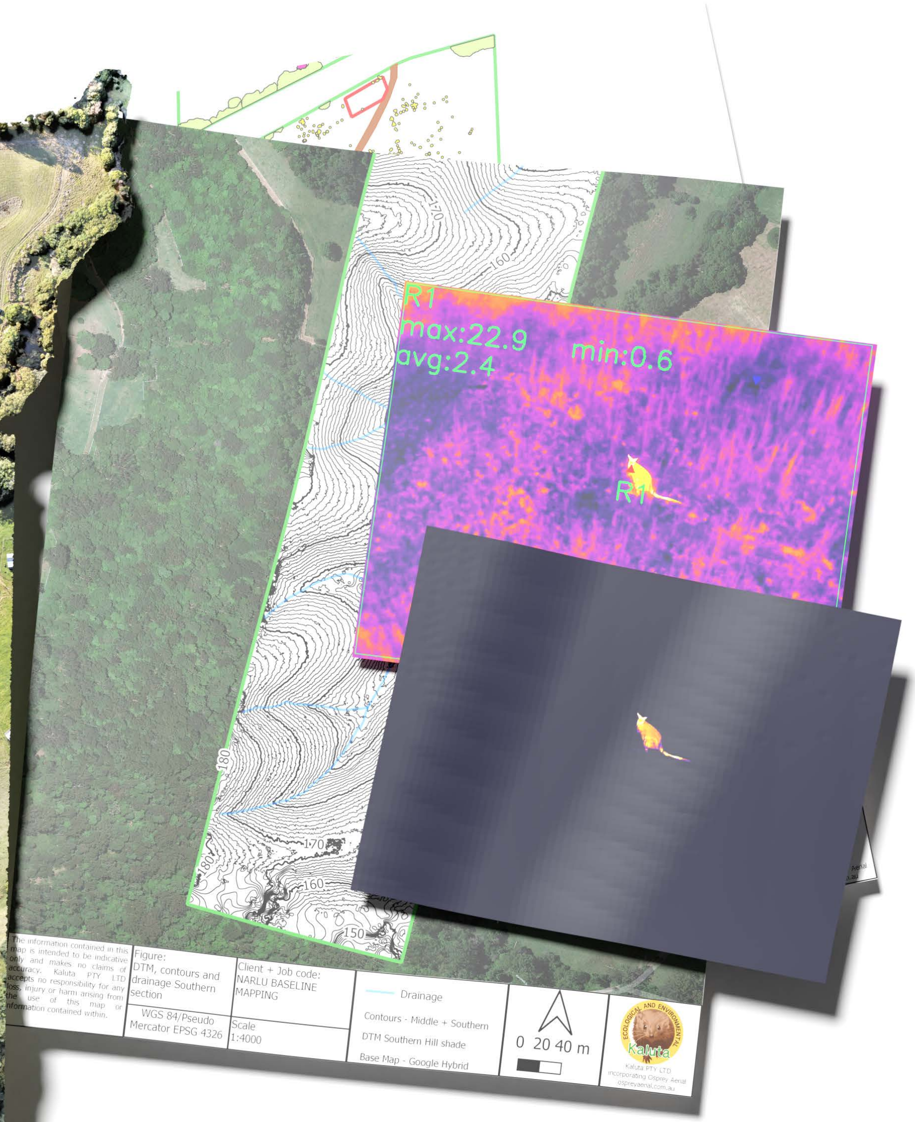

Case Study:

UAV Derived Data for the Rewilding of Narlu

Nathan Litjens, Brett Vercoe and Lisa Vercoe

V1.1

CASE STUDY: UAV DERIVED DATA FOR THE REWILDING OF NARLU

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Glossary

CPESC	Certified Practitioner of Erosion and Sediment Control
DTM	Digital Terrain Model/Map – A representation of the shape of a landscape represented by colour or shading. Raw value DTMs include elevation data in addition to the colour palette.
GCP	Ground Control Point – a physical item painted or placed on the ground in strategic locations which are recorded by a surveyor and included in the map to allow precise alignment for high Absolute or Global accuracy.
GSD	Ground Sample Distance – The term used to describe the resolution of an orthomosaic, expressed as pixels per cm. For example a GSD of 1 means one pixel equals a centimetre on the ground in reality, or 1cm/px
NDVI	Normalised Difference Vegetation Index, Calculated from the visible and near-infrared

	light reflected by vegetation. Healthy vegetation absorbs most of the visible light that hits it and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light.
Orthomosaic	A map made of a series of overlapping aerial photographs. An orthomosaic may include location data within it and is then known as a "Georeferenced orthomosaic"
PCT	Plant Community Type – a method of classifying vegetation communities in NSW
QGIS	Quantum GIS – An open source Geographical Information Systems software package used for mapping, creation of shapefiles, calculations and other uses related to geography.
ReOC	Remote Pilot Certification. Issued by CASA it is required for all commercial RPA operations and allows a wider range of privileges than flying under the "excluded" category.
RePL	Remote Pilot Licence
RPA/RPAS	Remotely Piloted Aircraft, often known as a "Drone", though the term Drone may include remotely piloted craft that operate on the ground or water, so RPA or RPAS is preferred.
RTK	Real Time Kinematics – a real-time system involving ground stations, dedicated hardware and specialised workflows to give high levels of accuracy in recording points on the ground by a surveyor or positioning an RPA during flight.
Shapefile	A georeferenced point, series of points, polygon or line saved under the Esri SHP format.
UAV	Unmanned Aerial Vehicle. Synonymous with RPA or RPAS
VLOS	Visual Line-of-sight. An RPA is in VLOS when it is clearly visible with the unaided eye and unobscured by buildings, terrain, trees or other obstructions.

Abstract

In 2020, the Vercoe family purchased a property in the Coffs Harbour hinterland for the purposes of rewilding it by removing weeds, reversing the effects of land clearing and cattle grazing by re-planting native vegetation and halting erosion. This case study seeks to establish baseline data on the condition of the landscape at the beginning of the rewilding project primarily with the use of Unmanned Aerial Vehicles (also known as UAVs, RPAS or "Drones") to measure weed cover, erosion, canopy cover, replanting success, and plant health as well as mapping landform and other physical characteristics. Once the baseline data is established, the aim is to continue monitoring to track the success of the rewilding efforts using several methodologies as outlined in this study. This Case Study also includes technical challenges experienced on the flight days and their solutions.

Problems solved

This Case Study is an exploration in problem solving in itself. Throughout the study, issues that arise and their solutions and projected solutions are explored in great detail for the benefit of those that wish to take on these workflows. At any rate, Kaluta Pty Ltd is ready to solve these problems for public and private entities from farmers, land managers, government agencies, ecological companies and construction to individuals seeking information on their private properties.

Problems and solutions summarised

Table 1: Problems and solutions matrix

Problem	Solution
Government mapping of vegetation too broad and inaccurate	*Use of orthomosaics and QGIS to attain a far more detailed map which is done on the desktop so is more cost effective and faster than walking it out on the ground with a GPS. The workflow is simpler once the orthomosaic is produced.*
Weed cover estimates are inaccurate	*Use of orthomosaics and QGIS to understand weed spread, distribution and cover. As with vegetation mapping, it is far more cost effective and accurate to make measurements from orthomosaics than on the ground*
Aerial imagery is restricted to the low quality Google, Bing, etc… imagery	*Acquire high quality aerial imagery using photogrammetry completed with a UAV/RPA. Higher quality measurements can be made from these images, thus saving time from second-guessing blurry details.*
Aerial imagery is only taken when the providers decide, often it is many years old	*Capture the imagery by UAV/RPA when the client needs it at the appropriate frequency, again making projects more efficient as the information is taken on-demand.*
Contouring not available for most properties, especially not at a suitable resolution	*Use UAV/RPA made Digital Terrain Models to draw property contours, calibrated from known points on the ground. This allows for more effective decision making in regard to building tracks, avoiding erosion and more.*
Weed mapping very slow when done manually	*Develop weed mapping techniques that are as automated as possible for a low cost, saving the client money and resources.*
Data taken by walking the ground traditionally is more subjective and only useful for the data manually gathered at the time	*Reduce future costs by using aerial data that is "frozen in time" and useful for many retroactive measurements and data gathering in the future. It is also able to be peer reviewed by persons remotely that do not need to access the site.*
Safety concerns with walking over entire sites	*Aerial data in the form of orthomosaics is gathered at a distance and has far fewer risks such as slips/falls, ticks, snakes, bad roads, etc…*
Environmental degradation by walking over sensitive sites	*UAVs/RPAs do not spread weeds or trample the ground while they gather data.*
Long days in the field for traditional ecologists/data collectors	*Time in the field is generally less, though much of it can be in more comfortable situations such as shaded areas while flying the mission instead of walking it. Sun exposure can be reduced.*
Traditional data is harder to adapt, combine or transform	*Much of this data can more easily be changed or combined as new information comes or split off and put into other projects or interpreted in a variety of different ways to suit the needs of the client.*

Benefits of using UAV/RPA systems to collect data on the landscape should be weighed against the costs of traditional surveys, taking into account the long-term benefits and added uses for the data in the present and future.

Workflows and their outcomes are explored in the remainder of this Case Study.

Introduction and Site Overview

Brief Site Description

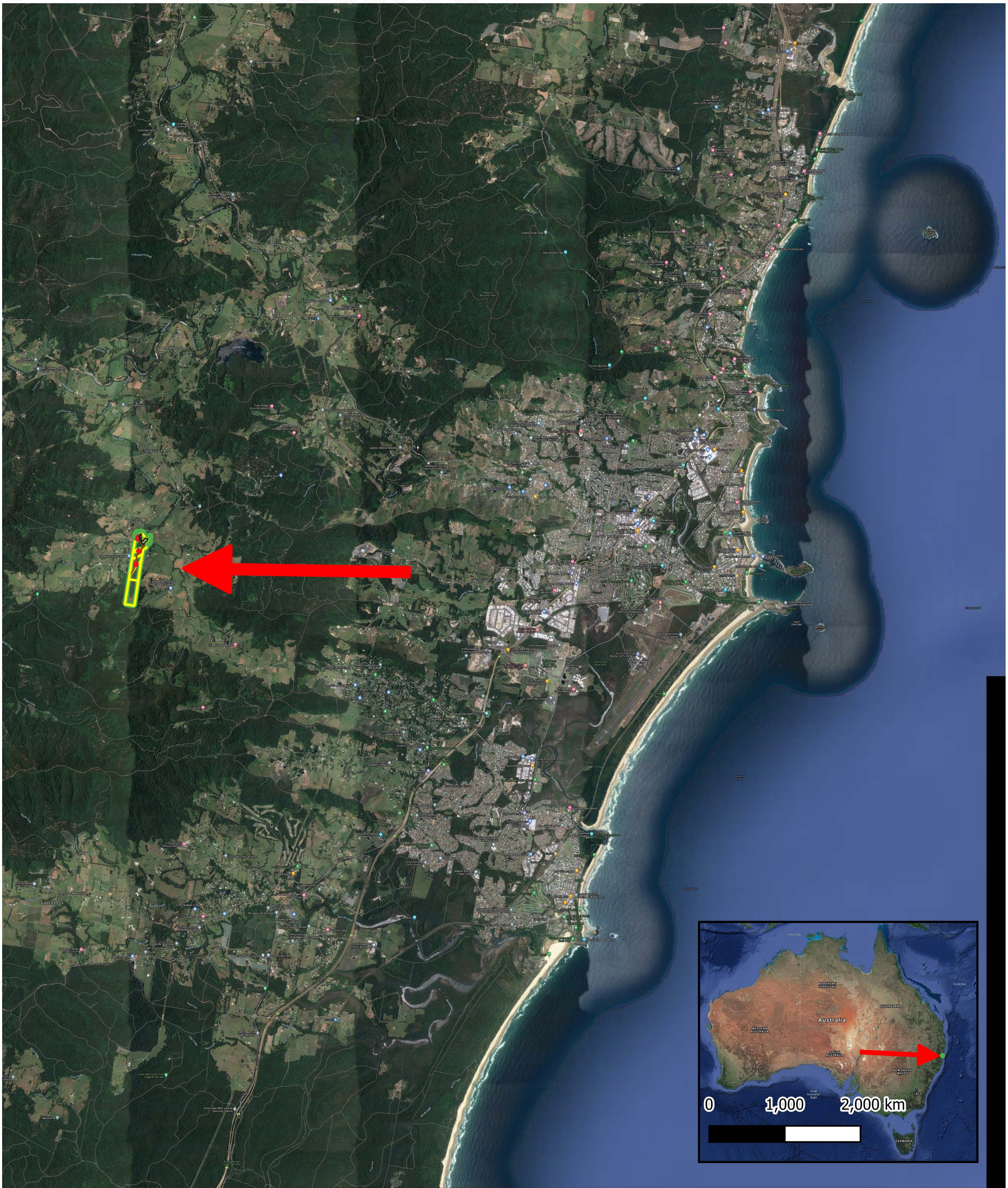
Narlu is a property on South Island Loop Road, Upper Orara in the Coffs Harbour hinterland, approximately 12km west of Coffs Harbour town centre. See Figure 1 for details. It is located within the Orara River catchment which is in turn within the southern Clarence River catchment. The property is split into two sections divided by the road. North of the road, the Orara River forms the northern and north-western boundary while the north-eastern boundary is Fridays Creek. The northern section of the site is largely on relatively level ground. South of the road the property is bounded by fences and is gently undulating cleared land covered in pasture with scattered weeds and few native trees remaining but for the purposes of this project is divided into two subsections as detailed in Figure 2. The table below shows the property dimensions in each section. In some instances, the southern section has been divided into the “Middle” and “Southern” sections for the purposes of more detailed maps.

Table 2: Property dimensions

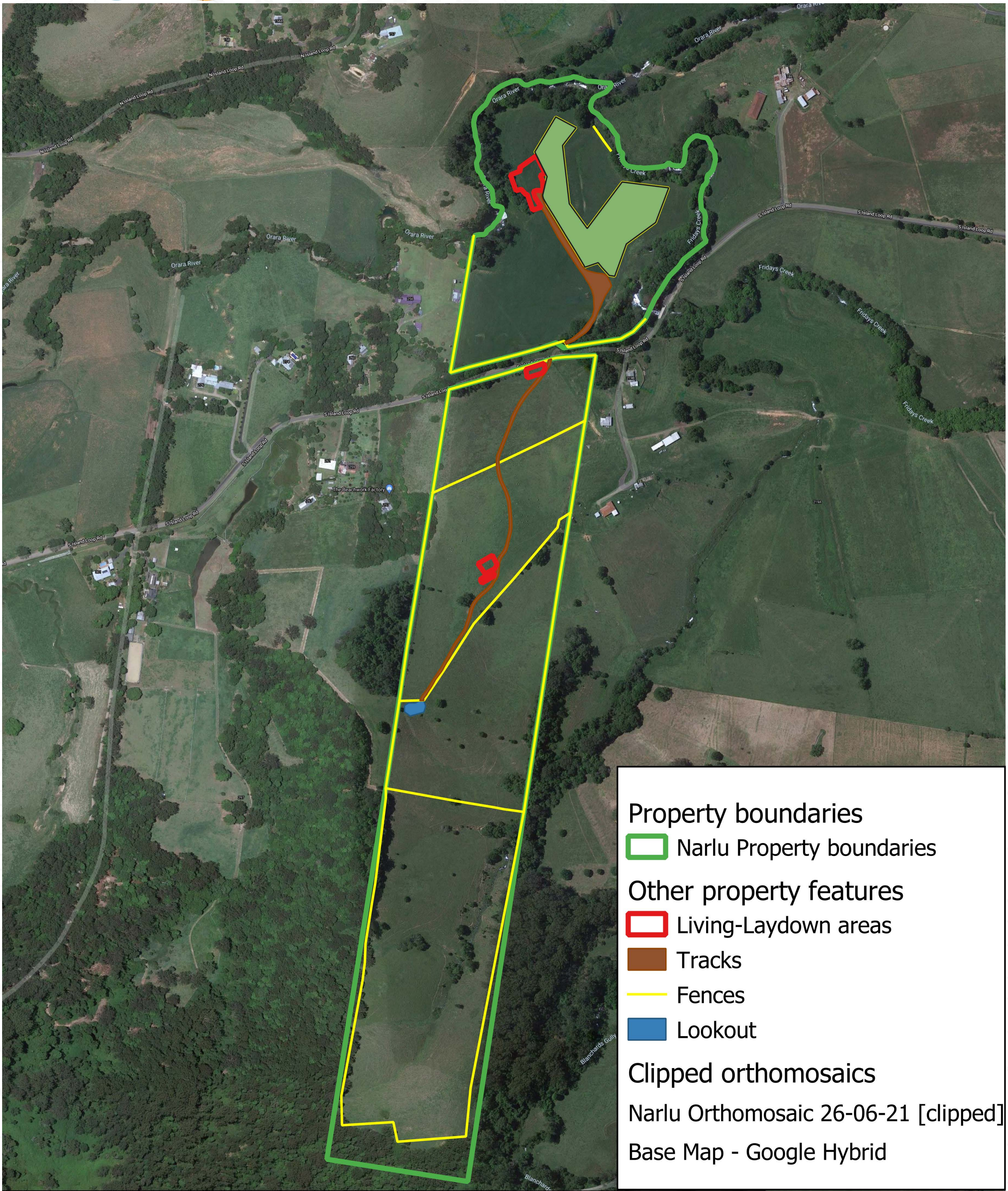
Section	Size in Hectares
Northern section	10.279
Southern section	23.706
Total Property area	33.985

Land Use History

Prior to purchase by the Vercoe family, the land was, following clearing for timber and pastoral purposes used for dairy farming. The site was purchased in 2020 and included in the Land for Wildlife Covenant to ensure preservation of habitat values into the future. Currently a portion of the northern section is reserved for horses in a fenced area and a non-permanent dwelling complex.



The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Client + Job code: NARLU BASELINE MAPPING WGS 84/Pseudo Mercator EPSG 4326	Figure: Locality Scale 1:128000	Narlu Base Map - Google Hybrid	0 1 2 km	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au



The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Property Boundaries WGS 84/Pseudo Mercator EPSG 4326	Client + Job code: NARLU BASELINE MAPPING Scale 1:9000	Notes: Numbers within property boundaries show measured area in Hectares.	0 50 100 m	Kaluta PTY LTD incorporating Osprey Aerial

Remnant Vegetation

The remnant vegetation within the property is primarily along the riparian zone in the northern section and forms a buffer between the river flats and the river itself with a small section of about 60m cleared to the water's edge in the eastern side of the property. This is heavily infested with camphor laurel and several other weeds. In the southern section of the property, the boundary is fringed with some remnant riparian vegetation and tall eucalypt forest with some regrowth evident.

Remnant plant species within the property include the following as at 28/06/2021:

Table 3: Remnant plant species

Common name	Scientific name
Banana bush	*Tabernaemontana pandacaqui*
Bangalow palm	*Archontophoenix cunninghamiana*
Birds nest fern	*Asplenium australasicum*
Black apple	*Pouteria australis*
Black bean	*Castanospermum australe*
Black booyong	*Argyrodendron actinophyllum*
Blackwood	*Acacia melanoxylon*
Bleeding heart	*Homalanthus populifolius*
Blue quandong	*Elaeocarpus angustifolius*
Blueberry ash	*Elaeocarpus reticulatus*
Bollygum	*Litsea reticulata*
Bolwarra	*Eupomatia laurina*
Brush box	*Lophostomen confertus*
Brush cherry	*Syzygium australe*
Callicoma	*Callicoma serratifolia*
Cedar fig	*Ficus henneana*
Celerywood	*Polyscias elegans*
Cheese tree	*Glochidion ferdinandi*
Churnwood	*Citronella moorei*
Coachwood	*Ceratopetalum apetalum*
Common lilly pilly	*Syzygium smithii*
Compressa	*Endiandra compressa*
Corkwood	*Endiandra sieberi*
Crow's ash	*Flindersia australis*
Cunjevoi	*Alocasia brisbanensis*
Dwarf Native ginger	*Alpinia arundelliana*
Elkhorn fern	*Platycerium bifurcatum*
Fire wheel	*Stenocarpus sinuatus*
Flame tree	*Brachychiton acerifolius*
Flintwood	*Scolopia braunii*
Flooded gum	*Eucalyptus grandis*
Foambark	*Jagera pseudorhus*
Forest maple	*Cryptocarya rigida*
Forest oak	*Allocasuarina torulosa*
Giant blood vine	*Austrosteenisia glabristyla*
Giant water gum	*Syzygium francisii*
Green leaved rose walnut	*Endiandra discolor*
Green wattle	*Acacia parramattensis*

Grey walnut	*Beilschmiedia elliptica*
Guinea flower	*Hibbertia scandens*
Guioa	*Guioa semiglauca*
Gum vine	*Aphanopetalum resinosum*
Hammock fern	*Blechnum occidentale*
Hard quandong	*Elaeocarpus obovatus*
Hoop pine	*Araucaria cunninghamii*
Jackwood	*Cryptocarya glaucescens*
Koda	*Ehretia acuminata*
Lemon aspen	*Acronychia acidula*
Love flower	*Pseuderanthemum variabile*
Maidens blush	*Sloanea australis*
Mistletoe	*Amyema miquelii*
Monkey rope vine	*Parsonsia straminea*
Moreton Bay fig	*Ficus macrophylla*
Murrogun	*Cryptocarya microneura*
Muttonwood	*Rapanea variabilis*
Native frangipani	*Hymenosporum flavum*
Native ginger	*Alpinia caerulea*
Native maiden hair	*Adiantum aethiopicum*
Native raspberry	*Rubus hillii*
Native tamarind	*Diploglottis australis*
Native wisteria	*Callerya megasperma*
Oliver’s sassafras	*Cinnamomum oliveri*
Pencil cedar	*Polyscias murrayi*
Pepperberry	*Cryptocarya obovata*
Pink Euodia	*Melicope elleryana*
Plum pine	*Podocarpus elatus*
Purple cherry	*Syzygium crebrinerve*
Red ash	*Alphitonia excelsa*
Red bean	*Dysoxylum mollissimum*
Red carabeen	*Karrabina benthamiana*
Red cedar	*Toona ciliata*
River oak	*Casuarina cunninghamiana*
River red gum	*Eucalyptus camaldulensis*
Rose Myrtle	*Archirhodomyrtus beckleri*
Rosewood	*Dysoxylum fraserianum*
Rough tree fern	*Cyathea australis*
Rusty fig	*Ficus rubiginosa*
Rusty plum (Vulnerable)	*Niemeyera whitei*
Sandpaper fig	*Ficus coronata*
Sassafras	*Doryphora sassafras*
Scribbly gum	*Eucalyptus haemastoma*
Scrub bloodwood	*Baloghia inophylla*
Silky oak	*Grevillea robusta*
Silver ash (cudgerie)	*Flindersia schottiana*
Small bolwarra	*Eupomatia bennettii*
Small leaved fig	*Ficus obliqua*
Small leaved lilly pilly	*Syzygium luehmannii*
Small supplejack	*Ripogonum fawcettianum*

Socket wood	*Daphnandra apetala*
Soft cork wood	*Duboisia myoporoides*
Soft corkwood	*Caldcluvia paniculosa*
Spiny mat-rush	*Lomandra longifolia*
Staghorn fern	*Platycerium superbum*
Steelwood	*Sarcopteryx stipata*
Strangler fig	*Ficus watkinsiana*
Swamp mahogany	*Eucalyptus robusta*
Sweet pittosporum	*Pittosporum undulatum*
Tallowwood	*Eucalyptus microcorys*
Thick leaved laurel	*Cryptocarya meissneriana*
Turpentine tree	*Syncarpia glomulifera*
Two veined hickory wattle	*Acacia binervata*
Veiny wilkea	*Wilkiea huegeliana*
Walking stick palm	*Linospadix monostachyos*
Water Gum	*Tristaniopsis laurina*
Weeping lilly pilly	*Waterhousea floribunda*
White apple	*Endiandra virens*
White beech	*Gmelina leichhardtii*
White bollygum	*Neolitsea dealbata*
White booyong	*Argyrodendron trifoliolatum*
White cedar	*Melia azedarach*
White euodia	*Melicope micrococca*
White hibiscus	*Hibiscus splendens*
Willow bottlebrush	*Callistemon salignus*
Yellow ash	*Emmenosperma alphitonioides*
Yellow carabeen	*Sloanea woollsii*
Yellow pear fruit	*Mischocarpus pyriformis*
Zeiria	*Zieria smithii*

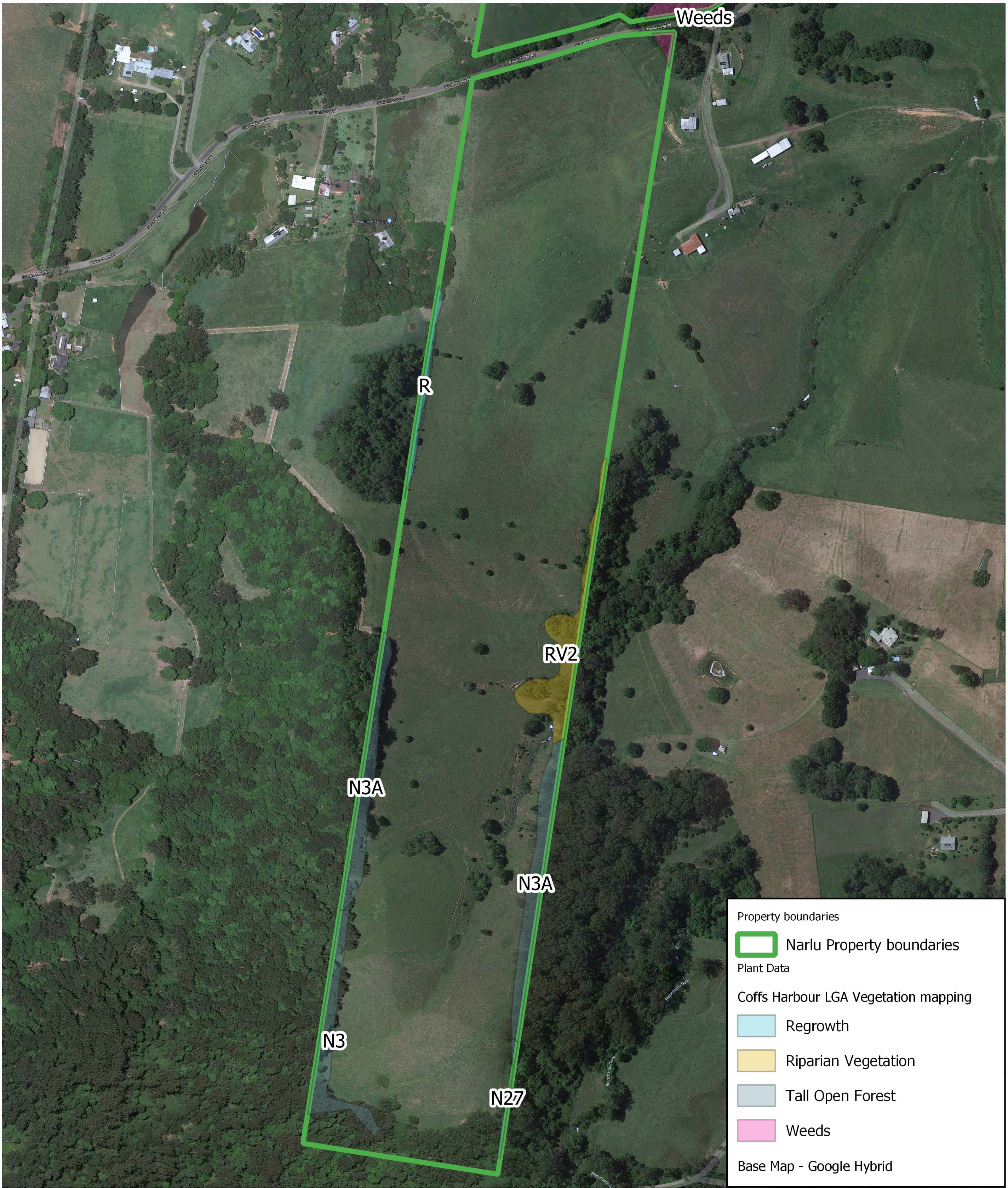
In addition, some native trees have persisted in the southern section of the property, scattered in low densities on the open grassland with some clustering of trees in the drainage lines.

The results of the Coffs Harbour LGA vegetation mapping shows the following area in hectares of mapped vegetation within the property, compared to the orthomosaic truthed results. See Figure 3: Coffs Harbour LGA Vegetation Mapping Northern section and Figure 4 for further details. The results of orthomosaic truthing are listed in *Table 15: Orthomosaic truthed Vegetation Type cover* on Page 59 and in Figure 17 to Figure 19.

Table 4: Vegetation coverage on the site according to Coffs harbour LGA mapping

Vegetation Category	VEG2003 code	Characteristics	Total coverage on property (Hectares) as per Government data	Percentage of total property as per Government data (Total coverage/33.985) x 100
Riparian Vegetation	RV2	*Casuarina cunninghamiana, Eucalyptus grandis, Cinnamomum camphora*, Tristaniopsis laurina, Callistemon salignus, Ligustrum sinense* & lucidium**	3.597	10.584%
Tall Open Forest	N3A	*Eucalyptus saligna, E. grandis, E. microcorys, E. pilularis.*	0.777	2.29%
Tall Open Forest	N3	*Eucalptus microcorys and E. saligna*	0.359	1.06%
Weeds	Weeds	*Cinnamomum camphora* (Camphor laurel), *Ligustrum sinense* (small-leaved privet), *Ligustrum lucidium* (Large-leaved privet)	0.3	0.88%
Regrowth	R	-	0.105	0.31%
Tall Open Forest	N27	*Eucalyptus grandis*	0.038	0.11%

The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Coffs harbour LGA Vegetation type mapping Northern section WGS 84/Pseudo Mercator EPSG 4326	Client + Job code: NARLU BASELINE MAPPING Scale 1:2750		0 20 40 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au



The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Coffs Harbour Vegetation Type mapping Southern section	Client + Job code: NARLU BASELINE MAPPING	0 40 80 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au
	WGS 84/Pseudo Mercator EPSG 4326	Scale 1:6500		

Native fauna

Between the purchase of the property and June 2021, the following native fauna had been observed within its boundaries:

Table 5: Observed native fauna within the property since July 2020

Common name	Scientific name
Amphibians	
Green tree frog	*Litoria caerulea*
Giant barred frog	*Mixophyes iteratus*
Common Froglet	*Crinia signifera*
Green stream frog	*Litoria barringtonensis*
Wilcox's frog	*Litoria wilcoxii*
Reptiles	
Macquarie River Turtle	*Emydura macquarii*
Water Dragon	*Intellagama lesueurii*
Red-bellied Black Snake	*Pseudechis porphyriacus*
Lace Monitor	*Varanus varius*
Birds	
Australian pelican	*Pelecanus conspicillatus*
Australian Pipit	*Anthus novaeseelandiae*
Brown Cuckoo-dove	*Macropygia phasianella*
Brown Thornbill	*Acanthiza pusilla*
Brush Turkey	*Alectura lathami*
Cattle Egret	*Ardea ibis*
Eastern broad-billed Roller	*Eurystomus orientalis*
Eastern Yellow Robin	*Eopsaltria australis*
Fan-tailed Cuckoo	*Cacomantis flabelliformis*
Glossy black cockatoo	*Calyptorhynchus lathami*
Golden whistler	*Pachycephalus pectoralis*
Grey butcherbird	*Cracticus torquatus*
Grey Fantail	*Rhipidura albiscapa*
Grey Shrike-thrush	*Colluricincla harmonica*
Kookaburra	*Dacelo novaeguineae*
Pied butcherbird	*Cracticus nigrogularis*
Red tailed black cockatoo	*Calyptorhynchus banksii*
Red wattlebird	*Anthochaera carnuculata*
Red-browed Finch	*Neochmia temporalis*
Rufous Whistler	*Pachycephala rufiventris*
Sacred Kingfisher	*Todiramphus sanctus*
Sulphur-crested Cockatoo	*Cacatua galerita*
Superb Fairy-wren	*Malurus cyaneus*
White headed pigeon	*Columba leucomela*
White-headed Pigeon	*Columba leucomela*
Yellow tailed black cockatoo	*Zanda funurea*
Fish	
Australian bass	*Percalates novemaculeata*

Common name	Scientific name
Australian smelt	*Retropinna semoni*
Eel tailed catfish	*Tandanus tandanus*
Freshwater mullet	*Trachystoma petardi*
Long finned eel	*Anguilla reinhardtii*
Mammals	
Black Rat	*Rattus rattus*
Brown Antechinus	*Antechinus stuartii*
Bush Rat	*Rattus fuscipes*
Common Brushtail Possum	*Trichosurus vulpecula*
Mountain Brushtail Possum	*Trichosurus caninus*
Platypus	*Ornithorhynchus anatinus*
Red necked wallaby	*Notamacropus rufogriseus*

Source: Atlas of Living Australia, additional observations by the authors

Weeds

A number of weeds are established on the property and are presented in the table below:

Table 6: Weeds established on the property

Common name	Scientific name
Devil's fig	*Solanum torvum*
Wild tobacco	*Solanum mauritianum*
Blue billygoat weed	*Ageratum houstonianum*
Fireweed	*Senecio madagascarensis*
Privet	*Ligustrum lucidum*
Lantana	*Lantana camara*
Camphor laurel	*Cinnamomum camphora*

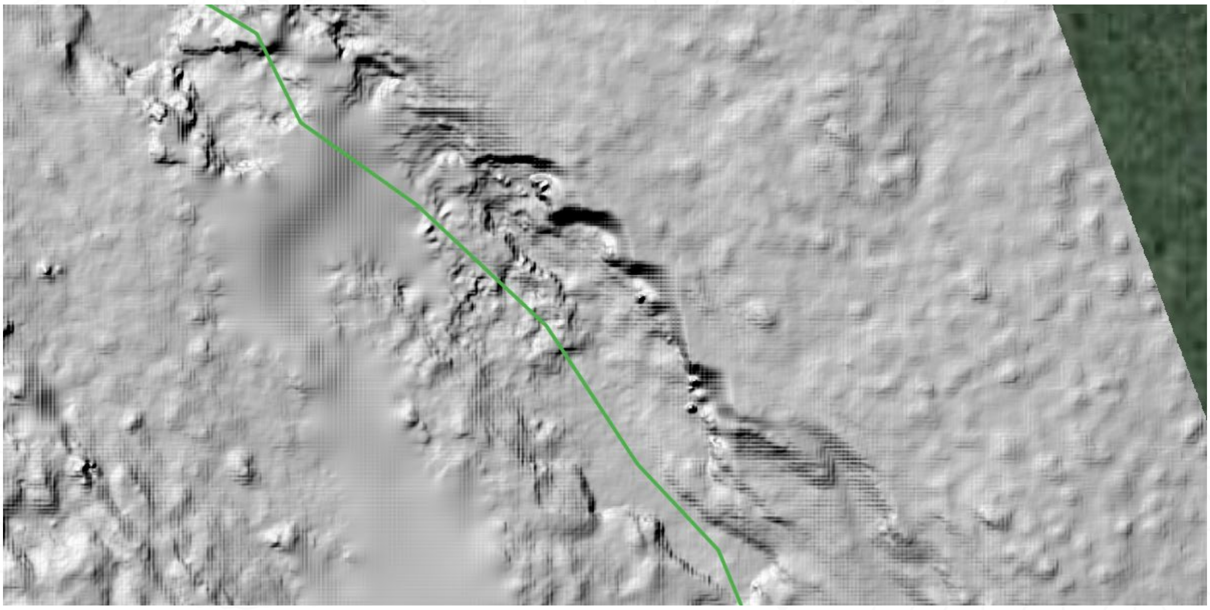
Weeds are currently in the process of being controlled, especially the Camphor trees which have almost all been ring barked and are beginning to die. They have been included as they are mostly not yet dead and the canopy cover of this species at the beginning of the project is important data to measure success with as per the KPIs. Other weeds such as Fireweed, although prevalent in some areas may be passively controlled by planting over them as they are a low growing species that is easily shaded out and as such are not regarded as a major problem.

Erosion

Erosion is not currently a major problem on the property, however a section of the bank at Fridays Creek just outside the far north-eastern section of the property has been cleared to the bank and grazed heavily from an adjoining property and is currently being undercut and slumping into the creek. As the remainder of the property is vegetated either by grass or riparian vegetation, it is well protected against scouring in the event of heavy rain. The images below show the erosion on the creek with the green line of the property border dividing the image between Narlu and the neighbouring property.

Photo Plate 1: Erosion screenshot from the orthomosaic

Photo Plate 2: Erosion as shown on the DTM (Hillshaded)



Goals and Key Performance Indicators

Immediate Goals

In summary, the desired data to be initially collected from the mapping of the site by UAV or Remotely Piloted Aerial Systems includes the following:

- Creation of a 2D Orthomosaic image or map to:
    - Measure weed coverage and density,
    - Determine canopy cover on the edge of the riparian zone,
    - Map areas that retain moisture most efficiently,
    - Locate and measure density of newly planted seedlings,
    - Show fence locations,
    - Provide area measurements of various fenced zones,
- Create files containing three-dimensional Digital Terrain Modelling (DTM) data to:
    - Map Drainage lines,
    - Create contour lines,
    - Model Erosion,
    - Create a 3D OBJ file of the landscape.
- Collect NDVI data to:
    - Ascertain plant health.

Without doubt, for this project the most important goal is to capture a georeferenced snapshot in the form of an orthomosaic to show changes over time as this is a re-wilding project that will benefit most from this data being captured as close to the beginning as possible with the key performance indicators being best measured from above.

Prior to June 26th, 2021, no seedlings had been georeferenced nor had details been kept about which species each represents. Due to the small size of the seedlings, it is important that a stocktake be taken on the 478 current seedling planting sites as to which species is represented by each datapoint and ensure all future plantings have the following recorded as they are planted, or as failed seedlings are replaced:

- Species,
- Date,
- Location, and
- New vs replanting.

In short, the goal is to establish a baseline for a variety of environmental and ecological metrics. It is important to note that many may not yet have been considered however in the future, information gleaned from this baseline survey may be consulted to answer these yet unasked questions.

Key Performance Indicators (KPIs)

Once the data is captured, the long-term goals, or key performance indicators will mostly be measured from above and will include:

- Success of weed control,
- Successful encroachment of canopy forming species into the open areas, and
- Success of replanting efforts.

As obvious unnatural erosion is restricted to the far north-eastern edge- outside of the property at a small site and scouring or rills are not visibly occurring, erosion at this stage is not being measured. However, if there is a change that causes its increase at any part of the property, the initial imagery prior to it happening will be available for reference purposes, for example to measure a newly formed gully against the baseline landform.

Measuring KPIs

Each KPI will be measured as a time beginning at the end of the last UAV mapping event and ending at the current mapping event with the first period beginning on 26 June 2021. Methods for measuring the KPIs are outlined below.

Table 7: Measuring KPIs.

KPI	Method	Outcome
Success of exotic plant (weed) control	○ *Emergent weed tree species to be measured by drawing shapefile in QGIS around the canopy of each to calculate their area of coverage. Note: This is only for emergent species.* ○ *Using QGIS, weeds are classified as per* **Measuring Plant Cover** (31)	○ *Combined area of exotic plant cover to be measured against total property size and expressed as a percentage. Individual species and total exotic plant cover may be measured if categorised by species.*
Successful encroachment of emergent canopy forming species into the open areas	○ *Draw a shapefile around the drip line (outer canopy edge) of individual native trees in the open* ○ *Draw a shapefile around the edge of the canopy species fringing the property.*	○ *Combined area of canopy measured against total property size and expressed as a percentage.*
Success of replanting efforts	○ *Ideal - When planted, each seedling to be marked on handheld GPS with: Planting date, Species.* ○ *Replacements to dead plants to be marked.*	○ *Success measured by creating a database recording: Location, Species, is this a replanting Y/N.* ○ *A plant is no longer considered a seedling when it exceeds either 1m tall or 1.5m in diameter of drip line. These plants become part of the canopy/native*

KPI	Method	Outcome
		plant cover at this point.

It should be noted that sections of the property are not to be rewilded as they are falling under other uses such as living areas, horse paddocks and access tracks. If these areas are more easily defined in the future, adjusting KPIs and their calculations will be possible.

Challenges with measuring KPIs and Solutions

There are some shortcomings with measuring the KPIs, such as:

- *Inability to detect or identify exceedingly small seedlings,*

  The challenges with small seedling detection and ground cover weed detection may be remedied by making lower flights over areas of interest in addition to the normal mapping flight at a greater altitude. For seedlings that are too small, geotagging on a mobile device at the time of planting will be sufficient, especially following correction with the orthomosaic overlay on QGIS. As the seedlings grow, the problem of assessing their health from orthomosaics will be vastly reduced as they will be easily visible.

- *Wind movement distorting tree canopy measurements,*

  The challenge with photogrammetry distortion of canopy species occurs when the RPA is mapping without enough clearance between itself and the trees to allow sufficient overlap and therefore enough images to stitch together accurately. This may be remedied with a much higher flight over the canopy in addition to the normal mapping height.

- *Difficulty in detecting some weeds that may blend in with surroundings, especially when not in flower,*

  Weed detection issues may be remedied by marking a patch of weeds by handheld GPS so that the weed may be more easily identified from the orthomosaic and mapped accordingly.

- *Distortion of tree canopy from photogrammetry errors.*

  Wind movement is an issue largely outside human control. If mapping is required on specific days, rescheduling to a calmer day may not be possible.

Methods of initial data collection

Information on the native flora and fauna as well as the weed species on the property was collected by incidental sightings in the case of fauna and by targeted surveys for plants by Brett and Lisa Vercoe and listed here. Incidental fauna sightings were made during the mapping period of 14th to 26th of June 2021.

Furthermore, using the mobile app Avenza Maps, individual trees of concern such as Camphor Laurels and Privet were ground truthed to assist with and cross reference classification of canopies in the orthomosaics. This was done following initial classification from the orthomosaics to check accuracy.

Mission Planning and Flight - Initial trial flight

An initial series of flights were undertaken to assess the capabilities of the new equipment and workflows on the 14th of June 2021 in an effort to identify issues and correct them, details are below.

Pre-Flight checks

In accordance with Kaluta/Osprey Aerial's Remote Operator's Certification and CASA legislation, the required pre-flight checks were conducted. These included but were not limited to:

- Airspace considerations
- Property boundaries
- Public safety

The software used was an evaluation version of AVCRM, an RPA management software package. During flight planning, the mobile app "OpenSky" was used to cross reference data on AVCRM in relation to airspace concerns.

OpenSky did not find any issues with the airspace, though AVCRM found that the property was partly in Class G airspace. With this conflict of results, the airspace classification was checked in relation to the ReOC documents and as a precaution Coffs Harbour Airport's (YCFS) control tower was consulted by telephone and the airspace was confirmed as acceptable to fly the RPA in.

Two UAVs were used for the flight, with the primary aircraft to be a DJI Inspire RAW due to the large sensor on the camera and excellent past mapping performance. As a backup, the DJI Mavic 2 Enterprise Advanced was on hand.

Pre-Flight checks follow Kaluta PTY LTD's Remote Operator Certificate directions.

The software used to plan the initial flight was Drone Deploy, a cloud-based mapping system with mobile app planning capabilities. The flight area was planned with a single flight at 20m above the tallest tree.

Flight Challenges and Solutions on the trial mapping days

Once set up ready for flight, the Drone Deploy mobile app stated that the camera was not calibrated and would not allow take off. The RPA was set on the roof of the vehicle and through the DJI GO app had the camera re-calibrated.

The RPA following this recalibration initiated a flight before reaching the first point, stating the camera was not functioning and promptly returned to home and landed. This repeated numerous times until the automated flight was cancelled and a mapping flight flown manually with around 817 photographs taken in the Southern section and subsequently landed. As the camera functioned perfectly within DJI GO, it is likely the issue was with the Drone Deploy app.

The issues with the app or the RPA caused the Inspire to be used only for video from that point and the Mavic 2 Enterprise Advanced (M2EA) to be the main mapping RPA. As Drone Deploy is not available on the DJI Smart Controller for this RPA, the nearly identical DJI Pilot planning app was used to plan the flight.

Starting at the northern section of the property, it was mapped with emphasis being put to detail on the ground at the expense of tree canopy detail and was flown at 60m above ground, with only 20m clearance above the trees. This section was mapped to the boundaries of the property north of the road and the road not flown directly over as no spotter was available to spot incoming traffic. As a result, it was acknowledged that there would be little if any overlap in the imagery for the sections of the property either side of the road and each section would be treated as a separate map.

The final section to be mapped would be the middle section. The mapping flight was planned on DJI Pilot; however, it did not initiate due to an unnamed “restriction” warning. As this day was the first time DJI Pilot was used for this purpose by Kaluta Pty Ltd, the “restriction” was not discovered until after the flight which was flown manually for that purpose. The issue was found to be a distance restriction, which was switched off as at no point would the RPA have left visual line of sight on that mapping flight as the restriction boundary was only 20m within the outer edge of the flight area.

The total flight time for the entire property was around 90 minutes including landing for battery swaps and flights to the first waypoint and from the last one to home.

Following the manual flight, the data was downloaded from the RPA SD card and sorted ready for upload to Drone Deploy.

Uploading Imagery

As the only internet available was metered mobile internet and the total upload would be over 20GB, most of the files were to be uploaded back at the home base in Brisbane.

Initially the property was split into the three sections with separate uploads, however this caused issues later with getting useable Digital Terrain Models, so uploading all the images onto one map was trialled with excellent 3D results on the middle and southern sections as they had adequate overlap, but with poor results on the more limited overlap zone between the middle and northern sections which resulted in highly inaccurate height mapping and edge artifacts. This was to be expected with the prior knowledge that not flying over the road dividing the two sections of property would cause this issue, however it was worth experimenting with.

Eventually the middle and southern sections were uploaded as one map and the northern section treated as its own map.

For maps requiring contiguous contours or maps between properties divided by roads or thoroughfares, several considerations need to be made to ensure legal compliance such as having a spotter present with radio communications to the pilot or possibly traffic control for busier roads.

Mission Planning and Flight - Final flight

Following the first experimental flight with new equipment, the final series of flights was due to occur on the 26th of June 2021.

Pre-Flight Checks for Final Flights

Pre-flight checks followed those from the initial test flights with the only RPA in use being the Mavic 2 Enterprise Advanced. All flight path planning was completed on DJI Pilot with a Linear mission planned for the perimeter of the property at 260ft AGL to capture canopy detail of the 30m tall trees and a standard mapping flight at 160ft AGL to capture ground detail. Significant overlap was planned for each of the three property sections.

Care was given to the road, as less than 1 car per hour on the road had been noted on the prior test flights, it was decided that the risk of collision in case of RPA malfunction was low enough to warrant planning for decent overlap between the sections either side of the road and the take-off point was in full view of the road to watch for approaching vehicles. The RPA in use was small enough to be unable to be caught on powerlines in case of malfunction and would not span the distance between the wires in a way that would cause shorting if it were to fall on them. Also, a high clearance was planned for the powerlines to minimise any further risk.

Coffs Harbour control tower (YCFS) was again called prior to flights as a courtesy with location being given and airspace confirmed as acceptable. The control tower requested a call upon mission completion.

Flight Challenges and Solutions on the Final Flight Mapping Days

The flights were completed without issues other than the low morning light causing a slow shutter speed on the first leg of the linear flight around the property. This was remedied with a manual flight the following morning to “patch” the blurred section.

Resulting File Types

In the final flight, over 2500 images totalling 32GB were captured and uploaded.

Drone Deploy’s upload and processing resulted in a series of file types produced and downloaded as relevant to this project in EPSG 4326:

- 2D Orthomosaics with a maximum resolution of 0.8cm/pixel (GeoTIFF)
- Digital Terrain Model with raw height data (GeoTIFF) at 2cm/px
- Point Clouds in Lidar file format (*.las)
- 3D terrain models (*.obj) at 5cm/px
- Plant Health NDVI (GeoTIFF) at 2cm/px – *Not used in this project*

Methods of Data Extraction from The Imagery

This section looks at the following problems that are generally not specific to any of the following headings but are touched on at least once and explores solutions for the management of Narlu that may be applied to other similar projects in a variety of other contexts:

- Counting seedlings,
- Mapping weeds with manual and semi-automatic methods,
- Correcting RE/PCT/Vegetation Community mapping to a more site specific, realistic output
- Determining exposed soil/covered soil ratios (not covered here but the methodology is directly transferrable),
- Determining contours and drainage,
- Erosion modelling (not directly covered here but very much applicable when analysed by a CPESC),
- Determining plant health and soil moisture by thermal mapping,
- Canopy cover – native vs exotic ratios,
- Correcting property boundaries and features,
- Stocktake of property on site,
- Obtain a detailed "snapshot" of a property on a specific day to track any number of outcomes over time and create a point to retroactively analyse back to in the future.

Relative Accuracy Versus Absolute Accuracy

It is important and should be noted that this project was not planned in anticipation of absolute accuracy, rather relative accuracy, and high precision.

The best comparison to offer is to imagine a tray full of items that require measuring and counting. It would not matter where the tray is placed, so long as the items are in their places within it.

Table 8: Relative and Absolute accuracy

Relative accuracy	Absolute Accuracy
Points are highly accurate in relation to each other on the resulting maps (high precision) but may not be as accurate in relation to actual points on the ground as measured by a surveyor. This is perfectly acceptable for lower budget projects, especially in circumstances that involve counting and measuring only within the map and ignoring data outside the map.	Points are highly accurate in relation to each other and areas outside the map and may be considered survey grade for civil and construction jobs. This type of accuracy is not required on a project of this type as the borders of the project are clearly defined in the map and the important data is all contained within the project borders.
Is capable of being implemented by RPA GPS and photogrammetry alone if GPS signal is good.	Requires GNSS/RTK and/or Ground Control points to be implemented. Considerably higher cost due to time and equipment required.

This project being of tight budget constraints and only focusing on data contained within the map as bounded by the clearly visible fences was determined to not require absolute accuracy.

In addition to the orthomosaic only requiring relative accuracy, the Digital Terrain Model also requires only relative accuracy as the contours are only needed for describing the landform within the project area and not outside it. In other words, the difference in height of the highest and lowest points in relation to each other and the drainage lines are more important than their height above sea level.

Also note that in future, the data collected in these flights may be retroactively adjusted to absolute accuracy if required.

Extracting and quantifying data from the imagery involved several steps, listed here in order as much as possible. Steps are shown and the amount of time it is expected to take subsequent projects of similar size and complexity are listed in Approximate labour hours (61).

Using a local processing system

Currently in the experimental phase is the use of Open Drone Maps (ODM) – a paid, open source solution to the issue of uploading and data constraints. The comparison between and Drone Deploy is shown below:

Table 9: Comparison between Drone Deploy and Open Drone Maps

Item	Drone Deploy		Open Drone Maps	
	Pros	Cons	Pros	Cons
Server upload	○ Frees computer load once upload complete	○ Data heavy, quickly uses up any metered data ○ Larger uploads take a very long time	○ Not required ○ Optional if desired as a cloud server is available	○ When done locally uses computer resources
Cost	○ Better customer support	○ Some plans are needed for certain output types such as thermal but are prohibitively expensive for small enterprise	○ One time cost that is much lower than a single month of Drone Deploy	○ Cost is per version. Updates if desired require another fee
Flight planning	○ Included	-	-	○ Not included
User interface	○ Basic and very easy	○ Sometimes a bit too basic	○ Allows much finer tweaking and more options prior to processing	○ Less intuitive
Plugins	○ Many at low or no added cost	-	○ Many at low or no cost, as for Drone Deploy	○ Less choice
GCPs	○ Can accurately attain global accuracy	○ At $50 USD added cost	○ GCP inclusion at no extra cost	○ Slightly more complicated interface
Processing	○ Attempts to work through tough data with higher tolerance for difficult imagery ○ On cloud server	○ Local processing not an option	○ Happens in the background, allowing computer to be used but at a slightly reduced capacity, ○ Cloud server optional	○ May wait for hours before announcing map cannot be made ○ When maps fail, very little useful information given if any ○ Problematic images not notified
Image upload and storage	○ Can be accessed anywhere with good internet	○ Although images can be viewed, and added to, problematic images do not seem to have a means to be deleted. An entire re-upload is often required, causing enormous data usage and time wasted.	○ Stored locally with a downsizing option prior to processing if required.	○ More hard disk usage ○ Locally stored data cannot be automatically accessed anywhere.
Thermal map creation	○ Available	○ Extremely expensive at $150,000/ AUD per year plan	○ In development	○ Not yet developed

Plant Health

Thermal imaging shows promise in assessing plant health during the day, especially on warm days with high sun. Living and dead grass in the following images are easily differentiated by their heat reflectance. Dead grass and bare earth show up several degrees warmer than living grass and herbs. This is a tool that will be useful when thermal orthomosaics soon become more cost effective. The side-by-side images presented below were taken at the same moment and show the warmer (yellow) dead plant material against the darker (purple) live material. This temperature varies by as much as 6-9°C according to DJI's Thermal Analysis Tool.

Thermal orthomosaics, when they become more cost effective will allow very easy classification and vectorisation of dead areas such as these for fast and accurate area estimates.

Also note that the thermal images are of lower resolution (640 x 512) than the RGBs to the right and are therefore slightly more cropped so appear zoomed in.

Photo Plate 3: Thermal image of dead and live ground cover

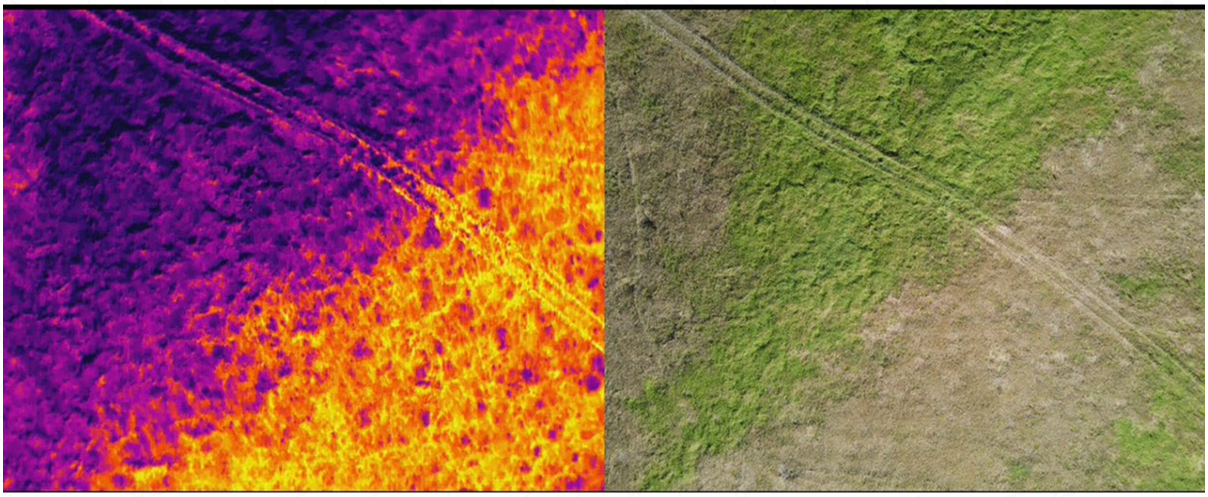
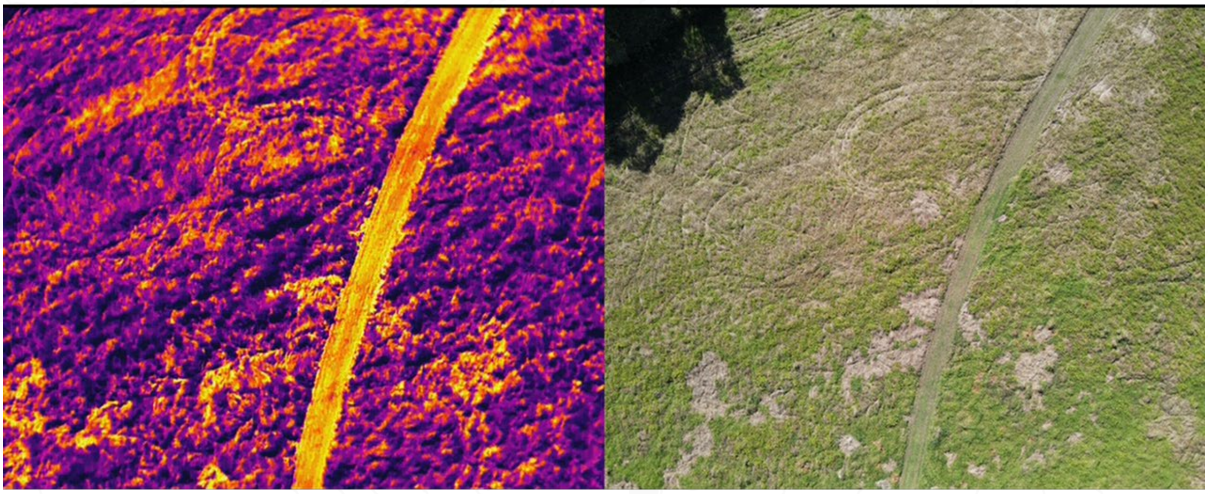


Photo Plate 4: Another image showing a comparison between live and dead ground cover



Orthomosaics

The most useful file type for most of the measuring and counting for this project is the orthomosaic. These are large photographs that may be used as maps and are made by stitching the imagery together in software that searches for common items in overlapping images, correcting for GPS drift in the process. Without the additional expense of Real Time Kinematics, Post Processing Kinematics or surveyor established Ground Control Points, the global accuracy is not expected to be high, however the position of the items within the orthomosaic are far more accurate in relation to each other. In this project, as stated earlier there was no requirement for global or absolute accuracy as the stated goals could be easily met with relative accuracy for the items within the orthomosaic.

Following upload, the Drone Deploy system once processing was finished allowed download of the stitched and ready orthomosaic. The highest resolution available was selected for each at a GSD of 4.9cm/px.

The Orthomosaics were downloaded, unzipped, and dropped into QGIS for incorporation into the project. As they are georeferenced, the orthomosaics automatically position themselves as overlays on top of the base map which in this circumstance is Google Maps. Unfortunately, the smaller and easier to handle JPG versions do not do this, so for simplicity were not used. The ragged edges were tidied by clipping to the property boundaries and the clipped orthomosaics were saved as separate files.

See the orthomosaics presented in Figure 7: Clipped orthomosaic Northern section and Figure 8: Clipped orthomosaic middle + southern sections on pages 40 & 41

Planting Site Counts

Due to the large amount of data contained in every orthomosaic, QGIS took some time to load when the files were zoomed either in or out. As the seedlings are far too small in many cases to verify from the orthomosaics, it was suggested that only the visible sites be counted and the success of each be tracked as the seedlings grow. In time, a full handheld GPS stocktake is likely to add value to the database.

Within QGIS, a new shapefile layer was created with the following fields:

Table 10: Data fields for planting site counts

Tree_ID	PL_DATE	Replant?	Canopy
Text field limited to 80 characters to list scientific name	*Date of planting. Those planted prior to the initial survey will be labelled 26/06/2021.*	*Text field limited to 1 character to track if this plant is replacing one that has died.* *Y=Yes* *N=No*	*Text field limited to 1 character to track which trees have grown to measurable canopy size at over 1m tall or 1.5m across as outlined in* **Measuring KPIs** (21)

The process of adding data points was simple but time consuming. The "Add Point Feature" function was used to assign data points to each planting site by clicking on each one and pressing "Enter" to confirm the point placement. The sites themselves were easily seen in the imagery, each having a zone of 30cm-90cm of dead grass around them. It took around 30 minutes to add over 400 sites. Once added, as they are all for the baseline data, the Attribute Table editor was used to assign the planting dates as all being 26/06/2021 and non-replants.

Measuring Plant Cover

Plant cover, which includes the separate subcategories of Native Plant Cover and Exotic Plant Cover were measured by creating shapefile layers for each and providing the following fields:

Table 11: Plant cover data fields

Scientific	Common_N	Area
Text field to list scientific name	*Text field to list common name*	*Area in Hectares to be calculated once shapefiles have been completed.*

Both subcategories, though treated separately were measured by manually drawing lines around each area covered by an identifiable plant species using a Wacom sketching tablet and the QGIS plugin "Bee pen". When the lines were completed for the map, the command "Vector > Geometry Tools > Line to Polygon" was initiated. This converted all the lines around each plant into a closed polygon and then put through the "Fix Geometry" command to repair any shapes that required it. This layer was then clipped to the project area and identifiable trees were selected with the Information pointer and named in the "Edit Feature Form" popup. It must be remembered that with the complexity of tree species on the property that the two most important distinctions are between native and weed. Some easily identifiable native species were marked with a name; however, it was most important to find the non-native species. Furthermore, native species usually require specialist identification by a trained botanist working on the ground or accepting samples. Marking the weed tree species on the ground was a very real time saving strategy in this case. In future, marking a selection of certain plant types on the ground and bringing that data into a QGIS project will make identification across sites much faster, especially if AI or algorithms are used and require "training".

The most difficult species was without doubt the Camphor Laurel (*Cinnamomum camphora*) as it has extremely varied foliage, especially when viewed from the air. Several trees in the same stand appeared to be completely different species and were verified on the ground to be all camphors.

The Layer Styling in QGIS was set to categorise the colouring of each type of plant based on the value in the Scientific field. Therefore, each polygon around, for example a Camphor tree would automatically be assigned the colour for that species when the Field information popup was manually given the correct information as a polygon was completed.

The problem with *Senecio* and some solutions

The weed coverage in the Middle and the adjoining fringe of the Southern sections of the property consisted notably of high-density **Fireweed** (*Senecio madagascarensis*). This weed was in lower densities elsewhere and was not noticed during drive-throughs or walking the property in the Northern or the remaining Southern sections. This weed was relatively easy to detect on the orthomosaics because of the larger leaves and yellow flowers and it was a simple, though time consuming task to place a point on each outbreak. See Photo Plate 7. To streamline the process, NDVI and colour isolation techniques were trialled to highlight the yellow flowers, but this was only partly successful as the light varied considerably over the property and the dead grass bore a similar colour signature. Currently, the QGIS plugin "DZETSAKA" is being trialled to learn and identify these weeds which will reduce timeframes dramatically.

The problem is that it is difficult to detect and very time consuming to do so accurately.

Manual estimation of *Senecio*

Manually circling *Senecio* outbreaks with Beepen and the Wacom tablet was much faster than with a mouse and point-to-point polygon but was far too time consuming to be taken seriously in this case. In smaller areas of higher detail such as transects for BioCondition (QLD) or Habitat Hectare (VIC) reports this may be a valid workflow as it was with canopy cover. To accurately circle 90% of the *Senecio* in the Southern section alone despite using the fastest manual methods would have taken 10 hours. A more effective method was required.

A more efficient method for manually estimating cover was devised as follows:

Five small random sample plots within the known infestation areas were created by $3m^2$ plots drawn in QGIS totalling $45m^3$, see Photo Plate 8. Within each plot, polygons were drawn over the living *Senecio*, ignoring the dead or other plant species, resulting in a cover of $25.124m^3$. The total area occupied by these polygons was measured against the total area occupied by the $3m^2$ plots. This gives the average Fireweed cover for the infested areas.

The infested areas may then be overlaid manually with a series of polygons and an area measurement taken from that, followed by adjustment for percentage of cover.

This method took around 2 hours to complete. Again, a more efficient and cost-effective solution – especially if it can run in the background, was required. A search online found the plugin “Dzetsaka” which was trialled, see below:

Machine Learning to detect *Senecio*

Dzetsaka is a QGIS plugin that is reasonably simple as far as detection algorithms go, despite this fact it remains a tool for more experienced users as its installation is not as straightforward as other plugins and it requires some prior knowledge of QGIS. Very little information is available on how to run this plugin, it took some time and trial and error over three full days to find a suitable workflow.

The basic workflow for Dzetsaka for this project is as follows:

Training Dzetsaka

A new shapefile layer (in this project’s case called “Training” for ease of identification among a large collection of shapefiles) is created with two fields: a whole number integer field called `“Class”` and a descriptive string field known as `“Type”`. The items of interest in the orthomosaic layer are drawn over with polygons. Each polygon is drawn *only* over and *not* outside the item of interest. It is then classed using the field popup when it is completed, with a name for the item in `“Type”` and a number that corresponds with it in `“Class”`. Note that if for example `“Grass”` is listed in `“Type”` and it is given a `“Class”` of `“1”`, every polygon covering grass will need to be given a class number of `“1”`. See the example below:

Table 12: Example of Class and Type identifiers for Dzetsaka

Class	Type
1	*Grass*
1	*Grass*
2	*Senecio*
1	*Grass*
2	*Senecio*
2	*Senecio*
3	*Dirt*

Figure 5: Example of training Dzetsaka with polygons in an earlier experiment

The "Train Algorithm" option is selected in the Dzetsaka menu from the QGIS "Processing Toolbox", and the parameters are set. The most successful combination was as follows:

- **Input raster:** Orthomosaic
- **Input Layer:** "Training"
- **Field Column:** Class
- **Select Algorithm to train:** K Nearest Neighbour
- **Pixels to keep for validation:** 50%
- **Parameters for the hyperparameters of the algorithm [optional]:** -
- **Output model (to use for classifying):** [Make up a model name].xml
- **Output Confusion matrix:** [output model name] confusion.xml

This process took about two minutes and generated a reasonable sized XML file at 10.686 MB.

Turning Dzetsaka loose on the imagery

The next step was to open the Dzetsaka "Predict Model" option. The settings were as follows:

- **Input raster:** Orthomosaic [section, see below]
- **Mask raster:** -
- **Model Learned:** Senecio Test.xml
- **Output raster:** [section]_classified.tif (see below)
- **Open output file after running algorithm:** [Yes]
- **Confidence raster [optional]:** [No]
- **Open output file after running algorithm:** [No]

This process is very lengthy and took overnight, only to fail when the entire orthomosaic was to be read. The solution was to clip smaller copies of the orthomosaic into sectors named "*Regions*" and classify each of those individually as a Batch Process. The middle or northern half of the southern section of the property was divided into six roughly equal parts for this purpose. Each took around an hour and a half to process, no doubt owing to the large file sizes.

The success of the algorithm was estimated at around 70-80% with it finding the *Senecio* flowers with little error, though smaller or less obvious flowers were occasionally missed, and it did falsely classify some live grass. It did fulfil the task of finding most of the *Senecio* and being able to do so in the background while QGIS and the computer was otherwise engaged for other purposes. The output raster comes out as a TIF file which QGIS easily incorporates, although very data-heavy.

Dzetsaka post processing

In the "Layer Styling" menu, the "Render type" dropdown should be selected as "Paletted/Unique values" and then Classified. Random colours are then applied by QGIS to the different values that were put into the training layer. Unwanted values may be made transparent.

To reduce the load on the system, which is considerable, the next option is to isolate *only* the required values. In this project, *Senecio* was Classed as "1", so the following expression was fed into the Raster Calculator, using "Region 1" as an example:

```
("Region 1 [Classified]@1"=1)
```

The name given to the output file was, in this example: "Region 1 [Classified] mask.tif"

This process was allowed to run its course and came out with a black and white image showing the *Senecio* as white "sandy" clusters. This puts extraordinary pressure on the computer if it is processed at this point into vectors, so another step is required.

To make matters easier, at this point re-combining the rasters into one again is a wise move. This is done on the Raster > Miscellaneous > Merge tool.

SAGA is software built into QGIS and it includes a "Majority Filter" to which the following settings were applied:

Grid: Merged mask
Search Mode: [1] Circle
Radius: 10
Threshold [Percent]: 25
Filtered Grid: [choose a file name].sdat

This will coalesce the scattered points into much more useful "blobs" which are much easier to use and convert to shapefiles very rapidly. **Note:** Majority Filter will periodically "freeze" during and at the end of the process, locking QGIS and having the appearance of failing for up to an additional 30 minutes. QGIS is best left alone during this entire process.

To convert the raster into a shapefile, the "Raster to Vector" option under the "Raster" menu on the main screen is selected and run. The other option if this does not work is to use "Raster pixels to polygons" under the Processing Toolbox.

Buffers if desired can be made around the accurately classified flowers to roughly encompass the plant and the unwanted items easily deleted.

Once this is complete, overlapping polygons will return area estimations that ae far higher than reality, so the overlap must be removed. In QGIS this was done with Vector > Geoprocessing Tools > Dissolve.

Pros and cons of Dzetsaka

Although a little complex, as mentioned previously it is much more efficient than individually circling each plant, which although accurate is extremely time consuming and not cost effective for so many small plants in such a large area. This workflow largely works in the background and with the appropriate Python script may be automated more effectively in the future.

Another essential point regarding this workflow is that Dzetsaka will fill the entire raster image with information. If it is given only one item to search for, it has nothing to compare and contrast the other items in the image with and will create an image 100% classified as that one item. In other words, one input creates only one output- it must be shown the items that are *not* the target. To effectively isolate items, it must be shown as many classifiers as possible, even if only a binary outcome of "Yes"/"No" is required. It could be shown the desired item to search for which might be something like the `Type: "Yellow Flower" Class: "1"`. If nothing else is important, it could simply be shown a variety of other items such as dirt, grass, trees, roads etc all classified as `Type: "Not Yellow Flower" Class "0"`. This would give a binary outcome which would be far less bulky than 10 or more classifiers.

Photo Plate 5: Camphor laurels showing extreme and unexpected variation in foliage, ground truthed with Avenza Maps

Photo Plate 6: Comparison between Senecio *fireweed on the left half of this photo and grass on the right*

Photo Plate 7: Manually circling Senecio *in QGIS*

Photo Plate 8: Sample plot of 3m x 3m showing Senecio *cover with polygons applied.*

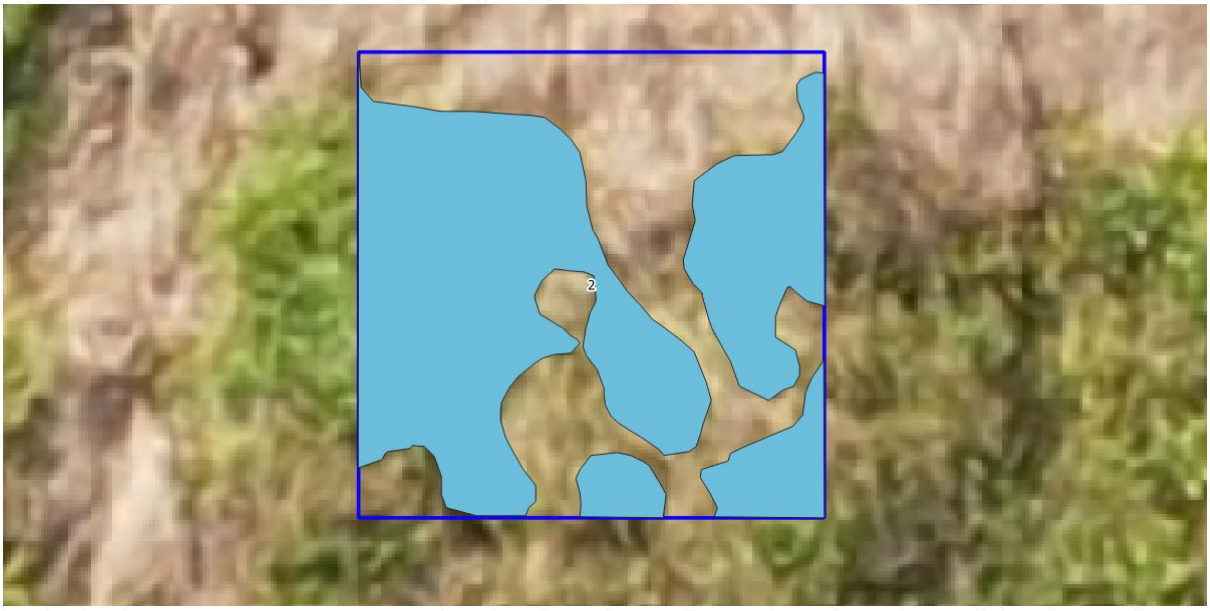


Figure 6: Dzetsaka output compared with orthomosaic

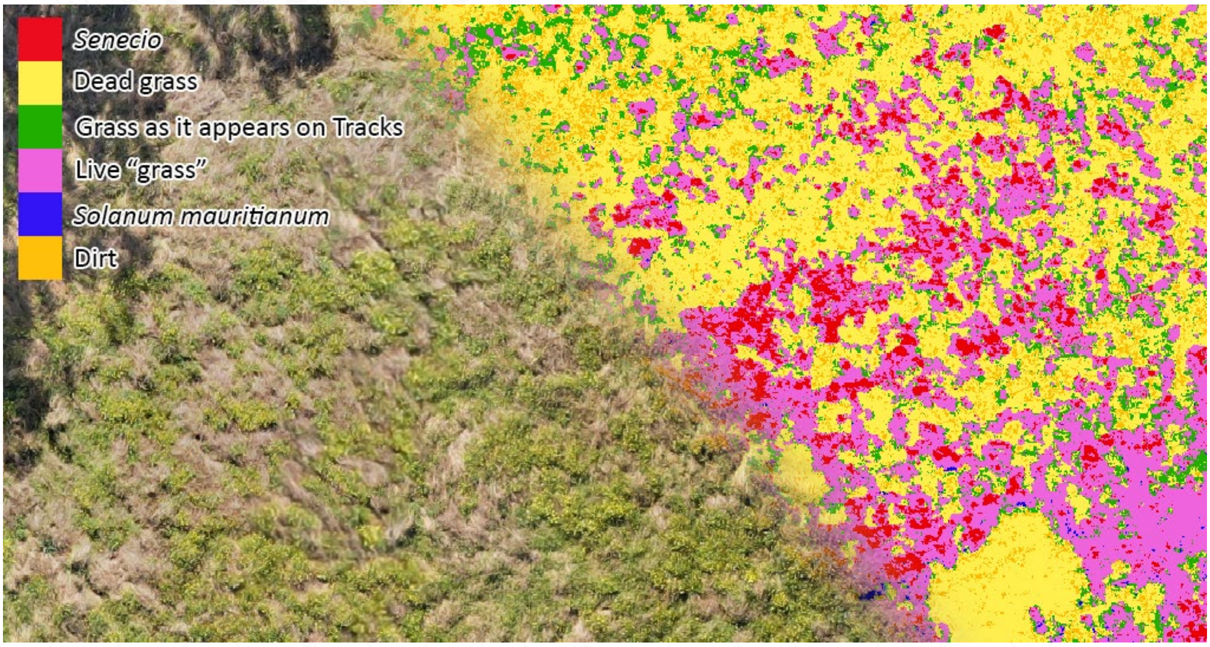


Photo Plate 9: Dzetsaka was good, though not perfect for detecting Senecio.

The image above shows an example of reasonable classification of *Senecio* as red sandy overlays with Dzetsaka, following switching off the other classifications, though some tidying of grass patches incorrectly marked may be required and some *Senecio* patches were clearly missed. This no doubt will be solved in future with more thorough algorithm training.

As a point of interest, the algorithm was trained to look for grass as it appears on "Tracks" as shown above in

Figure 6. This worked reasonably well for much of the access track, though did also tend to classify the edge of grass or *Senecio* clumps in the same way. *Solanum mauritianum* with its distinctive blue-green hairy leaves should have been easy to classify however Dzetsaka "found" it several times where it did not exist as indicated by the blue in Photo Plate 9.

Improving Dzetsaka's chances of detecting weeds

When looking at a weed such as *Senecio*, it must be acknowledged that it is a challenge for the algorithm as it is:

- Small,
- Similar in colour to reflective grass and foliage in the sun, especially if grass is of poor health, if it were another colour, such as pink it would be detected very easily with very few errors in comparison,
- Entangled within the non-weeds,
- Only detectable by algorithm when in flower due to its entangled nature and similar colour.

This also makes it a perfect candidate for the algorithm to be tested on. As a result of this challenge, there will be some confusion with the algorithm, especially when filters are applied to reduce the "noise" of false detections which also take out many of the smaller "true" detections.
To allow Dzetsaka the best chances at accurately detecting weeds, the following table lists the suggested fixes and the pros and cons of each:

Table 13: Solutions for Dzetsaka errors - pros and cons

Fix	Pros	Cons
Map on a cloudy day to ensure even light with no "hotspots" on the surrounding grass	*The map as a whole will be much easier to see features in without harsh light and shadows.*	*Mapping over large areas may mean the light changes dramatically unless under ideal conditions,* *Days such as this are rare and to only map on days such as this will come at a high cost, and outweigh the benefits of waiting for a "perfect" day.*
Train the algorithm more thoroughly	*A more accurate output,* *Ability to take metrics on a wider range of data.*	*The cost of spending more time on it,* *Trial and error can increase costs.*
Manually fix errors in the shapefile	*Excellent accuracy.*	*Very time consuming.*
Be less harsh with "Majority Filter"	*More Senecio will pass the filter.*	*More errors will pass the filter.* *More tidying up afterwards.* *Much longer processing times for the Raster to Vector tool.*
Use the confidence raster as an overlay to select "good" data and delete "bad" data automatically	*Less errors,* *Higher quality of detection.*	*Double the processing time,* *Double the file size – hard disk space is very quickly diminished.*
Map from a lower height and with higher detail to make the	*The entire project becomes higher*	*Increased data load,* *Increased upload and*

Fix	Pros	Cons
task easier for the algorithm	*resolution,* - *Detection of other metrics becomes much more accurate,* - *Increased ability to gather data of higher quality.*	*processing times,* - *Bulkier map that is slower to respond during analysis in QGIS,* - *All operations become much slower.*

For the purposes of this project and others like this, Dzetsaka seems more than adequate to provide data within accepted error margins.

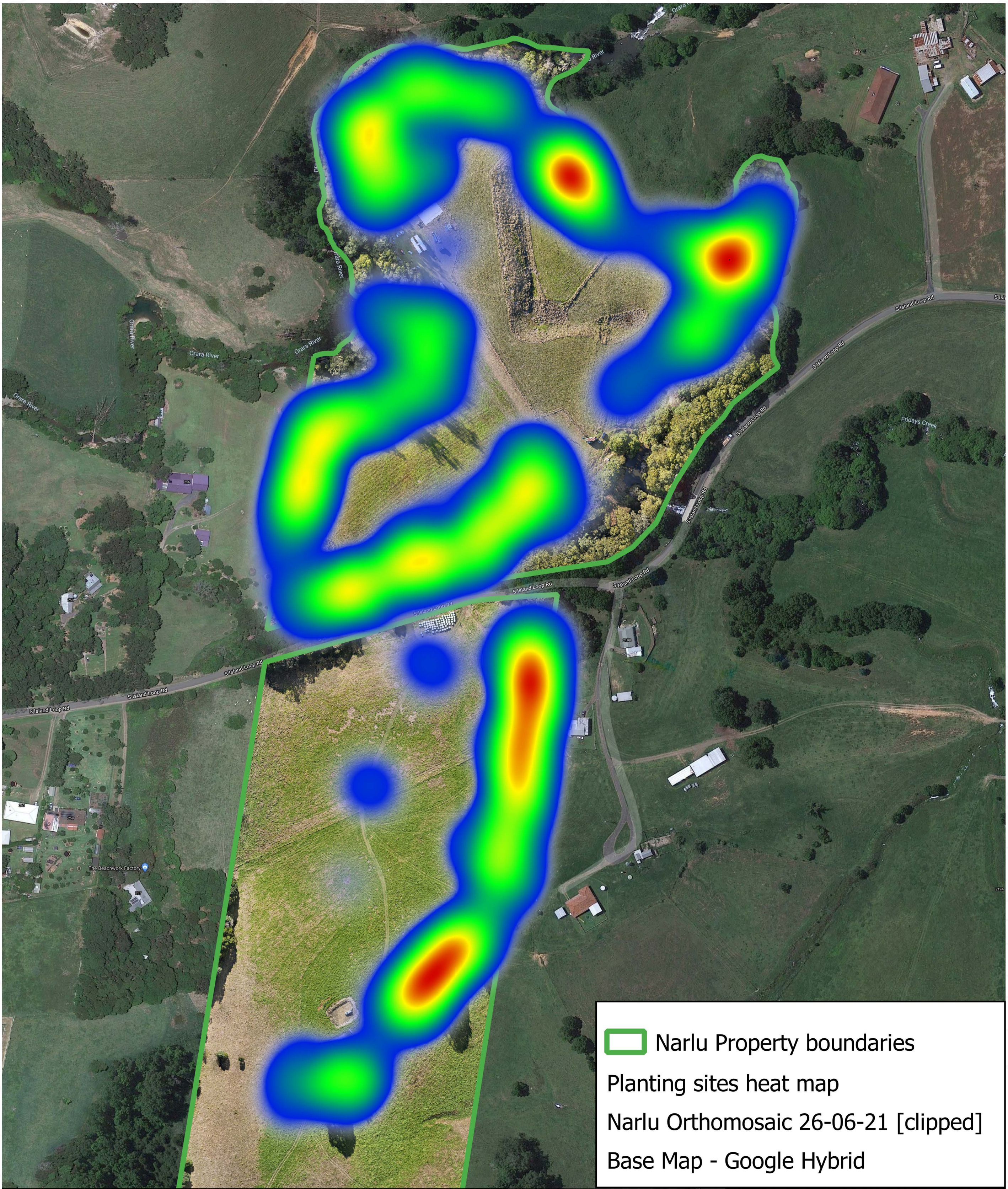
Fences and Boundaries

Also easily extracted from the orthomosaics are the property boundaries as defined by fences. Line type shapefiles were drawn along visible fences on QGIS using the “Add Line Feature” tool. Enabling “Snapping to Vertices” option allowed the polygons representing the area of the three sections of the property to be accurately overlaid on the project. The northern boundary as defined by the Orara River and Fridays Creek was measured by drawing lines along the mid sections of the waterways themselves. These boundaries may be seen in Figure 2: Property boundaries.

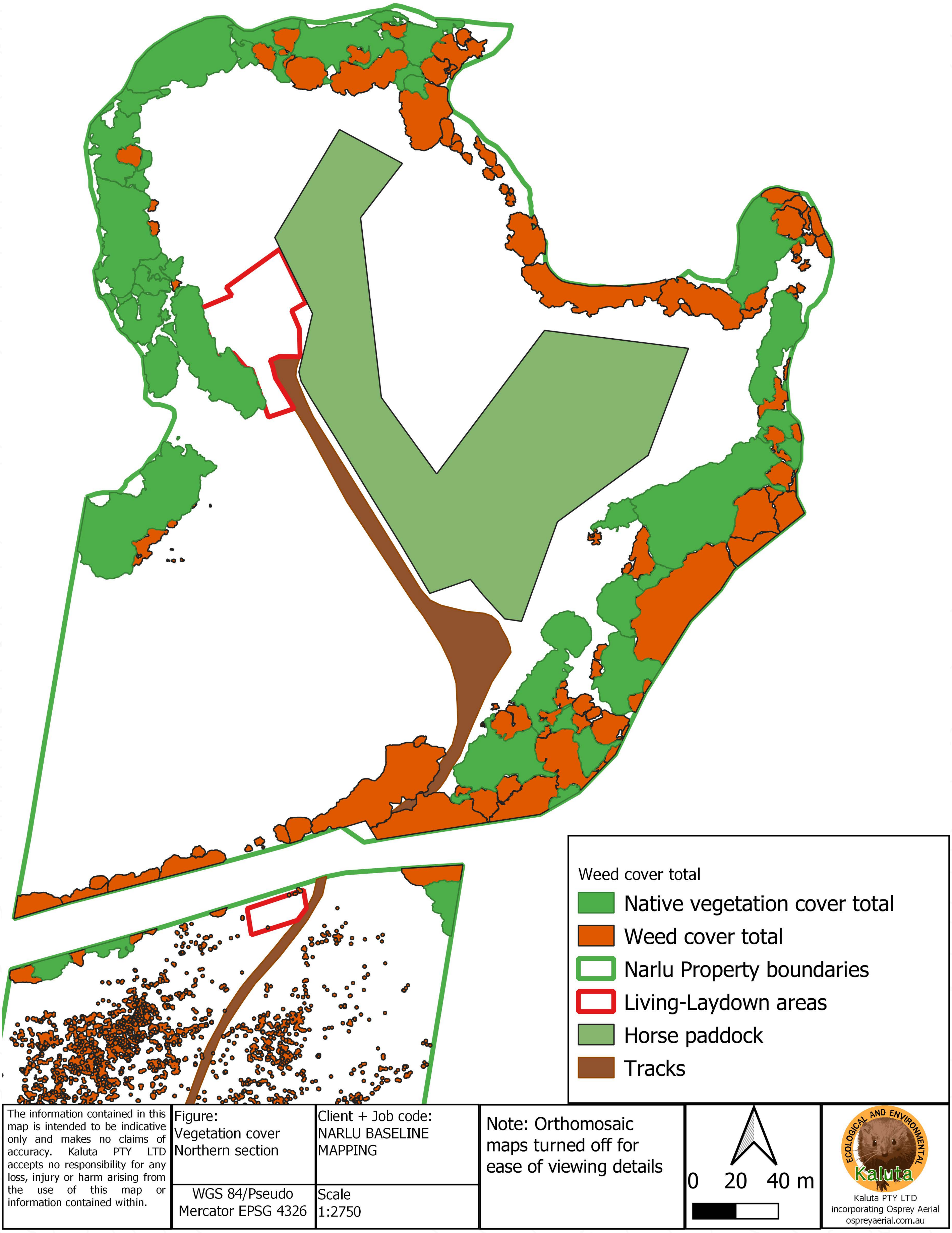
The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Clipped Orthomosaic Northern section	Client + Job code: NARLU BASELINE MAPPING		0 20 40 m
	WGS 84/Pseudo Mercator EPSG 4326	Scale 1:2750		Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au

The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Clipped Orthomosaic Middle and Southern sections	Client + Job code: NARLU BASELINE MAPPING		0 40 80 m
	WGS 84/Pseudo Mercator EPSG 4326	Scale 1:6500		Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au

The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Planting sites prior to June 26 2021 WGS 84/Pseudo Mercator EPSG 4326	Client + Job code: NARLU BASELINE MAPPING Scale 1:9000	0 50 100 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au

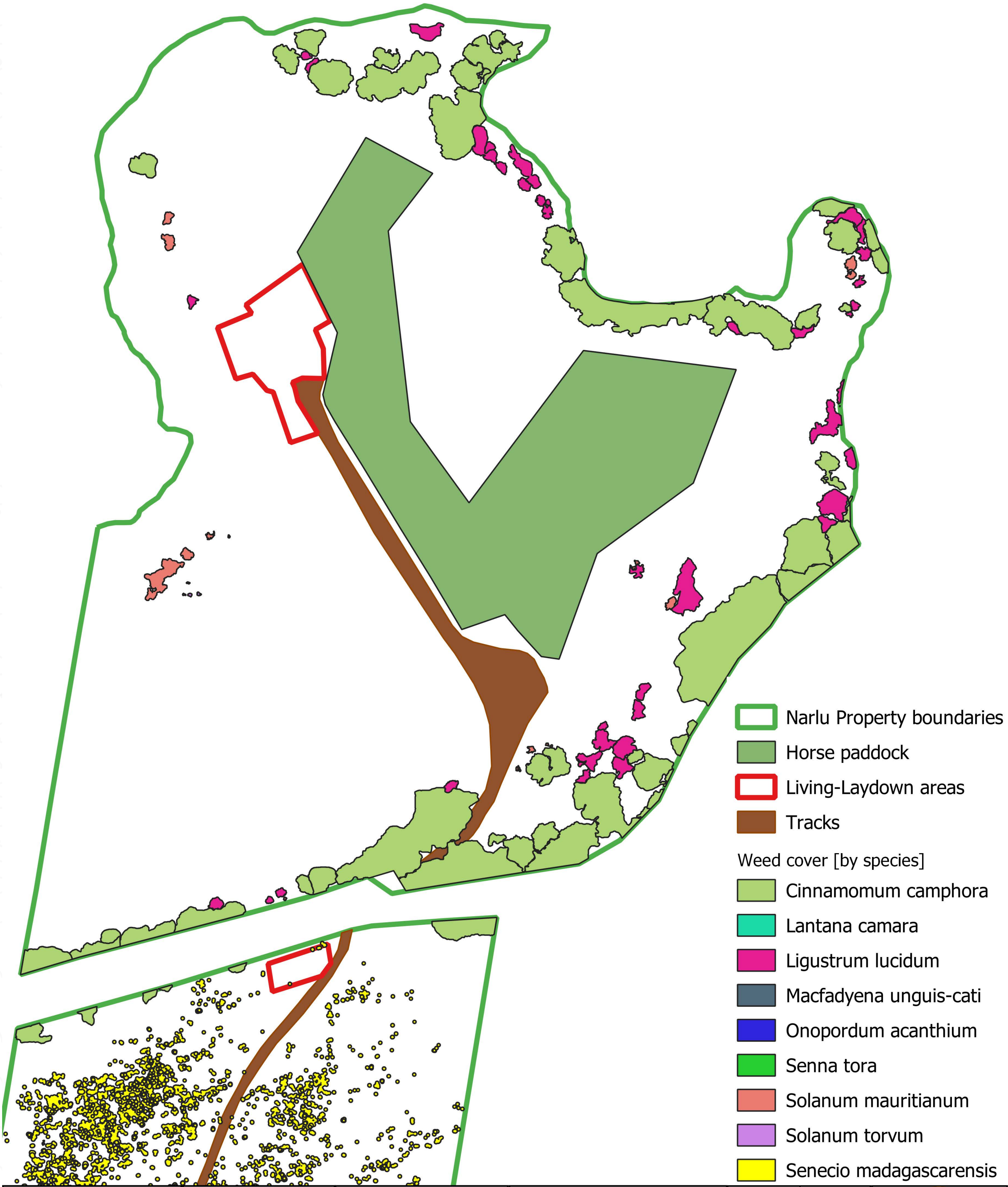


The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Planting sites prior to June 14 2021, expressed in density WGS 84/Pseudo Mercator EPSG 4326	Client + Job code: NARLU BASELINE MAPPING Scale 1:4500	Notes: This map shows the density of attempted plantings prior to June 14th 2021.	0 25 50 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au

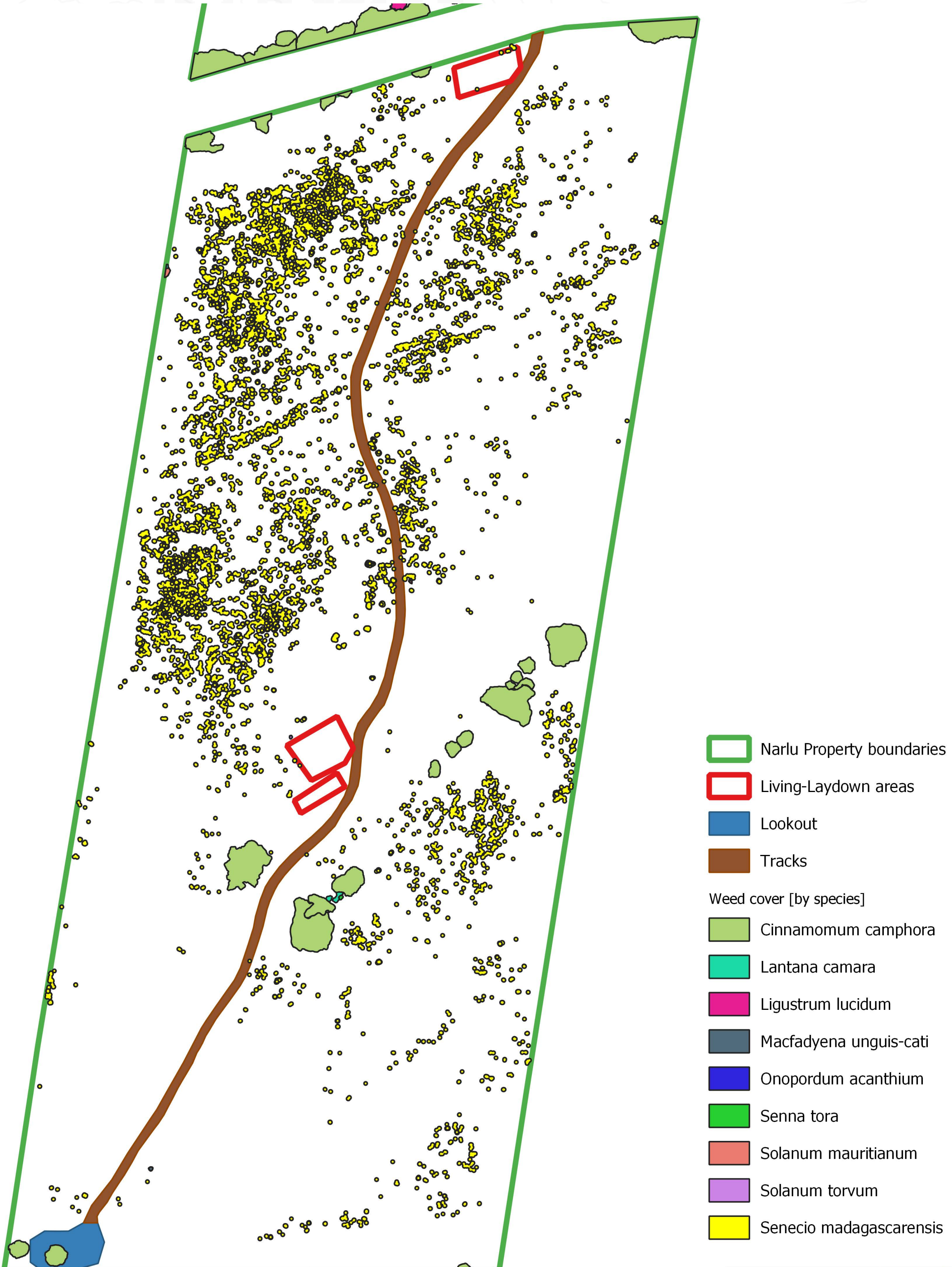

Weed cover total
Native vegetation cover total
Weed cover total
Narlu Property boundaries
Living-Laydown areas
Horse paddock
Tracks
The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.
Figure:
Vegetation cover
Northern section
WGS 84/Pseudo Mercator EPSG 4326
Client + Job code:
NARLU BASELINE MAPPING
Scale
1:2750
Note: Orthomosaic maps turned off for ease of viewing details
0 20 40 m
Kaluta
Kaluta PTY LTD
incorporating Osprey Aerial
ospreyaerial.com.au

The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Plant cover Middle section WGS 84/Pseudo Mercator EPSG 4326	Client + Job code: NARLU BASELINE MAPPING Scale 1: 2750	Note: For ease of viewing the details, Orthomosaic maps have been turned off.	0 20 40 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au

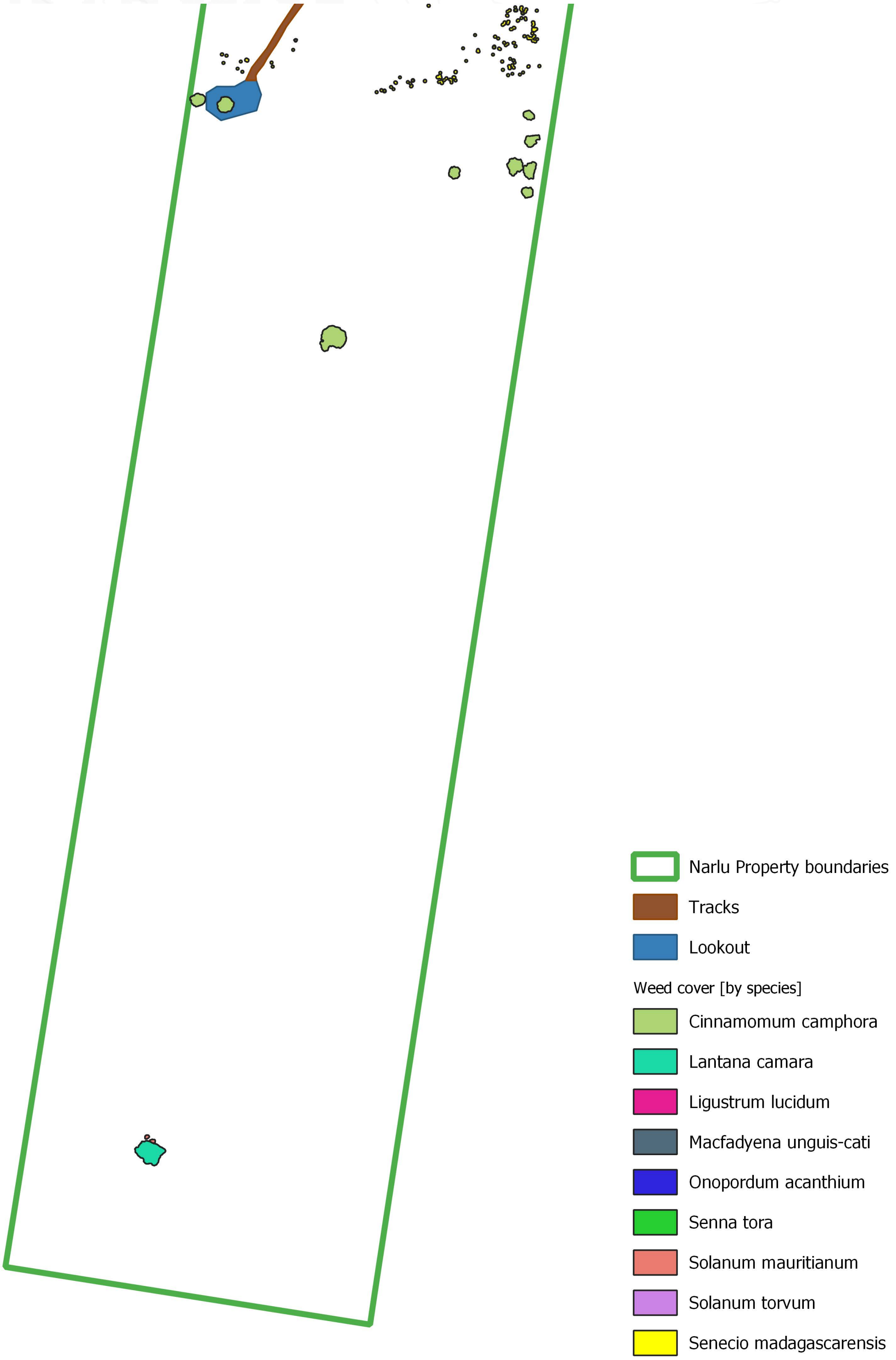
The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Plant cover Southern section	Client + Job code: NARLU BASELINE MAPPING	Note: For ease of viewing the orthomosaic map layer has been turned off	0 20 40 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au
	WGS 84/Pseudo Mercator EPSG 4326	Scale 1:4000			



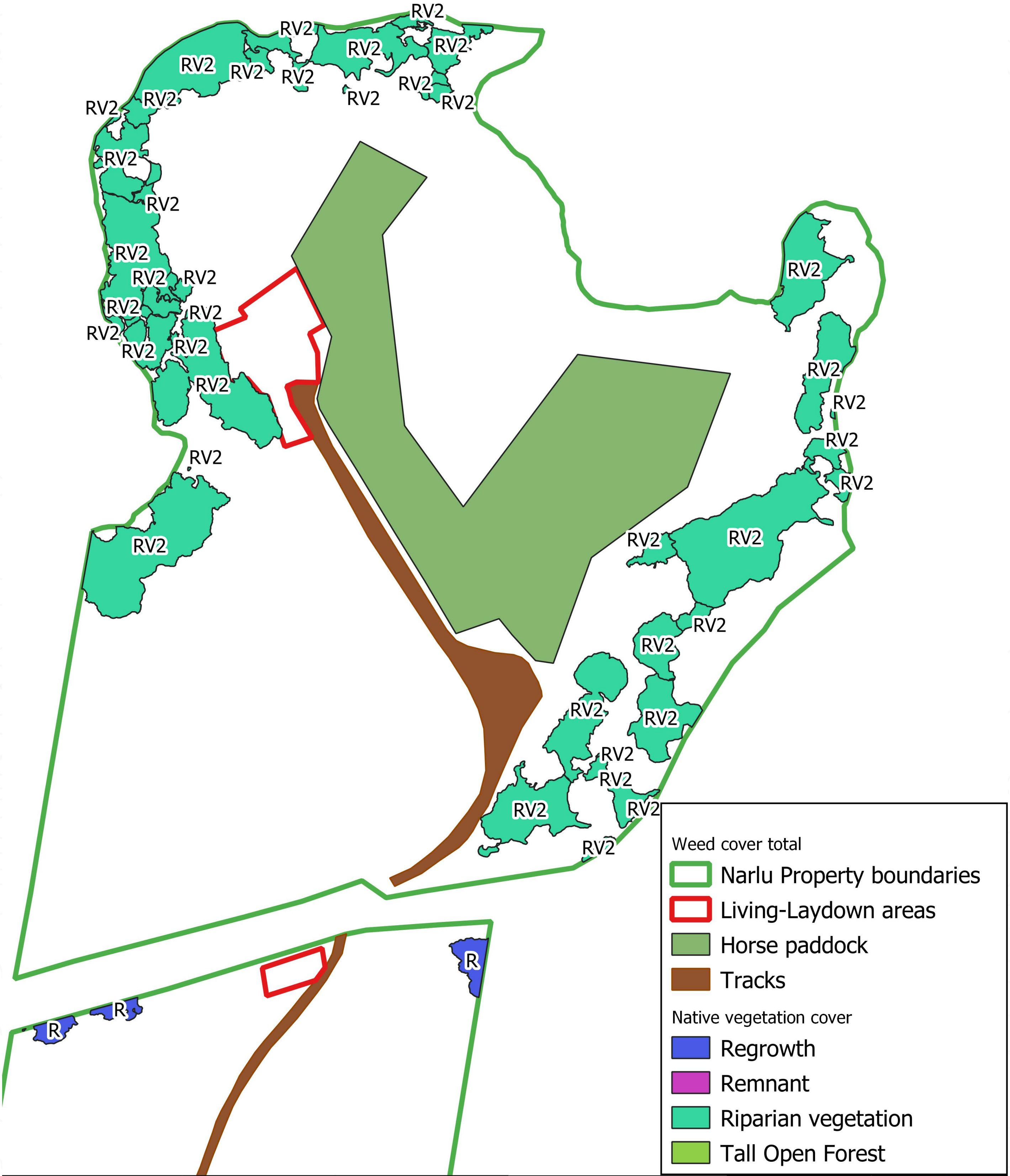
The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Weed cover by species Northern section WGS 84/Pseudo Mercator EPSG 4326	Client + Job code: NARLU BASELINE MAPPING Scale 1:2750	Note: Orthomosaic maps turned off for ease of viewing details	0 20 40 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au



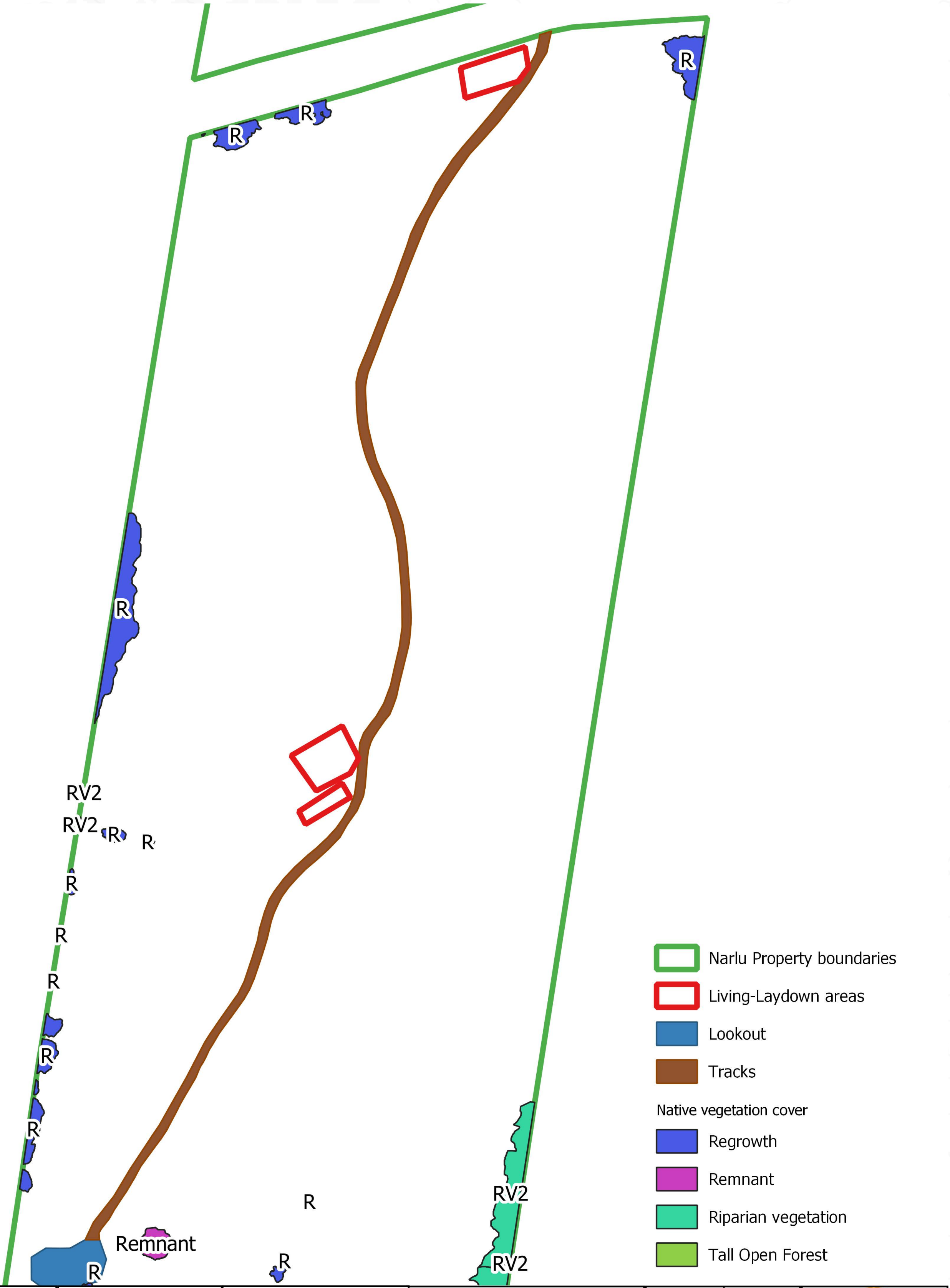
The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Weeds by species Middle section WGS 84/Pseudo Mercator EPSG 4326	Client + Job code: NARLU BASELINE MAPPING Scale 1: 2750	Note: For ease of viewing the details, Orthomosaic maps have been turned off.	0 20 40 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au



The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Weed cover by species Southern section	Client + Job code: NARLU BASELINE MAPPING	Note: For ease of viewing the orthomosaic map layer has been turned off	0 20 40 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au
	WGS 84/Pseudo Mercator EPSG 4326	Scale 1:4000			

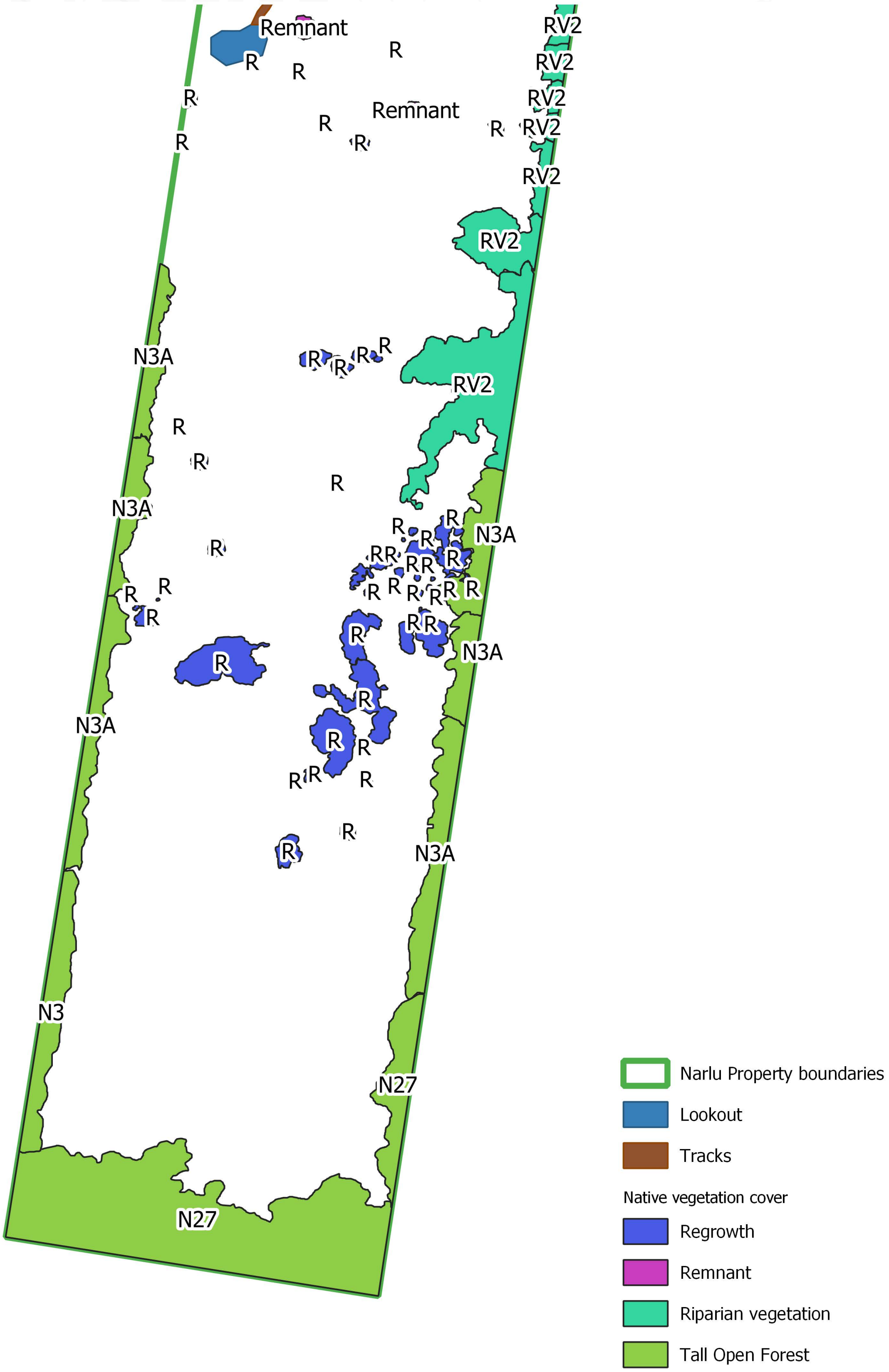


The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Orthomosaic truthed native vegetation classes Northern section WGS 84/Pseudo Mercator EPSG 4326	Client + Job code: NARLU BASELINE MAPPING Scale 1:2750	Note: Orthomosaic maps turned off for ease of viewing details	0 20 40 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au



The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Native Vegetation Types Middle Section - orthomosaic truthed	Client + Job code: NARLU BASELINE MAPPING	Note: For ease of viewing the details, Orthomosaic maps have been turned off.	0 20 40 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au
	WGS 84/Pseudo Mercator EPSG 4326	Scale 1: 2750			

CASE STUDY: *UAV derived data for the rewilding of Narlu*



The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: Native Vegetation Types Southern Section - orthomosaic truthed WGS 84/Pseudo Mercator EPSG 4326	Client + Job code: NARLU BASELINE MAPPING Scale 1:4000	Note: For ease of viewing the orthomosaic map layer has been turned off	0 20 40 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au

The Three-Dimensional Data

The overlapping photographs from the RPA flying over the landscape and the common points within them allow the software to form three-dimensional imagery by comparing their positions in as many images as possible. The resulting data, as with the orthomosaics can be highly accurate in a relative sense, but without the added time and expense of making survey-grade outputs, absolute accuracy cannot be guaranteed. For the purposes of this project, however, relative accuracy cross referenced with known height data is more than sufficient.

Calibrating the altitude

To access information on the approximate altitude of the property, The Australian Government Geophysical Archive Data Delivery System was consulted. Using the Elevation Profiles tool, the layer "DEM SRTM 1 Second over Australian Bathymetry Topography" was selected and a line drawn through the Lookout near the highest point of the property. As this is a section that is relatively level considering its surrounds, the resolution of the abovementioned layer is sufficient to calibrate the altitude of the entire project to within required parameters. As this project is not intended to be for detailed planning, an approximate global altitude is appropriate considering relative altitude within the project is of higher priority.

Once the altitude of the lookout had been ascertained, it was calibrated on Drone Deploy by opening "Map details" and using the point calibration tool and entering the altitude manually.

Following this, the three-dimensional files were downloaded:

- Digital Terrain Model
- Digital Elevation Toolbox
- Three-Dimensional OBJ file

Digital Terrain Models

Drone Deploy allowed the creation and download of Digital Terrain Models (DTMs), exported in TIFF format at a lower resolution than the orthomosaics. The RAW elevation data format was selected. This type includes the altitude values encoded in the file, as other formats only include the RGB or Greyscale palette with no additional data.

The DTMs were easily imported into QGIS by drag-and-drop. The Northern and Southern sections were treated separately for ease of use as overlap between these areas was insufficient due to the road not being mapped. As Drone Deploy deletes the trees from the landscape where possible, smooth sections appear on the DTMs. This is not a problem in the context of this project.

These DTMs may be displayed in several ways in QGIS by opening "**Layer Properties**" and under the **Symbology** tab making selections from the "Render type" drop-down menu. The chosen method of displaying these DTMs for this project was with "**Hillside**" on Band 1 (Gray) as it shows the shadowing of the landscape and the contours at their best.

Elevation Toolkits

The Elevation Toolkits were downloaded in the same format, however as they include the trees, they are of less use and were not incorporated into the project.

Contouring and Drainage models

The contouring workflow was more complex as it derived from the Raw Elevation Data DTMs. The workflow was as follows:

Step 1: Access the Contour menu by first selecting the DTM layer and then:

Raster menu > Extraction > Contour.

Step 2: Change "Interval between contour lines" to "1.000000" and **run** the algorithm.

Step 3: Once the contours have been extracted and appear, go to the Field Calculator and enter the following expression on a *New Field* named "`Index`" to create a field that ignores elevations in metres not ending in a zero – for example ignoring 12m or 16m but not 10m or 20m. This is to tidy the map and make it easier to read:

```
if("ELEV"%10=0, 1, NULL)
```

Click "**OK**"

Step 4: Open "Layer Properties" for the layer and go to the "Symbology" tab. Select "`Index`" under the "Value" dropdown and select "Categorized" from the dropdown menu at the top of the tab. Click on the "Classify" button at the bottom of the tab.

Step 5: Two categories should have appeared. Select "**all other values**" and select an appropriate line thickness and colour. Do the same for "**1**" but make them thicker. Click "**OK**" and the lines should change accordingly.

Step 6: Re-open the Field Calculator and create a *New Field*, naming it "`Label`". Type the following into the calculator:

```
"Index"*"ELEV"
```

Click "**OK**"

Step 7: Re-open "**Layer Properties**" and go to the Label tab. Select "**Single Labels**" from the top drop-down menu. In the "**Value**" drop-down, select "**123 Label**" and format the text according to the best style for the project. This style used a buffer, smaller text, curved placement and "**on line**" position.

The layer can be saved as an SVG, in this case it was saved as an Esri shapefile.

A separate layer was created for drainage lines. It is an easy matter to draw a point-to-point line Shapefile to show drainage patterns in the gullies. This is also easily verified with the orthomosaics showing vegetation changes and in some cases standing water on the drainages.

3D OBJ Model

The other option for download is a digital 3D model in OBJ format. This is useful for making animations and presentations of the property including virtual flythroughs and more. Another proven use is the 3D carving of the landscape as a real-world model in high density foam. Note that the images of the models below have retained their ragged edges from the processing well outside the property boundaries. These are easily cleaned up on a variety of software suites prior to use with the free and open source Blender possibly being a better option than most paid software.

Point Cloud data

Point cloud data was created and downloaded in RGB Lidar (*.las) format. Although not taken with Lidar hardware, this file format is useful for a variety of 3D models.

Photo Plate 10: OBJ model of Narlu North

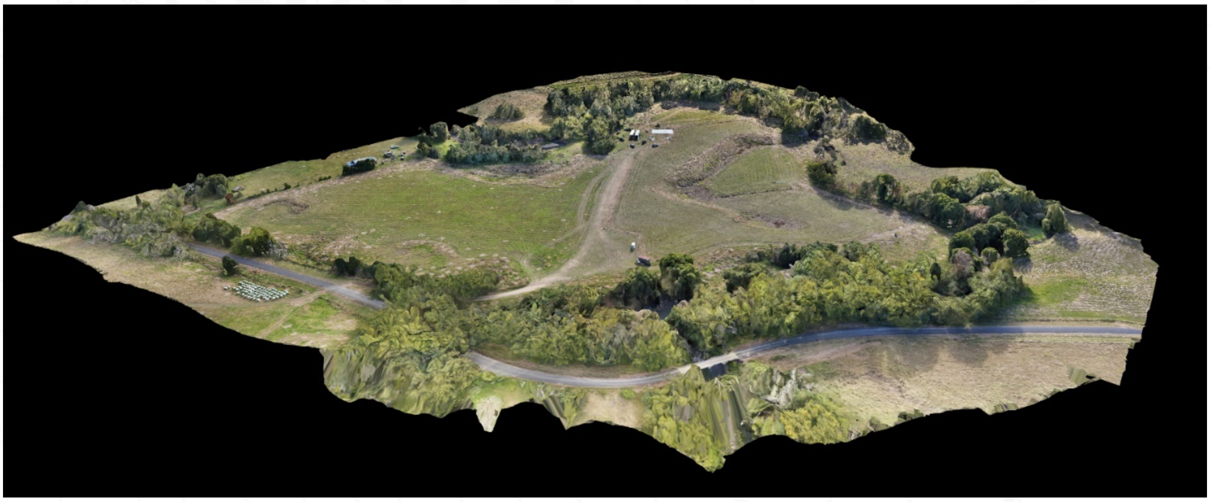


Photo Plate 11: OBJ model of Narlu Middle and South

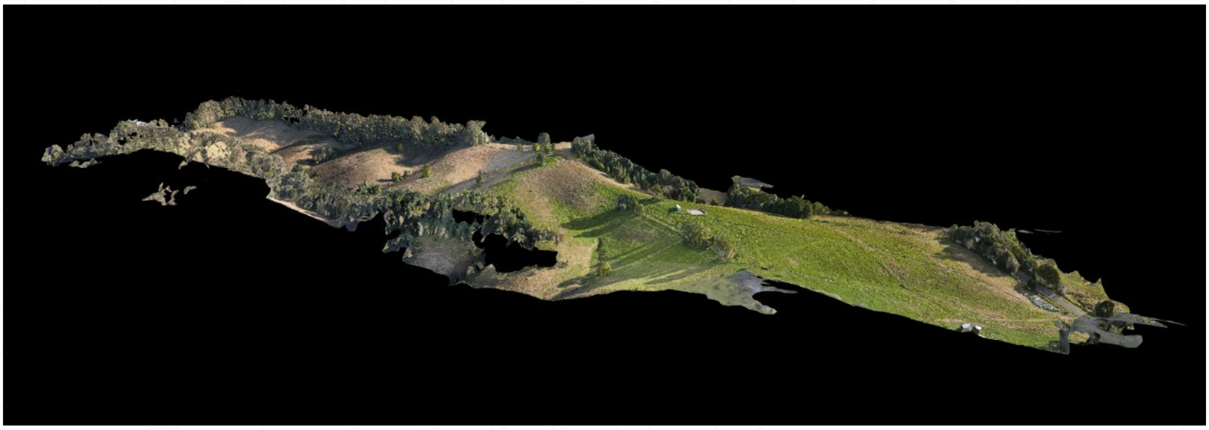
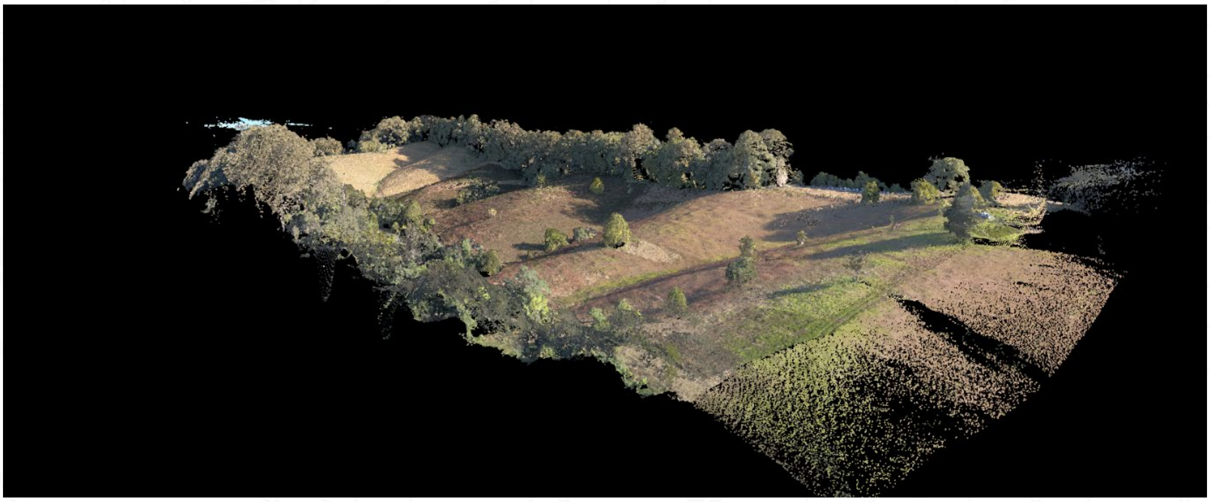
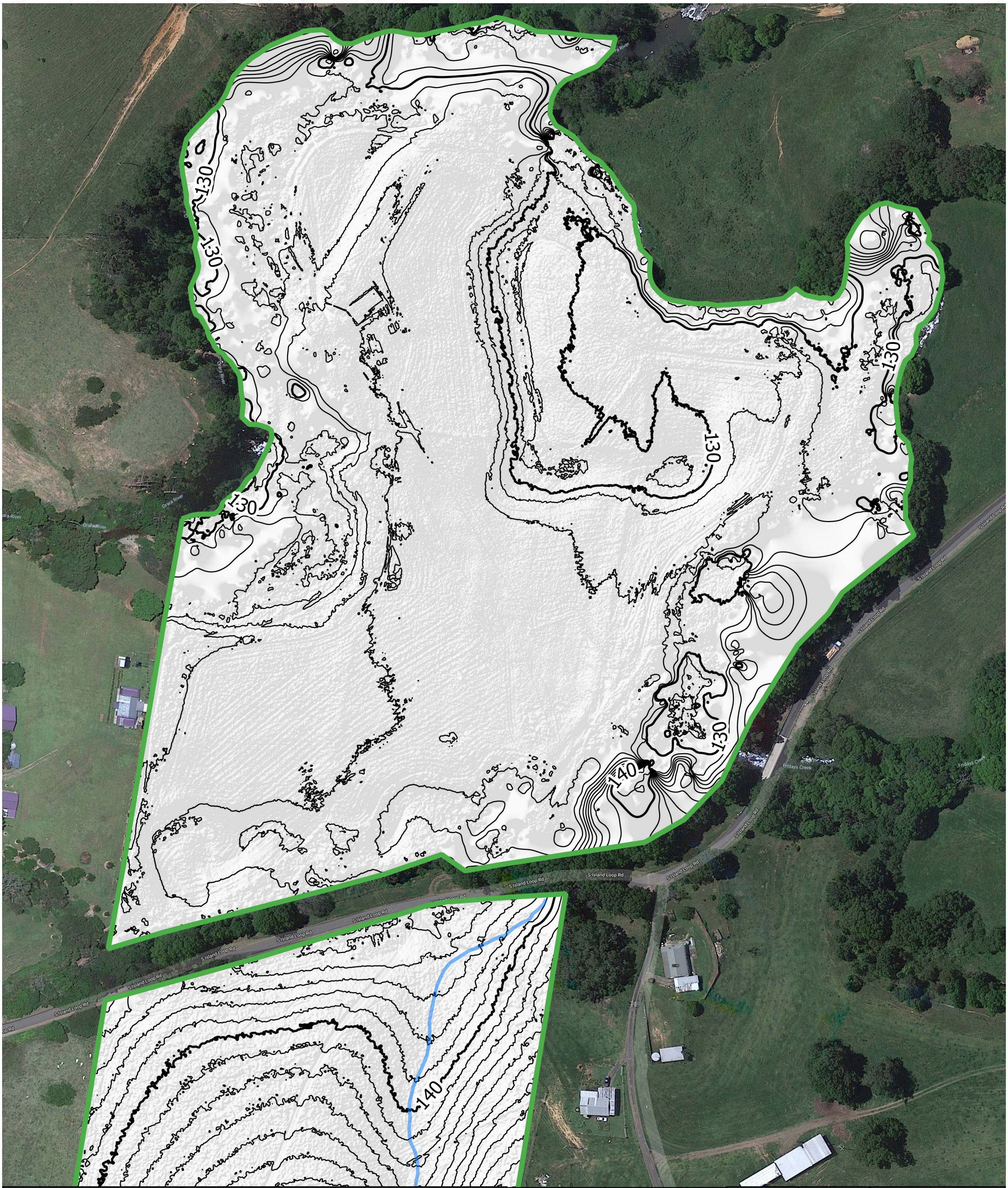
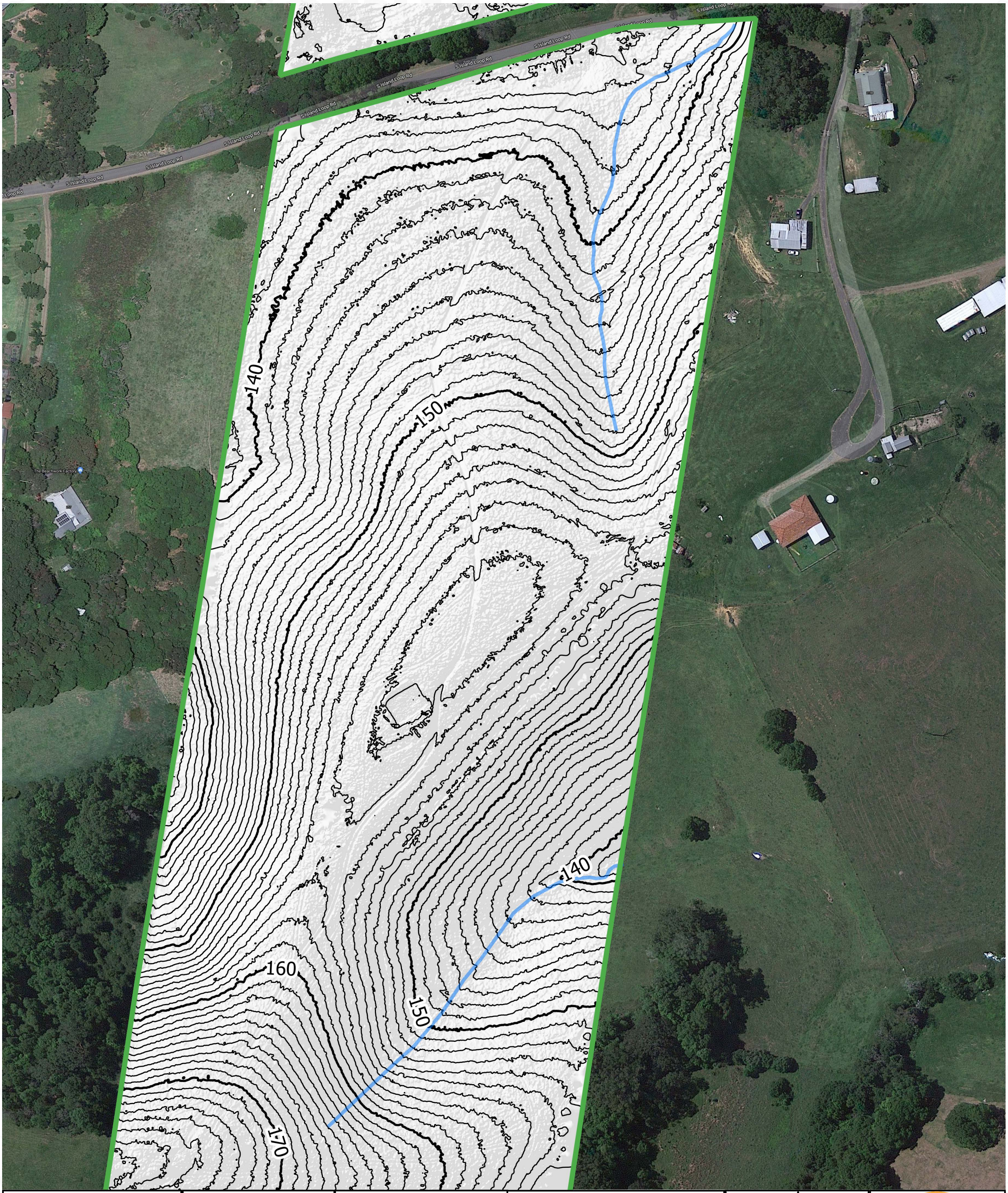


Photo Plate 12: Point Cloud visualised for Southern section, prior to tidying by trimming



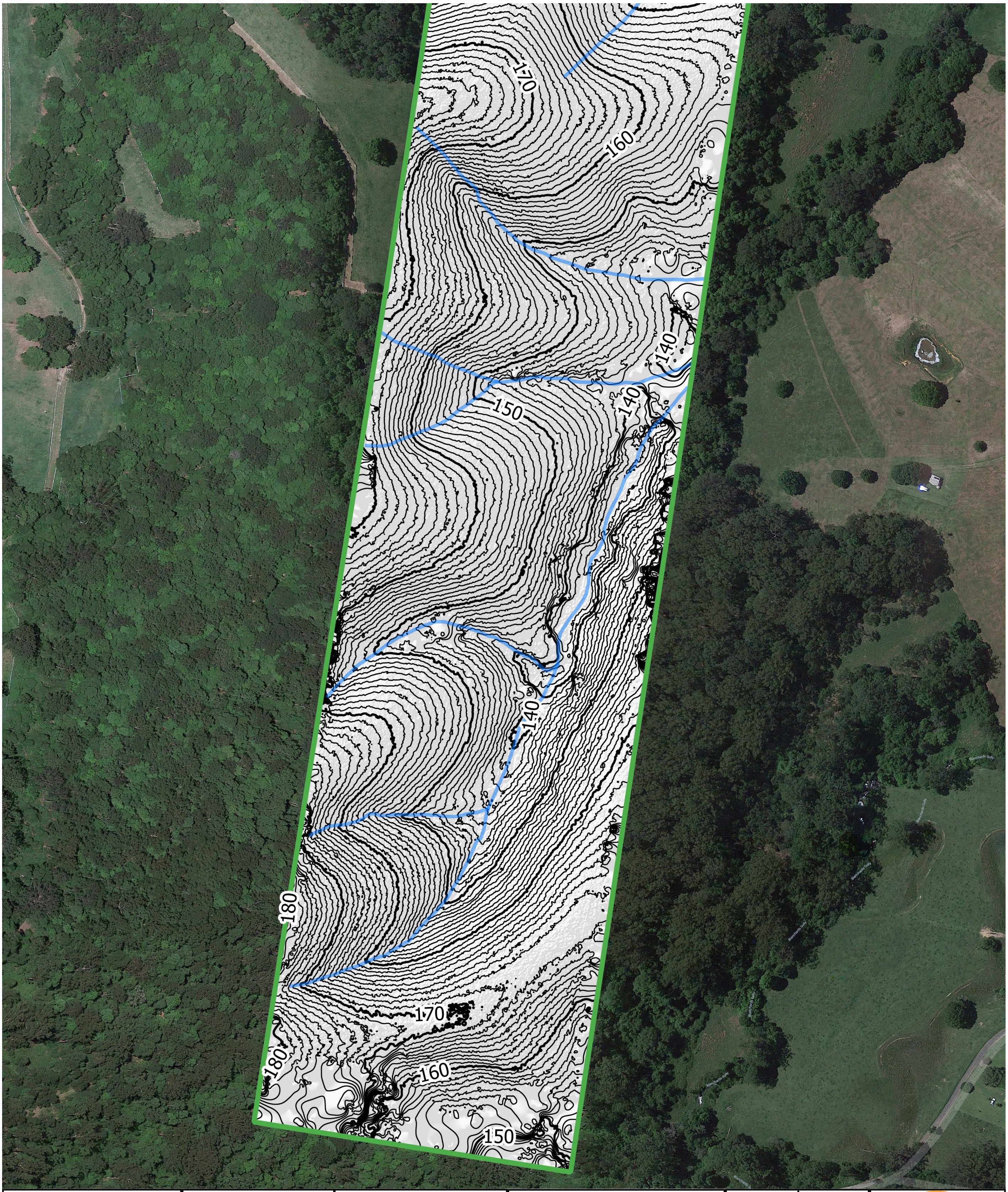


The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: DTM and contours Northern section WGS 84/Pseudo Mercator EPSG 4326	Client + Job code: NARLU BASELINE MAPPING Scale 1:2750	Contours North DTM Northern Hill shade Base Map - Google Hybrid	0 20 40 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au



The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: DTM, contours and drainage Middle section WGS 84/Pseudo Mercator EPSG 4326	Client + Job code: NARLU BASELINE MAPPING Scale 1: 2750	Drainage Contours - Middle + Southern DTM Middle + Southern Hill shade Base Map - Google Hybrid	0 20 40 m

Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au



The information contained in this map is intended to be indicative only and makes no claims of accuracy. Kaluta PTY LTD accepts no responsibility for any loss, injury or harm arising from the use of this map or information contained within.	Figure: DTM, contours and drainage Southern section	Client + Job code: NARLU BASELINE MAPPING	Drainage Contours - Middle + Southern DTM Southern Hill shade Base Map - Google Hybrid	0 20 40 m	Kaluta PTY LTD incorporating Osprey Aerial ospreyaerial.com.au
	WGS 84/Pseudo Mercator EPSG 4326	Scale 1:4000			

Summary of results

Property statistics

Table 14: Summary of property statistics

Area type	Total area in Hectares	Percentage of property
All of property	33.985	100%
Northern section	10.279	30.25%
Southern section	23.706	69.75%
Horse paddock	1.512	4.45%
Living area	0.193	0.57%
Laydowns (North to South)	0.033, 0.04, 0.013	0.25%
All laydowns, living areas and horse paddock	1.431	4.21%
Permanent marked tracks	0.461	1.35%
Lookout	0.049	0.14%
Total land currently available for regeneration	30.253	90.1%
Total land not currently available for revegetation	3.732	10.9%

Government mapped vegetation cover vs orthomosaic truthed results

Table 15: Orthomosaic truthed Vegetation Type cover

Vegetation Type	Total coverage on property (Hectares) as per Government data	Percentage of total property as per Government data (Total coverage/33.985) x 100	Total coverage as per orthomosaic-truthed data (Hectares)	Revised percentage of total property
Riparian Vegetation	3.597	10.58%	2.76	8.12%
Weeds (not including pasture	0.3	0.88%	2.38	7.003%

Vegetation Type	Total coverage on property (Hectares) as per Government data	Percentage of total property as per Government data (Total coverage/33.985) x 100	Total coverage as per orthomosaic-truthed data (Hectares)	Revised percentage of total property
grasses)				
Tall Open Forest (N3A)	0.777	2.29%	1.625	4.78%
Tall Open Forest (N3)	0.359	1.06%	0.415	1.22%
Tall Open Forest (N27)	0.038	0.11%	2.018	5.94%
Regrowth	0.105	0.31%	0.813	2.39%
Isolated large remnant trees	N/A	N/A	0.021	0.06%

Table of results – Coverage by species - uppermost layer only

Table 16: Species coverage by uppermost layer

Species	Total area covered by plant type in Hectares	Percentage of total property cover represented by this type (33.985 Ha)	Percentage of property covered by species (minus living areas/sheds, horse paddock) (30.253 Ha)
Senecio madagascarensis	0.932	2.74%	3.08%
Cinnamomum camphora	1.261	3.78%	4.16%
Solanum torvum	<0.01	0.03%	0.03%
Solanum mauritianum	0.028	0.08%	0.09%
Privet	0.148	0.44%	0.48%
Lantana camara	0.001	<0.001%	0.003%
All weeds in total	2.38	7.003%	7.866%
All native cover total	7.652	22.92%	24.99%

KPI Tracking table

Table 17: KPIs as at 27 June 2021

KPI	Percentage of property 27/06/2021 at first survey (minus living areas/sheds, horse paddock)	Next survey	Following survey
Success of exotic plant (weed) control	7.003% (7.866%)		
Successful encroachment of emergent canopy forming species into the open areas	22.92% (24.99%)		
Success of replanting efforts	479 sites total 1 reached canopy count size		

Approximate labour hours

Below is an approximate time frame to re-create aspects of this case study. Higher complexity sites will likely require more time for various tasks, such as CASA area approvals for example.

Table 18: Required time to complete tasks in this Case Study

Item	Time required
Setting up mapping flight	25 minutes
Setting up flight authorisation[1]	15 minutes
Flying mapping flight	4 hours 20
Upload to server[2]	10 hours
Server Processing time[2]	24 hours
Ground truthing Camphor trees	1 hour 20
QGIS	
Unzipping, Importing all orthomosaics to project	35 minutes
Preparing contours	25 minutes
Drawing boundaries and clipping (per layer)	20 minutes
Canopy cover shape drawing	1 hour 45
Fireweed mapping manually via polygons and 3m square samples	90 minutes
Teaching algorithm	45 minutes
Running algorithm classifier[2]	90 minutes per sector in background (approx. 6Ha at 4cm/px GSD or 430MB each)
Raster data filtering to completely isolate items[2]	8 minutes per 6Ha sector
Recombining sectors[2]	15 minutes
Majority Filter	20 minutes
Shapefile layer creation[2]	20 minutes

Item	Time required
Tidying of shapefile layer and incorporation into the “weeds” layer collection by merging	25 minutes
Planting site counts (points with no name tags)	35 minutes
Layer colour formatting (per layer)	15 minutes average
Print layout preparation	15 minutes each
Final steps	
Report writing	10 hours
Atlas of Living Australia data collection and tidying	1 hour 25
File packaging ready for delivery (imagery, text formatting, PDF preparation)	2 hours
[1] *Depending on complexity of site, CASA mandated area approvals at some sites will greatly affect time and expense.* [2] *Process happens in background.*	

Additional Thermal Fauna Surveying

Target Species

In addition to the mapping survey, an opportunity existed to fly a nocturnal thermal survey to potentially locate mammals with the target species including:

Table 19: Thermal survey targeted species.

Common name	Scientific name
Koala	*Phascalarctos cinerus*
Wallaby/Kangaroo species	Macropodidae
Southern Greater Glider	*Petauroides volans*
Rats and mice	Muridae

Flying The Thermal Mission

On the evening of the 13^{th} of June 2021, the thermal survey was flown. This was done in accordance with CASA Instrument 01/17 and included a well-lit take-off/landing area, two independent sources of light and the fitting of a highly visible flashing white strobe to the RPA for increased visibility at distance. VLOS was always maintained with clear conditions.

The ambient temperature varied across the site with the general area of the flight in the southern section of the property being around 5°C.

The RPA used was the new Mavic 2 Enterprise Advanced with a much higher thermal resolution than its predecessor at 640 x 512 px, versus 144 x 144 px.

The site was flown by meander from the take-off point to the remnant tree line, with special attention paid to the canopy for signs of mammals. No arboreal mammals were found, and to maintain line of sight, the RPA was not flown further out over the vegetation, instead following the property boundary. Attention was then turned to the open grassed areas for macropods, and these were almost immediately located.

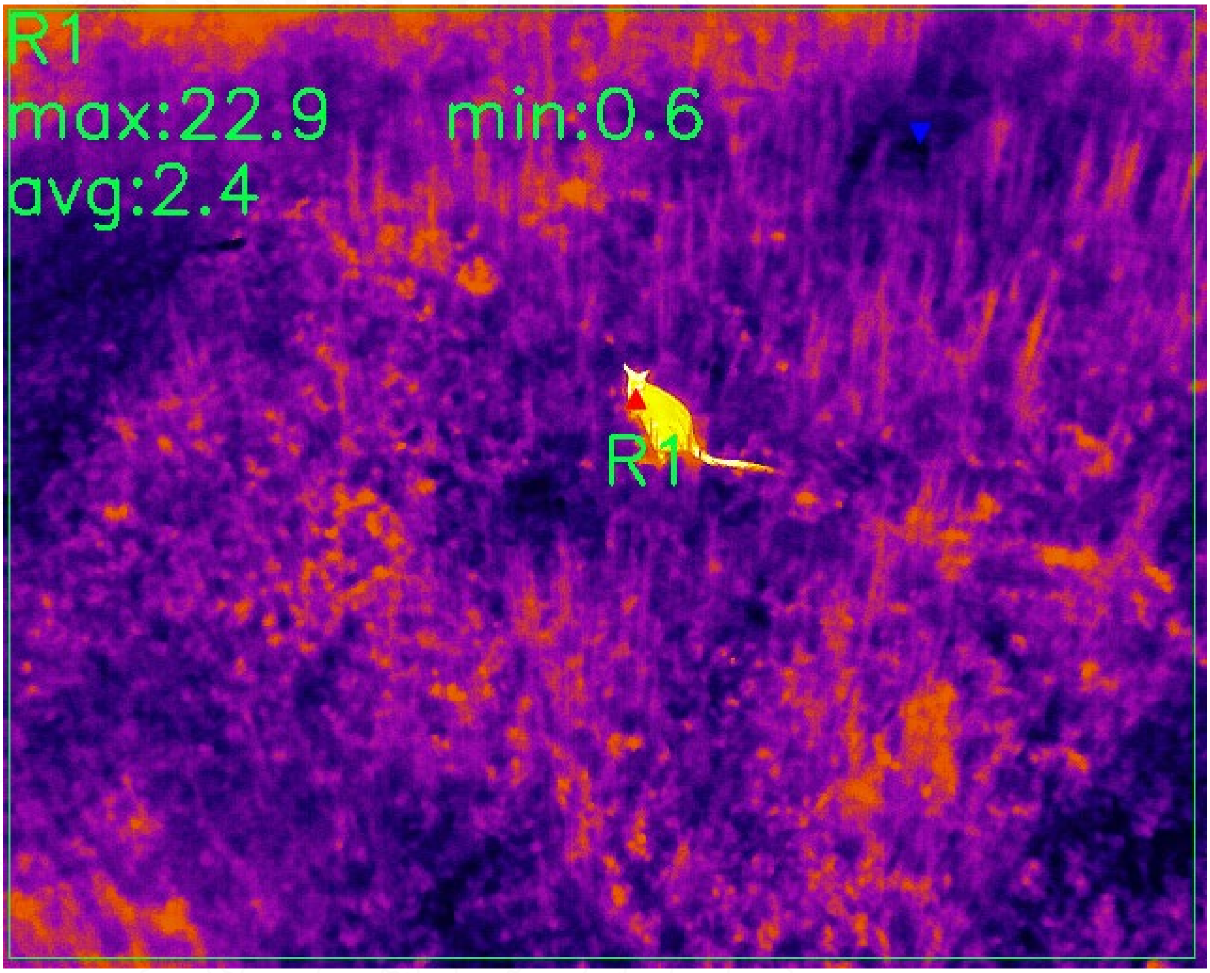
It was noted that these were the size of the quite common red necked wallaby (*Notamacropus rufogriseus*) and were most likely this species. Also, worth noting was the lack of disturbance the RPA caused as they continued feeding, looking up or occasionally moving no more than a few metres and continuing to feed. No panic was evident in their behaviour.

Also noted were small hot spots in the grass that were quickly identified as mice of undetermined species, likely *Mus musculus.* Around 7 were easily located and like the wallabies did not panic despite the RPA at times being within 4m.

Resulting Radiometric Imagery and Analysis

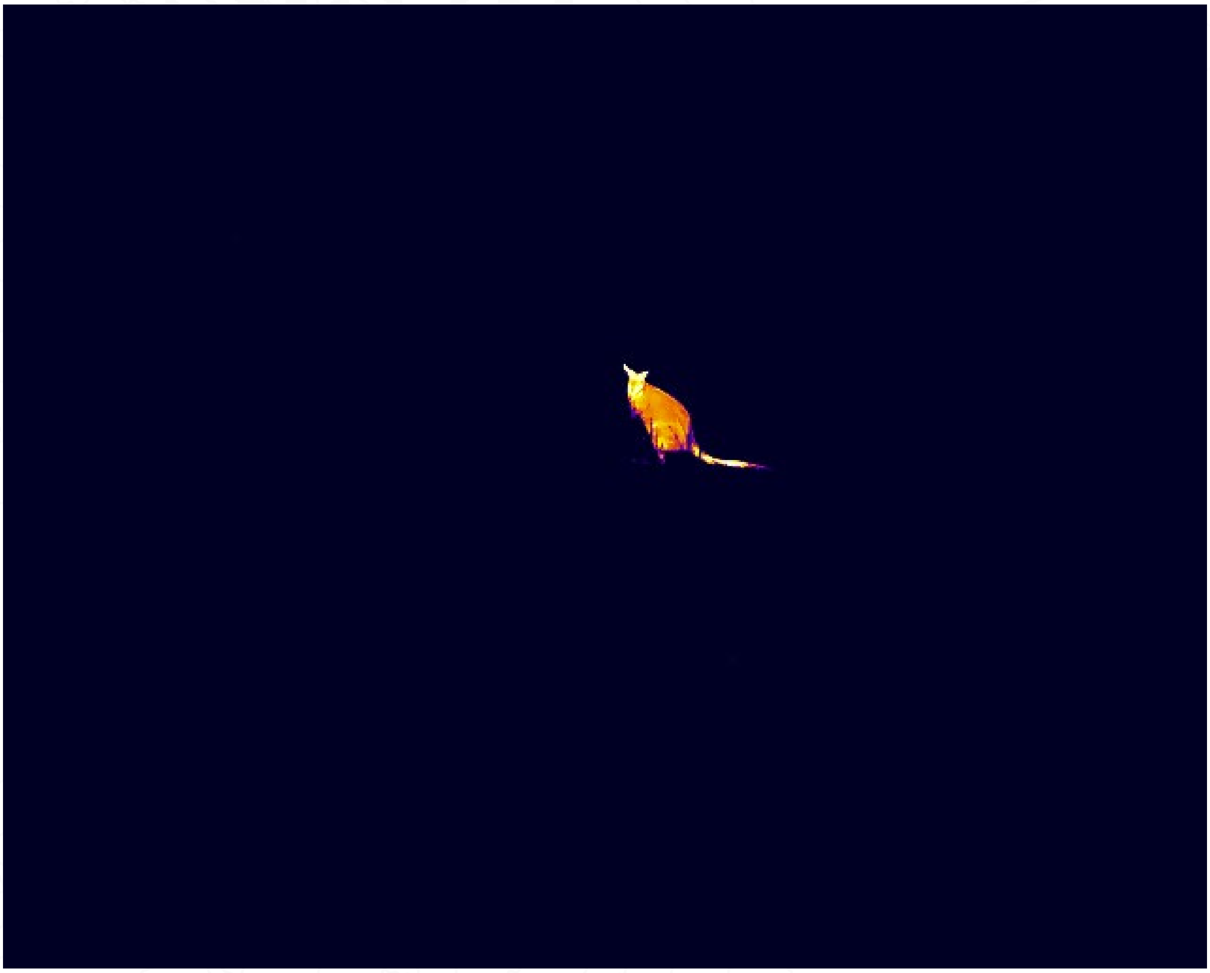
Images were analysed with DJI's desktop Thermal Analysis tool for Windows. Temperatures may be measured using the thermal data stored in the R-JPGs and several tools may be used to make a variety of measurements and comparisons. For the purposes of this survey, the location of fauna was the goal, though measuring the external temperature of the mammals may be helpful in future surveys when isolating narrow temperature ranges or "isotherms" for thermal maps of larger areas. Below are sample images taken of wallabies and a small selection of analysis outcomes:

Photo Plate 13: Radiometric image of a wallaby



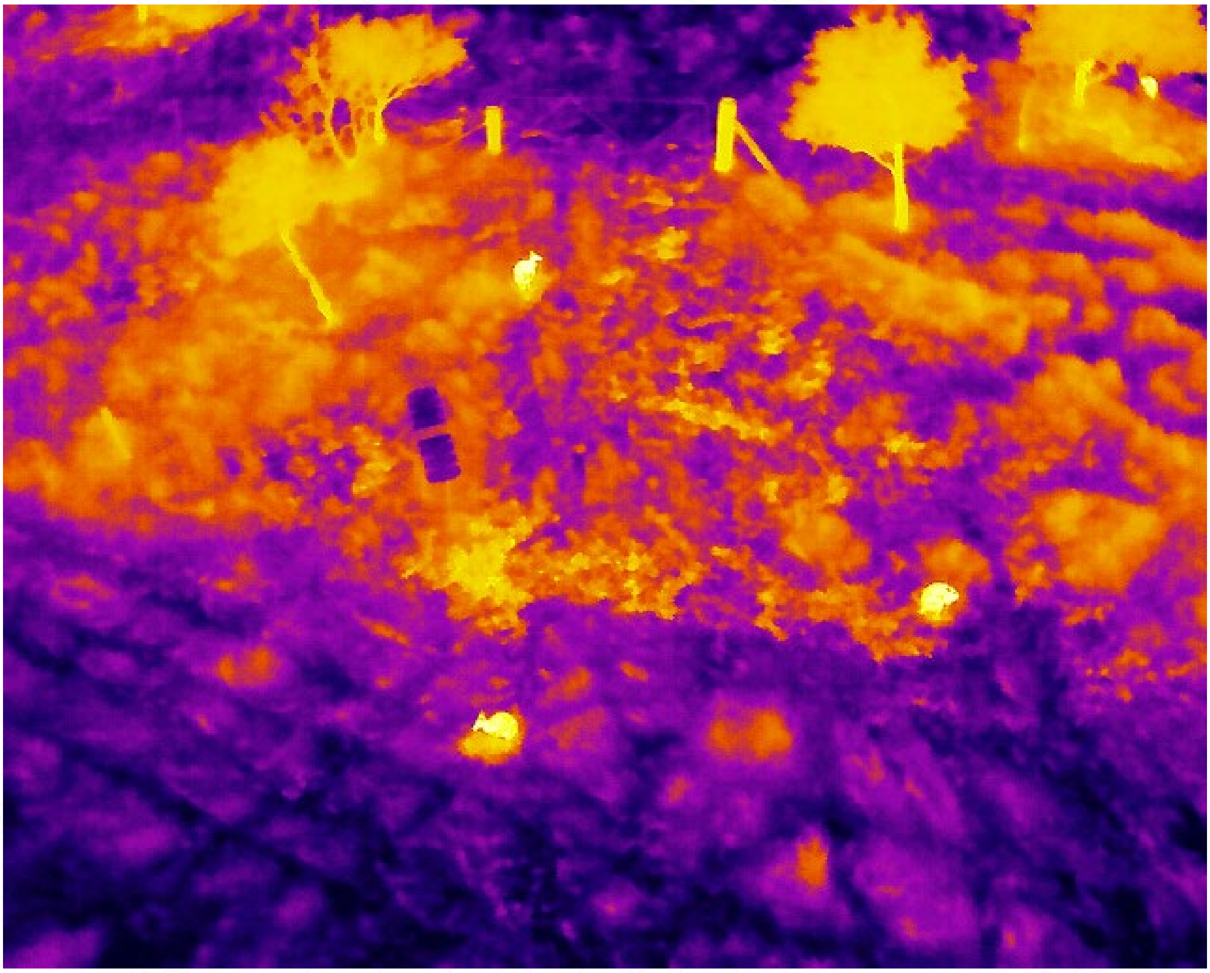
Note in the above image the wallaby is showing well against the grassy field. In the image "R1" denotes the region of analysis bounded by the thin green border. Within this, the maximum temperature was found to be 22.9°C as shown in the top left text and marked with the red triangle on the wallaby. The minimum is shown to be 0.6°C and is marked by the blue triangle in the top right region.

Photo Plate 14: Wallaby isolated from background



The radiometric image above shows the wallaby isolated from the surrounds simply by ignoring any temperature below 10°C in the analysis software. Obviously, this will work best in cold conditions with warm targets.

Photo Plate 15: Four wallabies prior to image processing

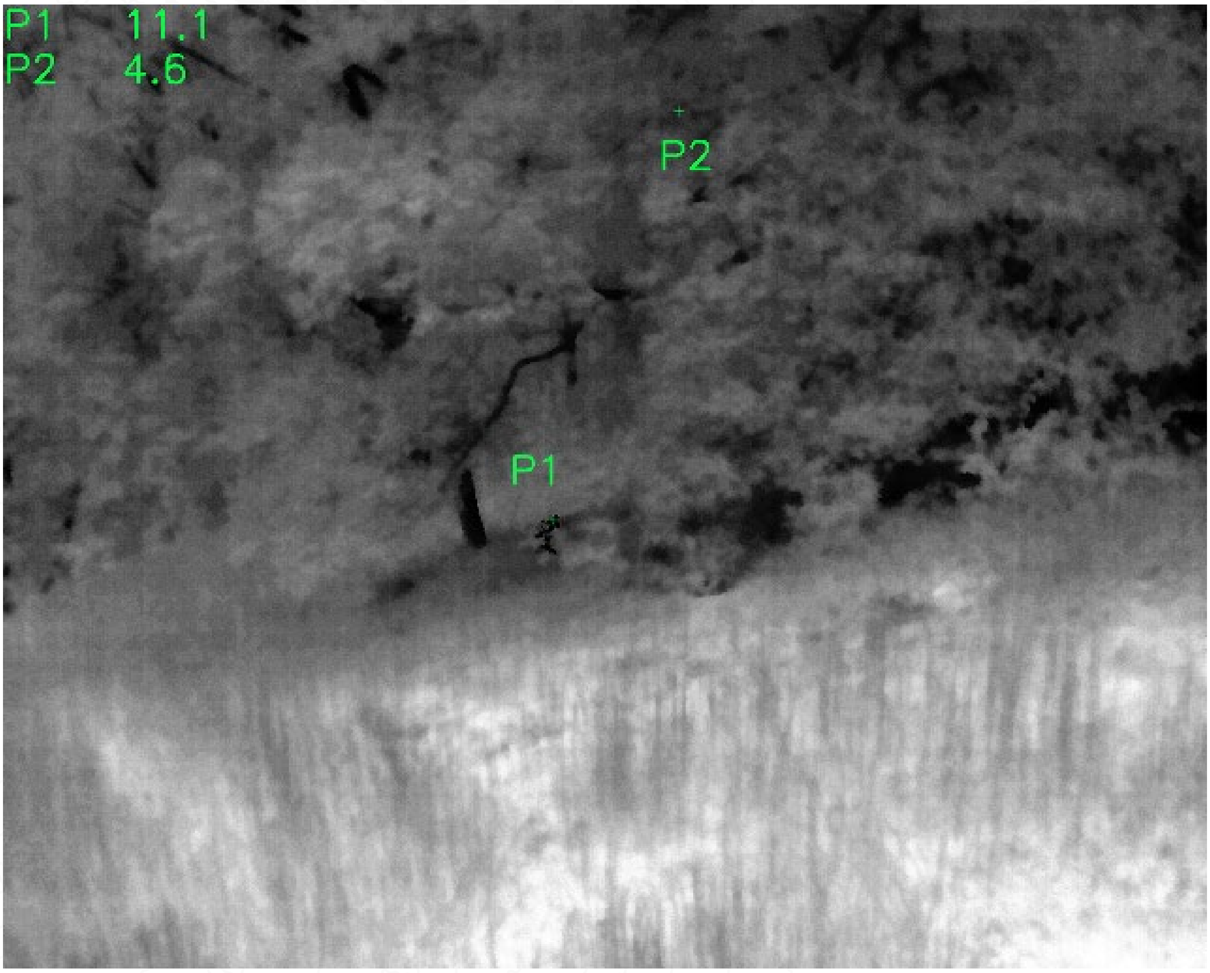


The image above shows four wallabies prior to adjusting the visible temperature range.

Photo Plate 16: Wallabies in processed image

The image above shows the same image after ignoring temperatures below 10°C. In this case, wallabies are extremely easy to count, the individual on the top right may have been overlooked otherwise.

Photo Plate 17: Point data and a hidden wallaby



The above image shows an image set to "black hot" where the hottest portions of the image are black for the purposes of making the text overlays more visible. "P1" is set on a wallaby obscured by vegetation, showing the ability of mammals to hide easily in foliage. The numbers on the top left refer to the temperature of each point.

Strengths and Shortcomings Evident in Thermal Surveys

Although this technique is very promising for locating mammals at night, the following shortcomings and strengths were quickly noted:

Table 20: Strengths and shortcomings in the thermal survey

Strengths	Shortcomings
Mammals were very easily located, down to the size of mice	Mice were only visible when 10m away or less
Despite being close to ambient temperature, trees were easily seen in the camera view and avoided	Resolution is limited to 640 x 512 on any consumer thermal camera
The photographs were recorded in Radiometric (R-JPG) which preserves absolute temperature data in each pixel which allows for many advanced post-processing options	The automated refresh feature causes a short lag in camera output every time it occurs and may be a problem when navigating tight spaces as the feed pauses for around a second without warning

Strengths	Shortcomings
Mammals were more curious than afraid and did not panic or try and escape	Mammals may easily hide behind leaves in trees and become virtually invisible
This form of survey avoids many safety concerns and vastly reduces site disturbance	Some birds such as frogmouths are virtually invisible in thermal cameras if viewed from above or behind
Location data is recorded with the images for ease of plotting on GIS software later	Flights are best performed at night when hot spots from the sun are eliminated, and temperatures are more stable. Pre-dawn is the most suitable

REFERENCES:

Note about references: Few external references were called upon and those that were have been dealt with in detail throughout the text.

GeoScience Australia **GEODATA TOPO 250K Series 3 - (Personal Geodatabase format) downloaded on 21/06/2021 at** https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/63999

Geophysical Archive Data Delivery System “DEM SRTM 1 Second over Australian Bathymetry Topography” accessed 21/06/2021 at https://portal.ga.gov.au/persona/gadds

GeoCortex viewer https://datasets.seed.nsw.gov.au/dataset/svtm-modelling-grid-collection "© State Government of NSW and Department of Planning, Industry and Environment 2014"

Coffs Harbour LGA Vegetation 1996 and 2005. VIS_ID 3910
https://datasets.seed.nsw.gov.au/dataset/coffs-harbour-lga-vegetation-1996-and-2005-vis_id-391016f08 "© State Government of NSW and Department of Planning, Industry and Environment 2012"

NSW Weed Wise **https://weeds.dpi.nsw.gov.au/** State Government of NSW and Department of Planning, Industry and Environment 2021

Appendix 1: Species recorded within 5km of Narlu on Atlas of Living Australia

Common name	Scientific name
Striated Thornbill	*Acanthiza lineata*
Yellow Thornbill	*Acanthiza nana*
Brown Thornbill	*Acanthiza pusilla*
Eastern Spinebill	*Acanthorhynchus tenuirostris*
Collared Sparrowhawk	*Accipiter cirrocephalus*
Common myna	*Acridotheres tristis*
Feathertail Glider	*Acrobates pygmaeus*
Tusked Frog	*Adelotus brevis*
Australian Owlet-nightjar	*Aegotheles cristatus*
Green Catbird	*Ailuroedus crassirostris*
Brush Turkey	*Alectura lathami*
Australian King-parrot	*Alisterus scapularis*
Pacific Black Duck	*Anas superciliosa*
Longfin Eel	*Anguilla reinhardtii*
Blackish Blind Snake	*Anilios nigrescens*
Yellow-footed Antechinus	*Antechinus flavipes*
Brown Antechinus	*Antechinus stuartii*
Little Wattlebird	*Anthochaera chrysoptera*
Australian Pipit	*Anthus novaeseelandiae*
Fork-tailed swift	*Apus pacificus*
Wedge-tailed Eagle	*Aquila audax*
Cattle Egret	*Ardea ibis*
Eastern Great Egret	*Ardea modesta*
Pacific Baza	*Aviceda subcristata*
Brown Tree Snake	*Boiga irregularis*
Sulphur-crested Cockatoo	*Cacatua galerita*
Little Corella	*Cacatua sanguinea*
Fan-tailed Cuckoo	*Cacomantis flabelliformis*
Southern Dwarf Crowned Snake	*Cacophis krefftii*
Golden-crowned Snake	*Cacophis squamulosus*
Yellow-faced Honeyeater	*Caligavis chrysops*
Yellow-tailed Black-cockatoo	*Calyptorhynchus funereus*
Glossy Black-cockatoo	*Calyptorhynchus lathami*
Freshwater shrimp	*Caridina indistincta*
White-eared Monarch	*Carterornis leucotis*
Pheasant Coucal	*Centropus phasianinus*
Red Deer	*Cervus elaphus*
Deer	*Cervus sp*
Azure Kingfisher	*Ceyx azureus*

Common name	Scientific name
Shining Bronze-cuckoo	*Chalcites lucidus*
Emerald Dove	*Chalcophaps indica*
Gould's Wattled Bat	*Chalinolobus gouldii*
Chocolate Wattled Bat	*Chalinolobus morio*
eastern snake-necked turtle	*Chelodina longicollis*
Green Turtle	*Chelonia mydas*
Maned Duck	*Chenonetta jubata*
Cusped yabby	*Cherax cuspidatus*
Silver Gull	*Chroicocephalus novaehollandiae*
Golden-headed Cisticola	*Cisticola exilis*
Grey Shrike-thrush	*Colluricincla harmonica*
Little Shrike-thrush	*Colluricincla megarhyncha*
White-headed Pigeon	*Columba leucomela*
Rock Dove	*Columba livia*
Black-faced cuckoo-shrike	*Coracina novaehollandiae*
Cicadabird	*Coracina tenuirostris*
White-throated Treecreeper	*Cormobates leucophaea*
Australian Raven	*Corvus coronoides*
Torresian Crow	*Corvus orru*
Pied Butcherbird	*Cracticus nigrogularis*
Grey Butcherbird	*Cracticus torquatus*
Common Froglet	*Crinia signifera*
Eastern Small-eyed Snake	*Cryptophis nigrescens*
Kookaburra	*Dacelo novaeguineae*
Varied Sittella	*Daphoenositta chrysoptera*
Eastern Bristlebird	*Dasyornis brachypterus*
Bindjulang	*Dasyurus maculatus*
Common Tree Snake	*Dendrelaphis punctulatus*
Mistletoebird	*Dicaeum hirundinaceum*
Spangled Drongo	*Dicrurus bracteatus*
Emu	*Dromaius novaehollandiae*
White-faced Heron	*Egretta novaehollandiae*
Black-shouldered Kite	*Elanus axillaris*
Murray Turtle	*Emydura macquarii*
Macquarie River Turtle	*Emydura macquarii*
Blue-faced Honeyeater	*Entomyzon cyanotis*
Galah	*Eolophus roseicapilla*
Eastern Yellow Robin	*Eopsaltria australis*
Red Goshawk	*Erythrotriorchis radiatus*
Beach Stone-curlew	*Esacus magnirostris*
Unidentified spiny crayfish	*Euastacus sp*
Pacific Koel	*Eudynamys orientalis*
Eastern Water-skink	*Eulamprus quoyii*

Common name	Scientific name
Eastern broad-billed Roller	*Eurystomus orientalis*
Eastern Shrike-tit	*Falcunculus frontatus*
Crested Shrike-tit	*Falcunculus frontatus*
Inland Galaxias	*Galaxias olidus*
Gambies	*Gambusia holbrooki*
Bar-shouldered Dove	*Geopelia humeralis*
Brown Gerygone	*Gerygone mouki*
Olive Gerygone	*Gerygone olivacea*
Cox Gudgeon	*Gobiomorphus coxii*
Magpie-lark	*Grallina cyanoleuca*
Australian Magpie	*Gymnorhina tibicen*
Australian Pied Oystercatcher	*Haematopus longirostris*
white-bellied sea-eagle	*Haliaeetus leucogaster*
brahminy kite	*Haliastur indus*
White-throated Needletail	*Hirundapus caudacutus*
Welcome Swallow	*Hirundo neoxena*
Stephens' Banded Snake	*Hoplocephalus stephensii*
Empire Gudgeon	*Hypseleotris compressa*
Firetail Gudgeon	*Hypseleotris galii*
Water Dragon	*Intellagama lesueurii*
Northern Brown Bandicoot	*Isoodon macrourus*
Dark-flecked Garden Sunskink	*Lampropholis delicata*
Fletcher's Frog	*Lechriodus fletcheri*
Wonga Pigeon	*Leucosarcia melanoleuca*
Brown-striped Frog	*Limnodynastes peronii*
Barrington Tops Frog	*Litoria barringtonensis*
Green-thighed Frog	*Litoria brevipalmata*
Green Tree Frog	*Litoria caerulea*
Red-eyed Tree Frog	*Litoria chloris*
Bleating Tree Frog	*Litoria dentata*
Eastern Dwarf Tree Frog	*Litoria fallax*
Dainty Green Tree Frog	*Litoria gracilenta*
Gunther's Frog	*Litoria latopalmata*
Lesueur's Frog	*Litoria lesueuri*
Pearson's Frog	*Litoria pearsoniana*
Peron's Tree Frog	*Litoria peronii*
Leaf-green Tree Frog	*Litoria phyllochroa*
Revealed Frog	*Litoria revelata*
Tyler's Tree Frog	*Litoria tyleri*
Verreaux's Frog	*Litoria verreauxii*
Wilcox's Frog	*Litoria wilcoxii*
Topknot Pigeon	*Lopholaimus antarcticus*
Southern Angle-headed Dragon	*Lophosaurus spinipes*

Common name	Scientific name
Clarence River cod	*Maccullochella ikei*
Red necked wallaby	*Macropus rufogriseus*
Brown Cuckoo-dove	*Macropygia phasianella*
Superb Fairy-wren	*Malurus cyaneus*
Variegated Fairy-wren	*Malurus lamberti*
Red-backed Fairy-wren	*Malurus melanocephalus*
Noisy Miner	*Manorina melanocephala*
Doublay's Rainbowfish	*Melanotaenia duboulayi*
Lewin's Honeyeater	*Meliphaga lewinii*
Brown-headed Honeyeater	*Melithreptus brevirostris*
Superb Lyrebird	*Menura novaehollandiae*
Little Pied Cormorant	*Microcarbo melanoleucos*
Jacky Winter	*Microeca fascinans*
Little Bentwing-bat	*Miniopterus australis*
Eastern Bent-winged Bat	*Miniopterus orianae*
Stuttering Frog	*Mixophyes balbus*
Great Barred Frog	*Mixophyes fasciolatus*
Giant Barred Frog	*Mixophyes iteratus*
Black-faced Monarch	*Monarcha melanopsis*
Carpet Python	*Morelia spilota*
Scarlet Honeyeater	*Myzomela sanguinolenta*
Red-browed Finch	*Neochmia temporalis*
Southern Boobook	*Ninox novaeseelandiae*
Powerful Owl	*Ninox strenua*
Red-necked Wallaby	*Notamacropus rufogriseus*
Eastern curlew	*Numenius madagascariensis*
Whimbrel	*Numenius phaeopus*
Eastern Long-eared Bat	*Nyctophilus bifax*
Gould's Long-eared Bat	*Nyctophilus gouldi*
Crested Pigeon	*Ocyphaps lophotes*
Olive-backed Oriole	*Oriolus sagittatus*
Platypus	*Ornithorhynchus anatinus*
Australian Logrunner	*Orthonyx temminckii*
Ride's Free-tailed Bat	*Ozimops ridei*
Golden Whistler	*Pachycephala pectoralis*
Rufous Whistler	*Pachycephala rufiventris*
Eastern Osprey	*Pandion cristatus*
Australian Paratya	*Paratya australiensis*
Spotted Pardalote	*Pardalotus punctatus*
Striated Pardalote	*Pardalotus striatus*
Little Lorikeet	*Parvipsitta pusilla*
House sparrow	*Passer domesticus*
Australian pelican	*Pelecanus conspicillatus*

Common name	Scientific name
Long nosed bandicoot	*Perameles nasuta*
Yellow-bellied Glider	*Petaurus australis*
Sugar Glider	*Petaurus breviceps*
Great Cormorant	*Phalacrocorax carbo*
Little Black Cormorant	*Phalacrocorax sulcirostris*
Brush Bronzewing	*Phaps elegans*
Koala	*Phascolarctos cinereus*
Little Friarbird	*Philemon citreogularis*
Noisy Friarbird	*Philemon corniculatus*
Sphagnum Frog	*Philoria sphagnicola*
Flathead Gudgeon	*Philypnodon grandiceps*
Dwarf Flathead Gudgeon	*Philypnodon macrostomus*
Golden-tipped Bat	*Phoniscus papuensis*
White-cheeked Honeyeater	*Phylidonyris niger*
Broad-tailed Gecko	*Phyllurus platurus*
Noisy Pitta	*Pitta versicolor*
Crimson Rosella	*Platycercus elegans*
Eastern Rosella	*Platycercus eximius*
Tawny Frogmouth	*Podargus strigoides*
Purple Swamphen	*Porphyrio porphyrio*
Red-rumped Parrot	*Psephotus haematonotus*
Red-bellied Black Snake	*Pseudechis porphyriacus*
Common Ringtail Possum	*Pseudocheirus peregrinus*
Pacific Blue Eye	*Pseudomugil signifer*
Red-backed Toadlet	*Pseudophryne coriacea*
Eastern Whipbird	*Psophodes olivaceus*
Black Flying-fox	*Pteropus alecto*
Grey-headed Flying-fox	*Pteropus poliocephalus*
Wompoo Fruit-dove	*Ptilinopus magnificus*
Rose-crowned Fruit-dove	*Ptilinopus regina*
Spotted Bowerbird	*Ptilonorhynchus maculatus*
Satin Bowerbird	*Ptilonorhynchus violaceus*
Red-whiskered Bulbul	*Pycnonotus jocosus*
Bush Rat	*Rattus fuscipes*
Black Rat	*Rattus rattus*
Smelt	*Retropinna semoni*
Ornate rainbowfish	*Rhadinocentrus ornatus*
Eastern Horseshoe-bat	*Rhinolophus megaphyllus*
Grey Fantail	*Rhipidura albiscapa*
Willie Wagtail	*Rhipidura leucophrys*
Rufous Fantail	*Rhipidura rufifrons*
Moritz's leaf tailed gecko	*Saltuarius moritzi*
Southern Leaf-tailed Gecko	*Saltuarius swaini*

Common name	Scientific name
Rose's shadeskink	*Saproscincus rosei*
Eastern Broad-nosed Bat	*Scotorepens orion*
Channel-billed Cuckoo	*Scythrops novaehollandiae*
Yellow-throated Scrubwren	*Sericornis citreogularis*
White-browed Scrubwren	*Sericornis frontalis*
Large-billed Scrubwren	*Sericornis magnirostra*
Regent Bowerbird	*Sericulus chrysocephalus*
Australasian Figbird	*Sphecotheres vieilloti*
Pied Currawong	*Strepera graculina*
Spotted Turtle-dove	*Streptopelia chinensis*
Starling	*Sturnus vulgaris*
Spectacled Monarch	*Symposiachrus trivirgatus*
Short-beaked Echidna	*Tachyglossus aculeatus*
Eel tailed catfish	*Tandanus tandanus*
Cattie	*Tandanus tandanus*
Crested Tern	*Thalasseus bergii*
Australian White Ibis	*Threskiornis moluccus*
Straw-necked Ibis	*Threskiornis spinicollis*
Red-legged Pademelon	*Thylogale stigmatica*
Eastern Blue-tongue	*Tiliqua scincoides*
Forest Kingfisher	*Todiramphus macleayii*
Sacred Kingfisher	*Todiramphus sanctus*
Pale-yellow Robin	*Tregellasia capito*
Scaly-breasted Lorikeet	*Trichoglossus chlorolepidotus*
Rainbow Lorikeet	*Trichoglossus haematodus*
Mountain Brushtail Possum	*Trichosurus caninus*
Common Brushtail Possum	*Trichosurus vulpecula*
Rough-scaled Snake	*Tropidechis carinatus*
Eastern Barn Owl	*Tyto javanica*
Masked Owl	*Tyto novaehollandiae*
Sooty Owl	*Tyto tenebricosa*
Dusky Toadlet	*Uperoleia fusca*
Masked Lapwing	*Vanellus miles*
Lace Monitor	*Varanus varius*
Bandy-bandy	*Vermicella annulata*
Large Forest Bat	*Vespadelus darlingtoni*
Eastern Forest Bat	*Vespadelus pumilus*
Southern Forest Bat	*Vespadelus regulus*
Unidentified forest bat	*Vespadelus sp*
Common Wombat	*Vombatus ursinus*
Fox	*Vulpes vulpes*
Swamp Wallaby	*Wallabia bicolor*
Russet-tailed thrush	*Zoothera heinei*

Common name	Scientific name
Silvereye	*Zosterops lateralis*
Lemon throated scrubwren	*Sericornis citreogularis*

Source: Atlas of Living Australia, accessed 20/06/2021.