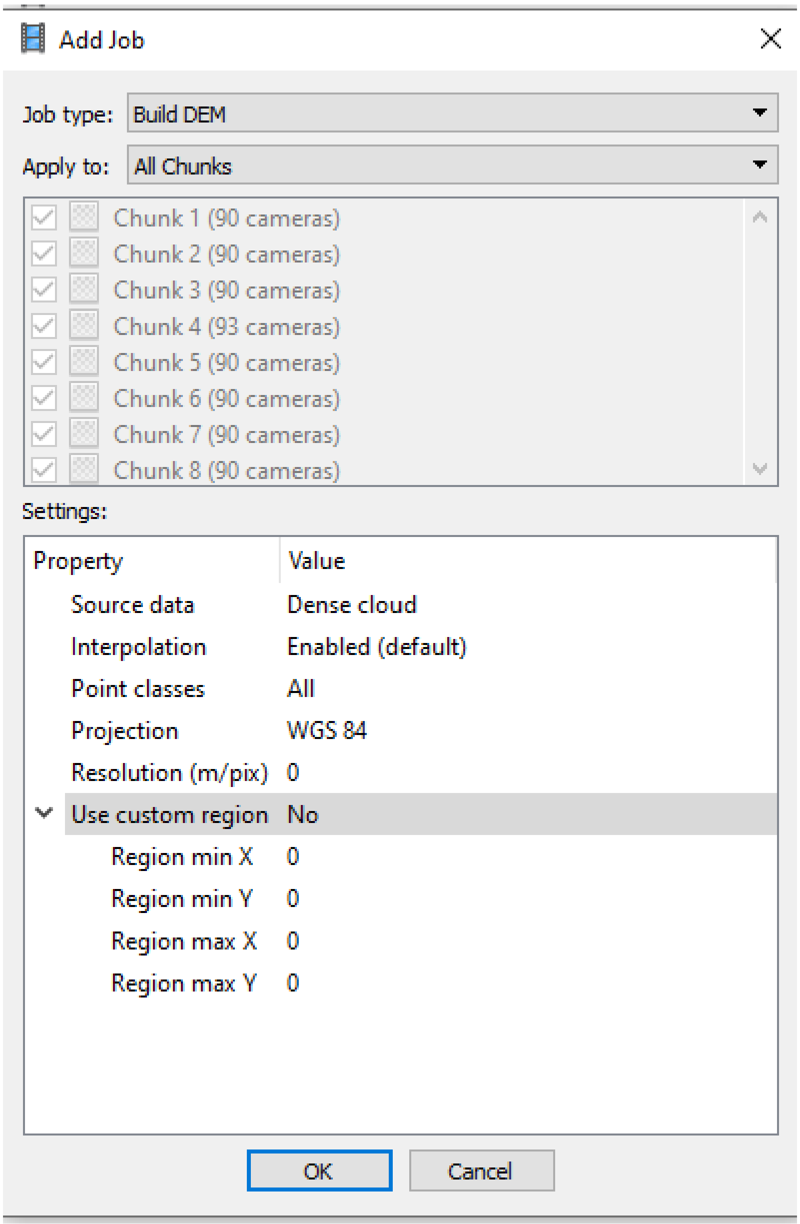
3. Build Mesh


Edit Job
Job type: Build Mesh
Apply to: All Chunks
Chunk 1 (90 cameras)
Chunk 2 (90 cameras)
Chunk 3 (90 cameras)
Chunk 4 (93 cameras)
Chunk 5 (90 cameras)
Chunk 6 (90 cameras)
Chunk 7 (90 cameras)
Chunk 8 (90 cameras)
Settings:
Property
Value
General
Surface type
Height field
Source data
Dense cloud
Depth maps quality
Medium
Face count
High
Custom face count
200,000
Advanced
Interpolation
Enabled (default)
Point classes
All
Calculate vertex colors
Yes
Reuse depth maps
No
Use strict volumetric masks
No
OK
Cancel

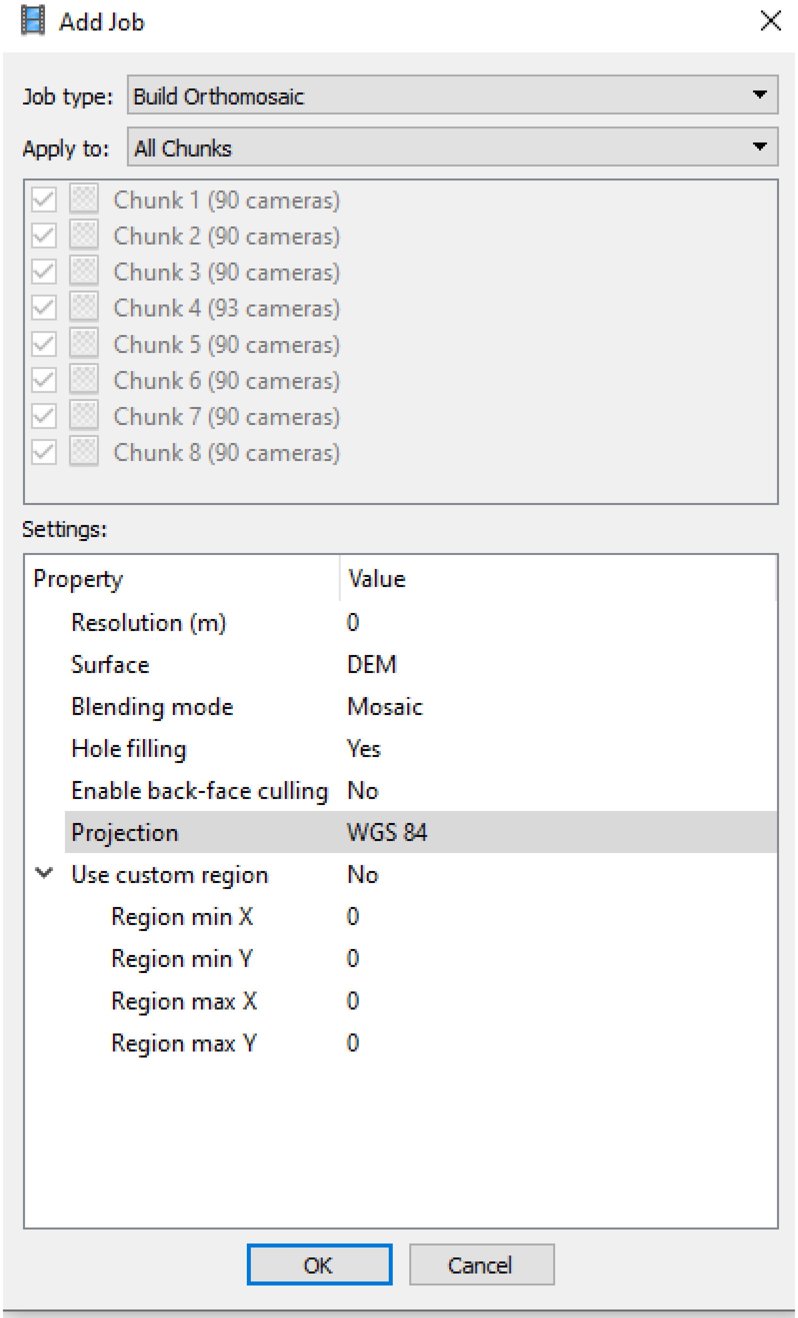
4. Build Texture



5. Build DEM


Add Job
Job type: Build DEM
Apply to: All Chunks
Chunk 1 (90 cameras)
Chunk 2 (90 cameras)
Chunk 3 (90 cameras)
Chunk 4 (93 cameras)
Chunk 5 (90 cameras)
Chunk 6 (90 cameras)
Chunk 7 (90 cameras)
Chunk 8 (90 cameras)
Settings:
Property
Value
Source data
Dense cloud
Interpolation
Enabled (default)
Point classes
All
Projection
WGS 84
Resolution (m/pix)
0
Use custom region
No
Region min X
0
Region min Y
0
Region max X
0
Region max Y
0
OK
Cancel

6. Build Orthomosaic

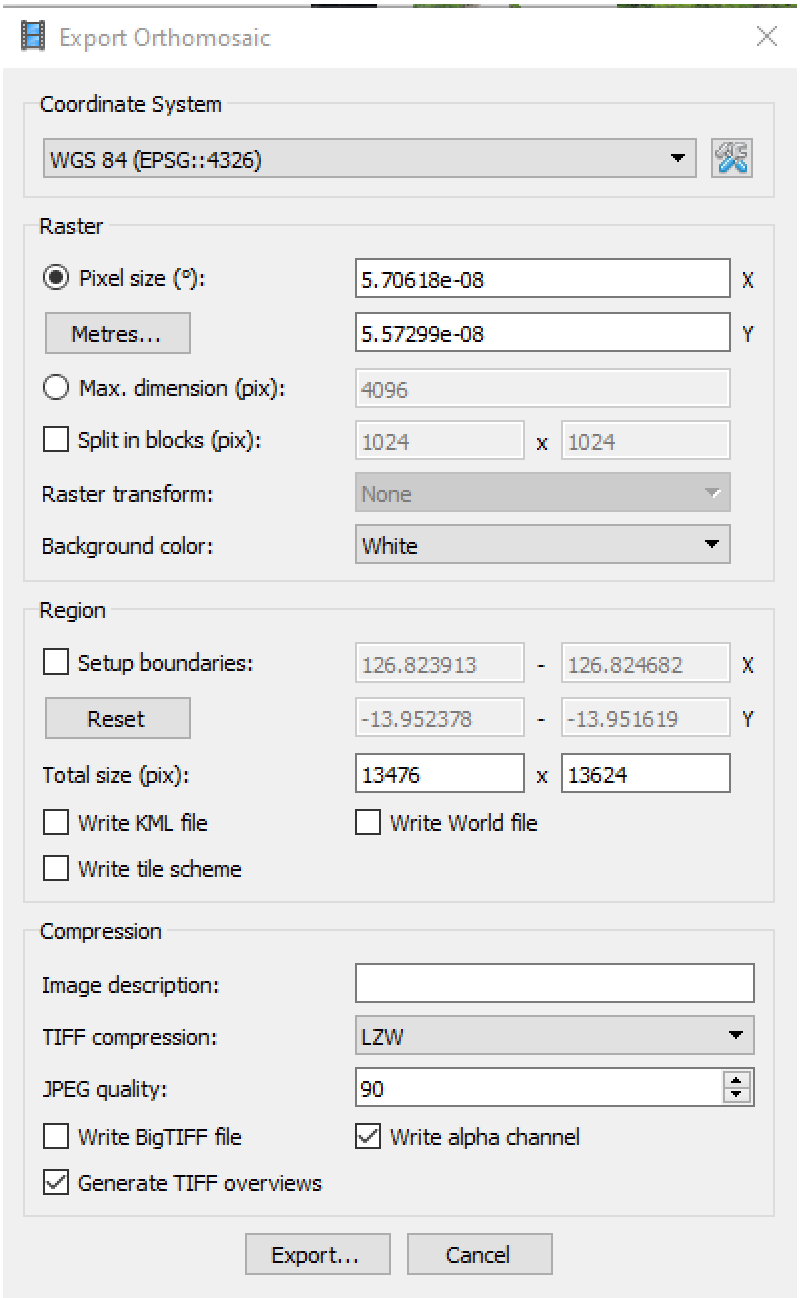


7. Exporting

Once AgiSoft has finished processing the batch, export the Orthomosaic, the DEM and generate a report for each Chunk.

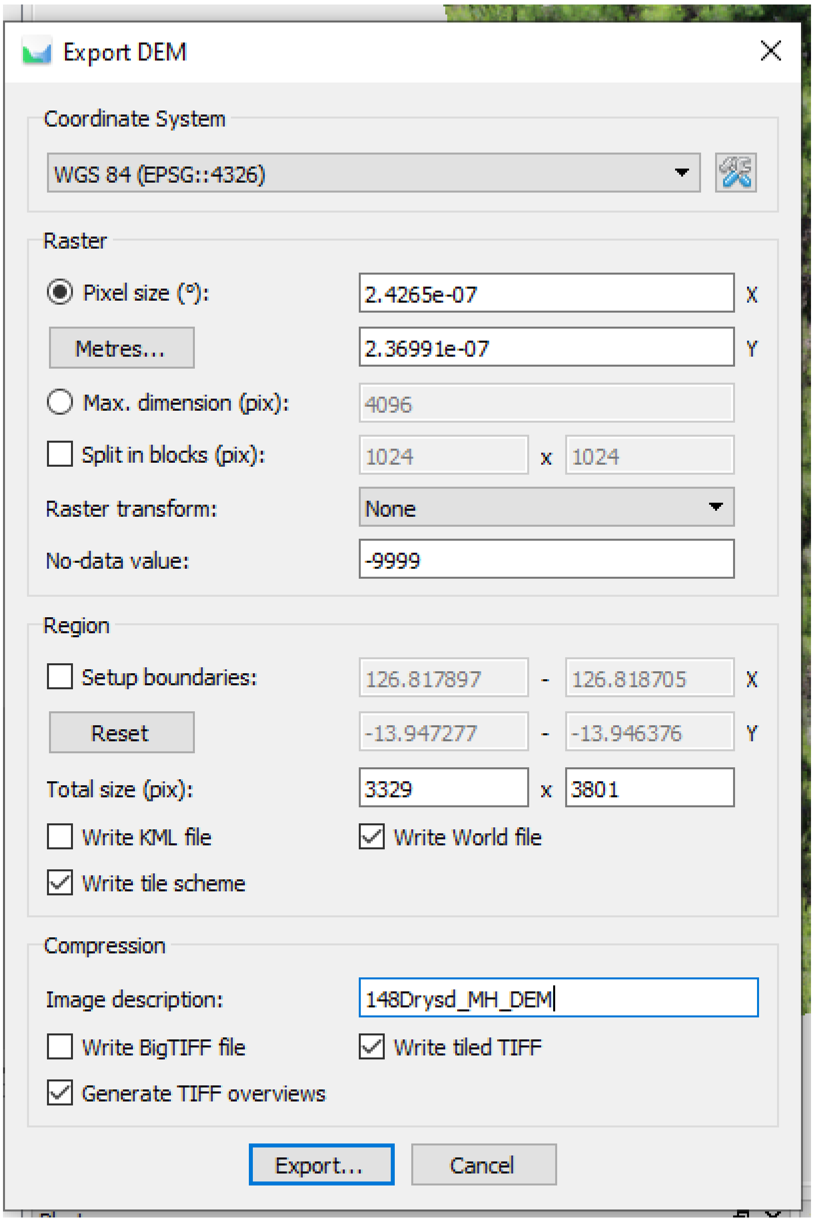
Export Ortho

File > Export > Export Orthomosaic > Export JPEG/TIFF/PNG…



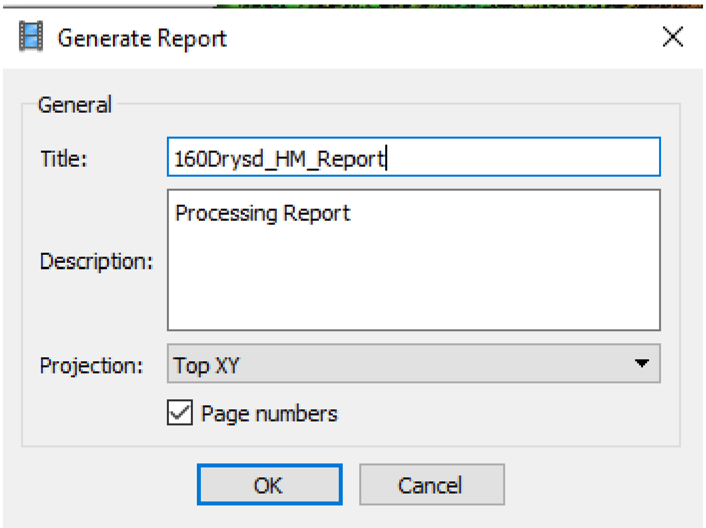
Export DEM

File > Export > Export DEM > Export TIF/BIL/XYZ



Generate Report

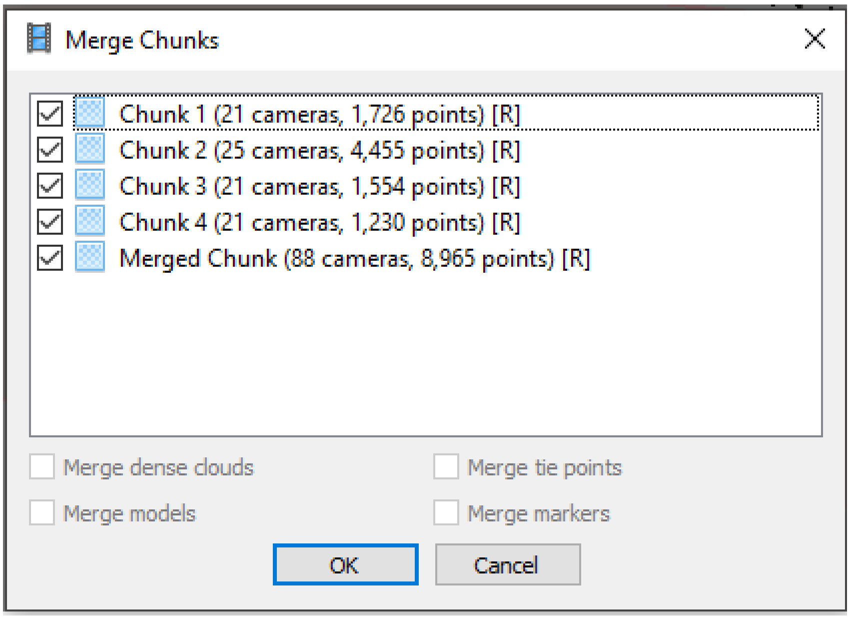
File > Export > Generate Report



8. Merge Chunks

When processing M-H sites the photos may have trouble initially aligning. Here's how we got it to work.

1. Add all the photos from a site into AgiSoft
2. Work out which photos form the four corners of the plot
3. I named these BL (bottom left), BR (bottom right), TL (top left), TR (top right). In the folder containing the photos drag them into their associated folders.
4. Add each of these new folders as a separate Chunk in AgiSoft
5. Go through manually aligning and setting the bounding boxes for all the Chunks. Ensure all the points are including in the bounding boxes in all dimensions.
6. Workflow > Merge Chunks > OK



7. Then go back up to Individual Sites Section and go through setting up the batch actions for the Merged Chunk.

Appendix 3

Trouble shooting

Photos not aligning with camera locations during processing in Agisoft Metashape

An issue found was during processing the photos did not align with the GPS derived camera locations. This would cause the derived products orthomosaic, DEMS etc. to be inaccurate in their position.

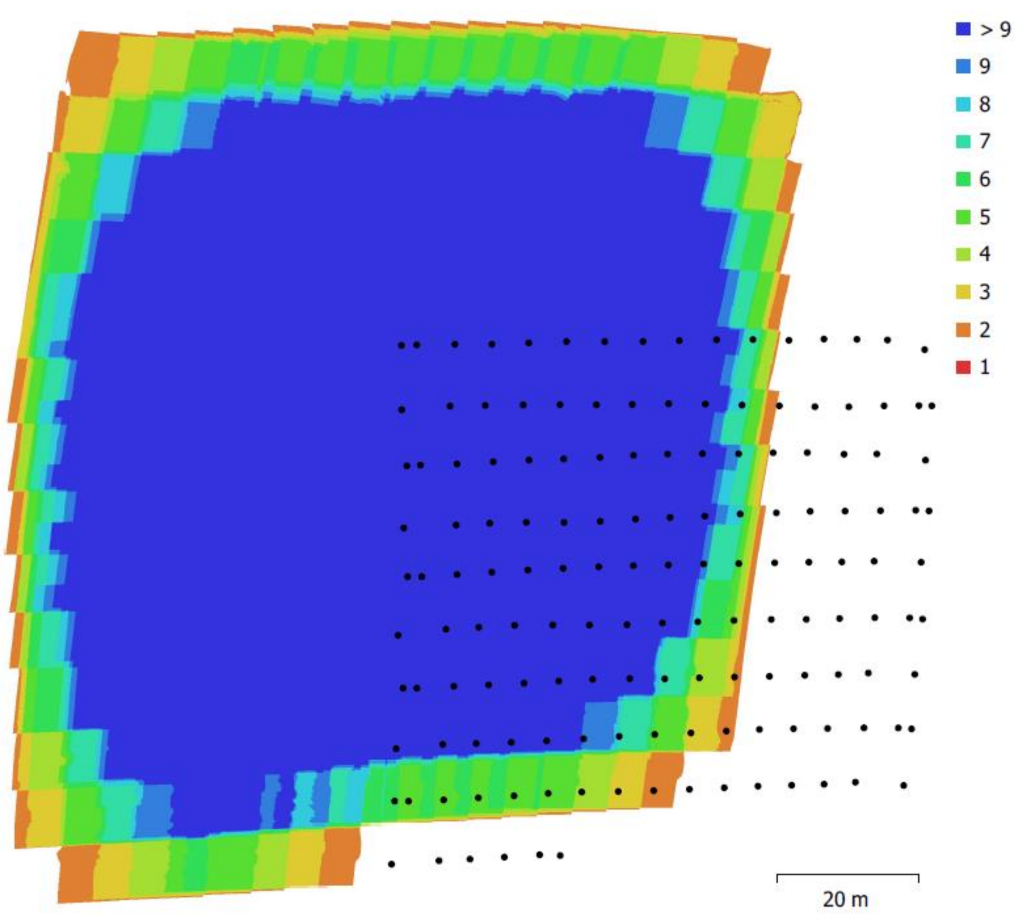


Fig. 1. Camera locations and image overlap.

Figure 11 Image from processing report of site, showing the cameral locations do not overlap with the images taken by the RPA. Black dots should overlay with images underneath.

One possible reason for this occurring is too much overlap when taking photos over the site. Unless operating in dense canopy keep overlap to 80% forward and 60% side overlap. To solve this issue remove or deactivate cameras before aligning in

Agisoft. A method removing every second column was adequate to allow the software to align correctly.

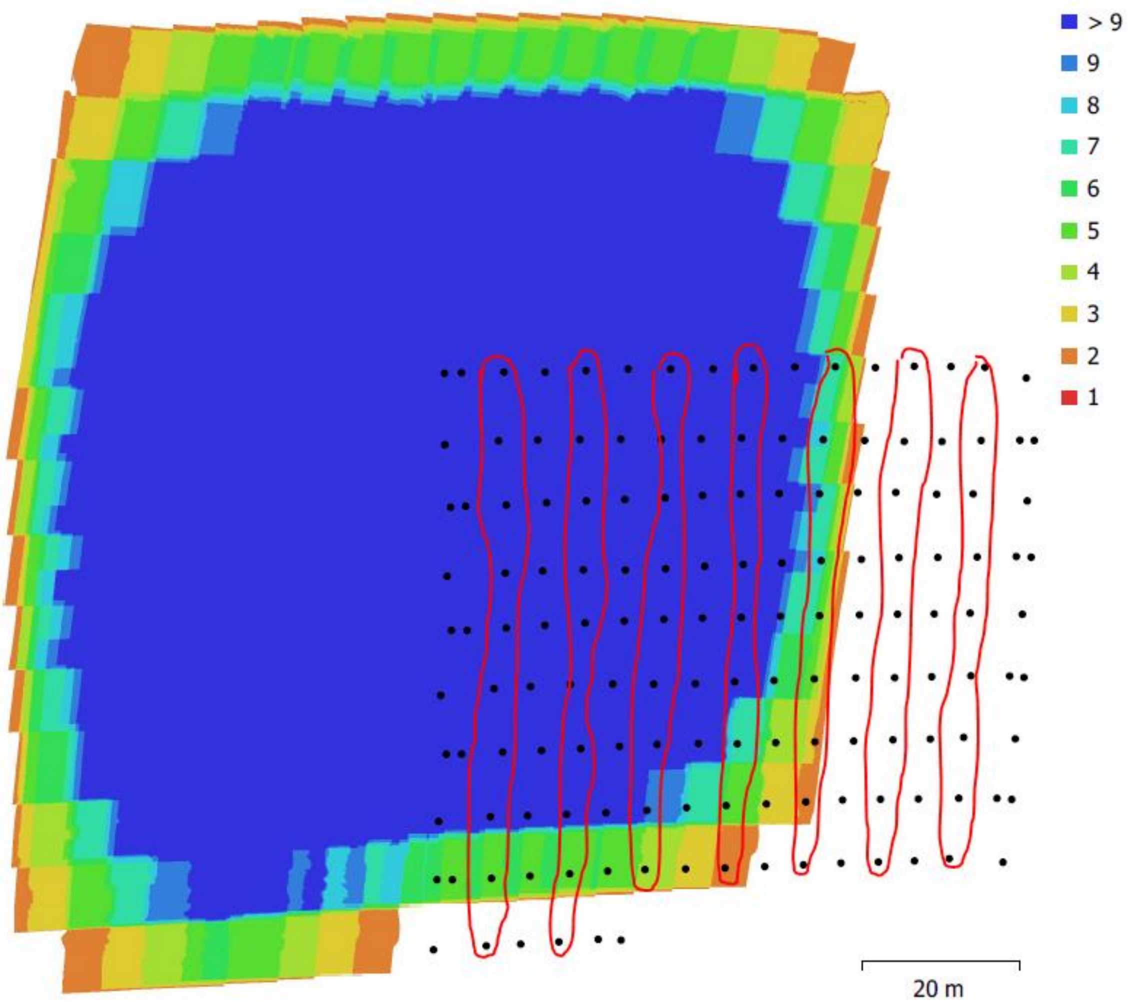


Fig. 1. Camera locations and image overlap.

Figure 12 Removing every second column of images solved the alignment error.

Select the images individually or by group then deactivate them or remove them. Run the alignment again and assess result.

Trouble shooting alignment issues for high density vegetation

See Z:\DEC\MangroveMonitoring\Working\Northern_Kimberley\FieldTrips\FieldTrip_201906\FieldData\Photos\Processed\Processing for high density vegetation.docx