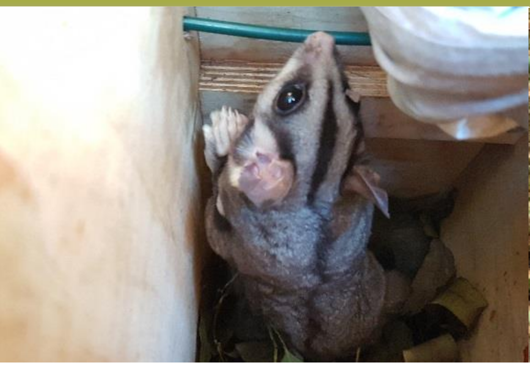
Squirrel Glider Radio Tracking for Post Construction Ecological Monitoring

Devils Pulpit Pacific Highway Upgrade



GeoLINK
environmental management and design

PO Box 119
Lennox Head NSW 2478
T 02 6687 7666

PO Box 1446
Coffs Harbour NSW 2450
T 02 6651 7666

PO Box 1267
Armidale NSW 2350
T 02 6772 0454

PO Box 229
Lismore NSW 2480
T 02 6621 6677

info@geolink.net.au

Prepared for: Transport for NSW

UPR	*Description*	*Date Issued*	*Issued By*
2885-1041	First issue	25/11/2020	David Andrighetto
2885-1059	Second issue	29/04/2021	David Andrighetto
2885-1067	Third issue	27/10/2021	David Andrighetto

Table of Contents

Illustrations

Tables

Plates

Appendices

Executive Summary

Squirrel Glider (*Petaurus norfolcensis*) radio tracking was undertaken at the two vegetated medians at the Devils Pulpit Pacific Highway Upgrade site as part of the post construction monitoring phase of the *Devils Pulpit Upgrade Ecological Monitoring Program* (EMP). The objective of the radio tracking was to determine if Squirrel Gliders are crossing the highway at the vegetated medians.

Nest box inspection and Elliott B trapping was undertaken to capture gliders. Five Squirrel Gliders were collared and radio tracked during July and August 2019. Four of the five gliders crossed the Pacific Highway northbound lane, moving between the vegetation within and west of the medians. A total of 48 crossings were recorded. Crossings were made at both medians by both male and female gliders. No glider movements between the medians and habitat east of the highway across the southbound lane were recorded.

Fifteen den trees were used by the Squirrel Gliders during the radio tracking averaging four den trees per glider (SD: 2.5). One male glider used a den tree in the northern median on most (70 per cent) days, although was mainly active in habitat west of the highway at night. No gliders denned in the nest boxes after the initial capture.

Home range sizes varied from 2.54 to 20.49 ha based on the MPC analysis and 2.52 and 14.09 ha based on the Kernel 95 analysis. The home range of four of the gliders included the respective median and habitat to the west of the highway. Only one glider included a median as part of its core home range.

Review of tree height data and glide performance calculations found that required glide performances to cross the northbound lane within recorded home ranges were within the average glide performance standard deviation range recorded by previous studies.

A chi square test of glider activity results and moon illumination found that gliders were:

- More active during no or low moon illumination periods
- Nocturnal denning more when night conditions were bright, corresponding with periods when the moon was present during the first quarter - full - last quarter half of the moon phase.

The radio tracking results demonstrate that both male and female Squirrel Gliders were able to cross the northbound lane of the Pacific Highway at both medians at the Devils Pulpit site under no night traffic conditions. No crossings of the southbound lane were recorded, therefore the maintenance of Squirrel Glider movement across this newly constructed carriageway has not been demonstrated.

The results do not rule out the potential for traffic related behavioural barriers at the site. Previous studies and the results from other Devils Pulpit post construction monitoring activities however suggests that traffic may not be a factor impacting glider movement across the highway at the site.

Overall, based on the clearing widths at the time of the radio tracking and records of gliders crossing high traffic volume roads; it is expected that Squirrel Gliders could cross both the northbound and southbound lanes of the Pacific Highway at the vegetated medians when both lanes are open to traffic. Several recommendations are provided for Transport for NSW consideration.

1. Introduction

1.1 Background

1.1.1 Introduction

The Devils Pulpit Pacific Highway upgrade (the project) comprises a 7.3 kilometre section of the Pacific Highway at Devils Pulpit, between Grafton and Ballina on the NSW north coast (refer to **Illustration 1.1**). The project involved widening the Pacific Highway from a single two-way carriageway to a four-lane dual carriageway and was completed in March 2014.

The *Devils Pulpit Upgrade Ecological Monitoring Program* (EMP - Hyder 2012) was prepared to address the ecological monitoring consent conditions for the project. The broad objective of the EMP is to monitor the effectiveness of the mitigation measures identified in the Biodiversity Offset Strategy for threatened species directly impacted by the project. GeoLINK is engaged by Transport for NSW (formerly Roads and Maritime Services) to implement the post construction terrestrial species monitoring component of the EMP. Year 3 and 4 post construction monitoring have been completed to date (GeoLINK 2018; 2019a), with the Year 6 post construction monitoring scheduled to finish in early 2021.

Section 7 Monitoring Crossing Structures of the EMP includes monitoring of the vegetated medians. An overview of this 'mitigation measure' and corresponding monitoring objectives as outlined in the EMP are provided in **Table 1.1**. The program includes a range of fauna monitoring techniques including hair tube, spotlighting and nest box monitoring methods, as well as provisional Squirrel Glider (*Petaurus norfolcensis*) radio tracking.

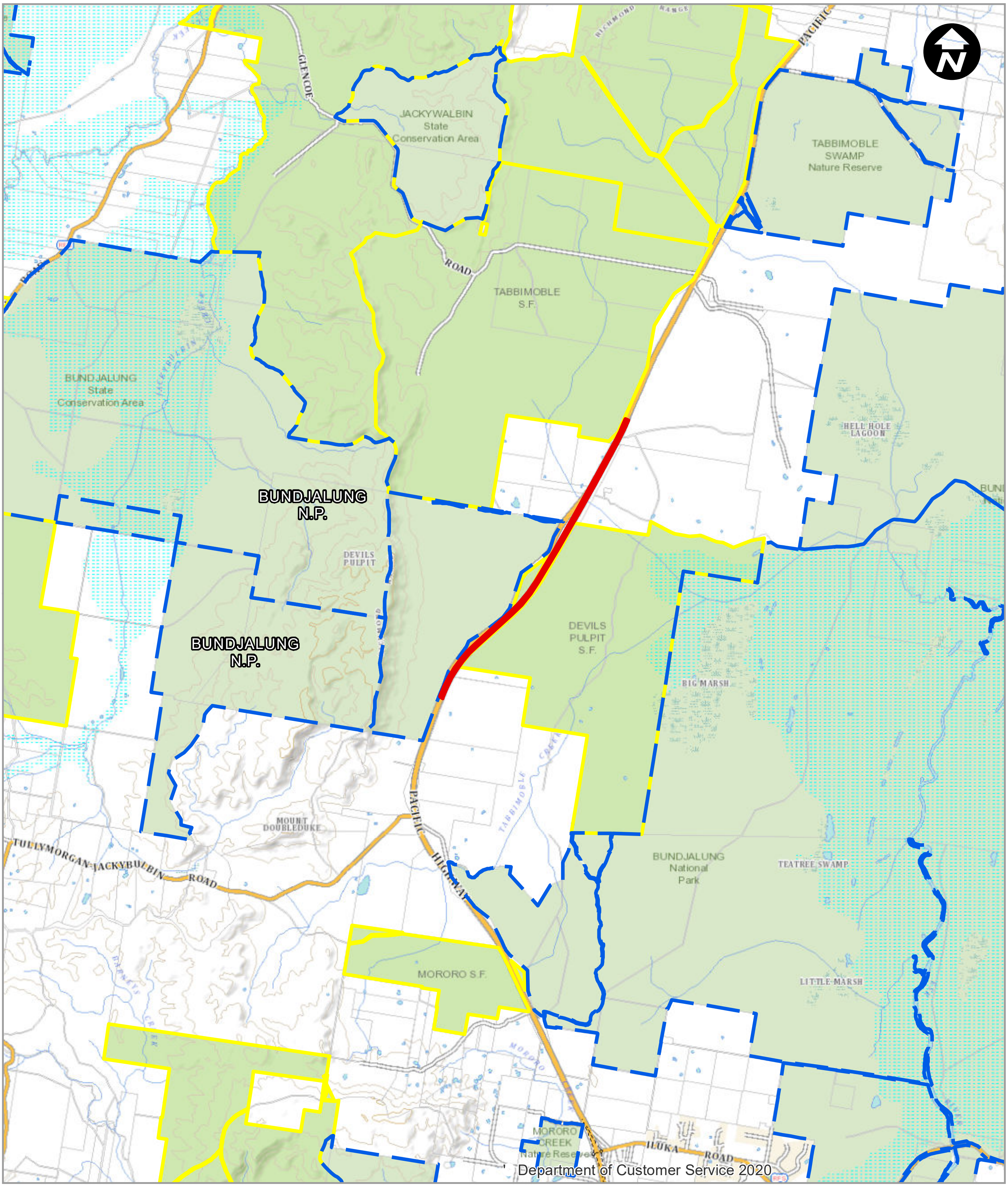
The provisional radio tracking was triggered during the Year 3 post construction monitoring by the detection of Squirrel Gliders in both vegetated medians associated with the project (GeoLINK 2018). The specific radio tracking requirements of the EMP state:

> *'**Radio-tracking.** Captured gliders will be weighed, sexed and assigned to age classes based on tooth condition, ventral fur colour and breeding status and fitted with a radio transmitter. A telemetry receiver will be used to located these gliders and will be radio tracked at least one night a week for the following 4 weeks. Individual will aim to be located between 2 and 4 times a night and at least once each day. Once located, a GPS recording will be made, the tree/shrub it is located in and behaviour will be recorded. Tagged individuals will be trapped and transmitters removed at the end of the monitoring period.'*

This report documents the results of the Squirrel Glider radio tracking undertaken for the project. The specific objective of the radio tracking is to determine if Squirrel Gliders are crossing the highway at the vegetated medians. The results will be incorporated into the final (Year 6) post construction monitoring report to determine the overall monitoring findings against the EMP performance measures.

Table 1.1 EMP Vegetated Median Monitoring Objectives – Hyder 2011

Mitigation Measure	*Objective*	*Target Species*	*Features Being Monitoring*
Vegetated medians	▪ Maintain fauna movements and habitat connectivity for arboreal mammals. ▪ Reduce gap crossing distance for gliding mammals. ▪ Reduce road kill.	▪ Greater Glider ▪ Sugar Glider ▪ Squirrel Glider ▪ Yellow-bellied Glider	▪ Two vegetated medians at chainage 66.300- 67.800 and 69.300- 70.700. ▪ Gliders will be able to use vegetated median to move between Devils Pulpit State Forest and Bundjalung National Park due to short glide distances. ▪ Supports Dry Sclerophyll Forest and Floodplain Forest vegetation communities.



LEGEND

- The project
- National park reserve
- State forest

GDA 1994 MGA Zone 56

0 2 Km

Site Locality - Illustration 1.1

GeoLINK environmental management and design

Squirrel Glider Radio Tracking for Post Construction Ecological Monitoring
2885-1042

Information shown is for illustrative purposes only
Drawn by: AB Checked by: RE Reviewed by: DSA
Source of base data: DFSI
Date: 12/08/2020

1.1.2 Vegetated Medians

The project encompasses two vegetated medians that are monitored as part of the EMP. Locations of the medians are shown in **Illustration 1.2**. A description of each median is provided in **Table 1.2**. As detailed in GeoLINK (2018), the southern median corresponds with monitoring Impact Site 2, while the northern median corresponds with monitoring Impact Site 4. The northbound lane at both medians comprises the original two lane highway alignment which has now been upgraded. The southbound lane was cleared and constructed during the project.

Tree height data of potential glide trees on both sides of the northbound and southbound lanes at the subject medians has been collected as part of previous glider crossing assessments (GeoLINK 2019b; 2012a) and are included in **Table 1.2** and **Table 1.3**. This data is relevant to conditions at the time of the radio tracking, prior to post fire hazardous tree removal in December 2019 and additional clearing and tree removal associated with the Woolgoolga to Ballina Pacific Highway upgrade (W2B) in early 2020. The information in **Table 1.3** was obtained as part of the *W2B Devils Pulpit Widened Median Glider Crossing Ability Assessment* (GeoLINK 2019b) and provides recent tree height and glide distance data at:

- Impact Site 2 (median): the entire northbound lane.
- Impact Site 4 (median):
  - The entire northbound lane
  - The southbound lane between chainage 69,770 and 70,970 only. The clearing width from Devils Pulpit construction elsewhere along the southbound lane was approximately 50 m or greater.

During data collection, the northbound lane at each median was divided into 100 m chainage zones. A minimum of one potential glide/launch tree was identified for each chainage zone. At the southbound lane between chainage 69,770 and 70,970 (corresponding with W2B chainages 108800 and 109000), all potential glide/launch trees were identified. Potential glide/launch trees were characterised as trees >20 cm diameter at breast height (DBH) opposite a potential landing tree on the other side of the respective lane (DBH >20 cm), where the distance to a potential landing tree was ≤50 m. Attribute data for each potential glide/launch tree was recorded and included survey location, species, DBH, tree height, ground height at base of tree, road height at base of tree and distance to closest landing tree.

The southbound lane at Impact Site 2 (median) was not included as part of the GeoLINK (2019b) assessment as impacts from W2B clearing in this area were minimal. Tree height and clearing width data was previous obtained as part of the *Devils Pulpit Pacific Highway Class A Upgrade – Rope Bridge Assessments for Target Glider Species at the Northern and Southern Vegetated Medians/ Glider Crossings* (GeoLINK 2012a) for 100 m chainage zones. Average recorded tree height, distance of trees to the clearing edge and clearing width data from this assessment is provided in **Table 1.4**. During data collection, tree height and the distance of trees to the clearing edge was recorded via field survey, while clearing width data was recorded by GIS analysis.

It should be noted that regrowth acacia trees up to 12.5 m tall and 0.1 m DBH are common within the previously cleared Devils Pulpit clearing limits along the southbound lane. The narrow DBH causes this vegetation not to satisfy the criteria of launch or landing trees in the GeoLINK (2019b) assessment. Glider use of the acacia regrowth reduces the required glide distance, however gliders using this vegetation to cross the highway may be vulnerable to vehicle strike.

Note: Unanticipated post fire hazardous tree clearing in December 2019 and additional clearing as part of the W2B project along the northbound lane in early 2020 impacted potential glider launch/landing trees at both medians. Therefore the conditions monitored as part of the radio tracking are different to current site conditions.

At the time of the radio tracking, the northbound lane at both medians was closed to traffic, and subject to construction works (drainage, pavement, minor realignment and fencing) during daylight hours. Northbound traffic was diverted to the southbound lane which supported two lanes with two-way traffic. The batch plant and construction access gate at Impact Site 4 (median) was operational as part of W2B construction. The distance between vegetation on opposite sides of the highway in areas within a vegetated median at Devils Pulpit ranged between approximately 55 m and 90 m.

Table 1.2 Vegetated Median Description

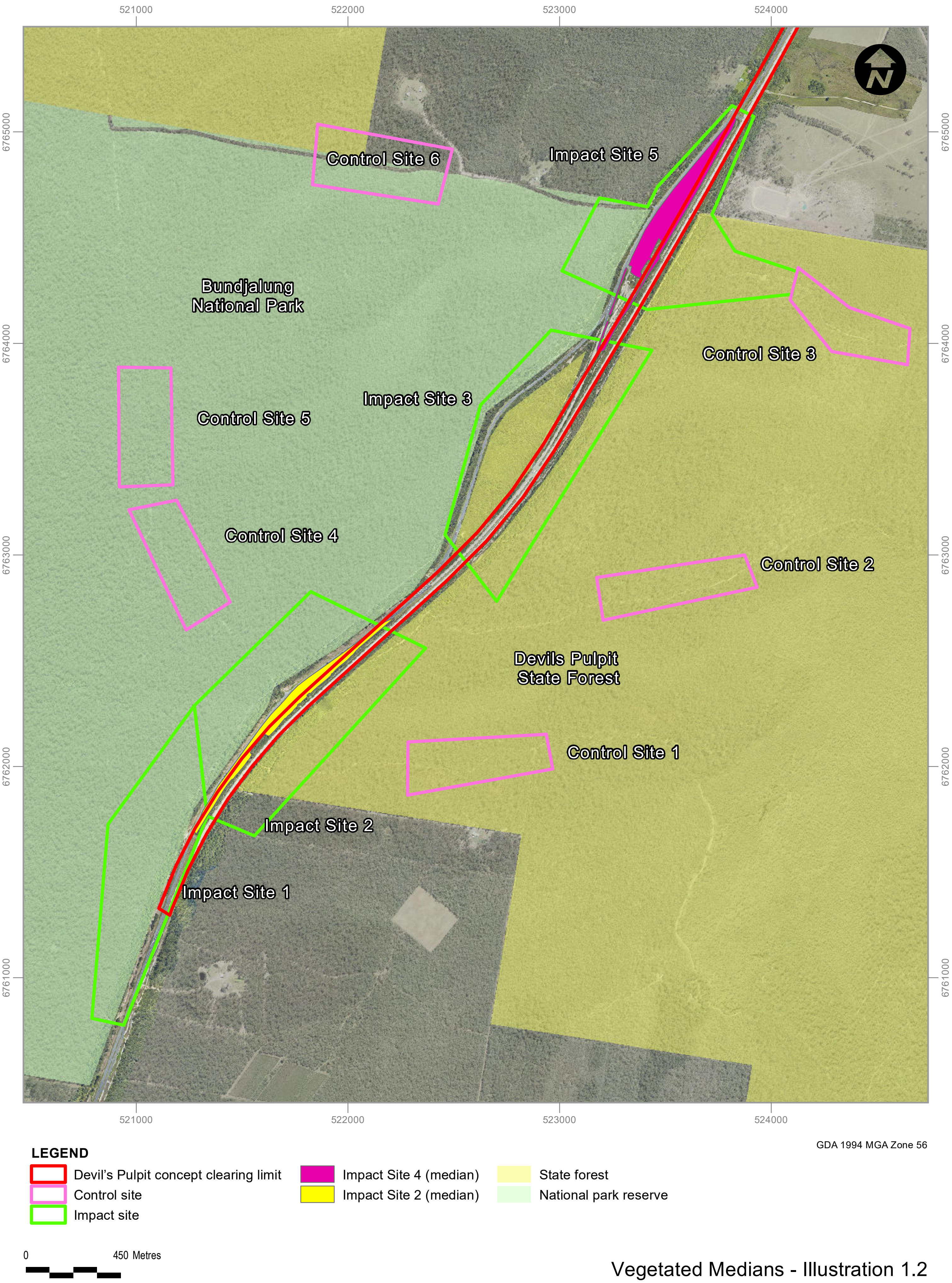
Site	Chainage	Length (km)	Width (m)	Area of Vegetation (ha)	Vegetation Form and Class (Hyder 2011)	Comment
Impact Site 2 (median)	66.300-67.800	1.4	15-65	5.58	■ Dry Open Sclerophyll Forest (shrubby sub formation): – Spotted Gum Dry Sclerophyll Forest – Blackbutt Dry Sclerophyll Forest. ■ Grassy Woodlands: – Forest Red Gum Floodplain Forest.	Southern median.
Impact Site 4 (median)	69.300-70.700	1.3	15-115	7.80	■ Dry Open Sclerophyll Forest (shrubby sub formation): – Blackbutt Dry Sclerophyll Forest. – Scribbly Gum Dry Sclerophyll Forest. ■ Grassy Woodlands: – Eastern Red Gum Floodplain Forest.	Northern median. Encompasses ancillary facility site used during Devils Pulpit and W2B construction.

Table 1.3 Potential Glide Tree Data: Impact Site 2 (northbound lane) and Impact Site 4 (both lanes) (Source: GeoLINK 2019b)

Site	***Average Tree Height (m)***			***Average Distance to Landing Tree (m)***	
	No. Trees Assessed	**West**	***East***	**West**	***East***
Impact Site 2 (median) – Northbound Lane	West: 11 East: 11	32.3 (SD: 4.46)	32.3 (SD: 4.41)	43.1 (SD: 4.88)	43.4 (SD: 4.94)
Impact Site 4 (median) – Northbound Lane	West: 12 East: 12	24.7 (SD: 5.25)	25.1 (SD: 4.95)	37.1 (SD: 3.41)	37.2 (SD: 3.43)
Impact Site 4 (median) – Southbound Lane Chainage 108800 to 109000	West: 12 East: 12	23.4 (SD: 4.24)	22.8 (SD: 3.20)	42 (SD: 6.56)	45.6 (SD: 5.75)

Table 1.4 Impact Site 2 Southbound Lane Potential Glide Tree Data (GeoLINK 2012a)

Location	**No. Trees Assessed**	***Average Largest Tree Height (m)***	***Average Distance of Trees to Clearing Edge***	**Average Clearing Width**
East	9	26.7 (SD: 2.40)	3.6 (SD: 2.53)	40.3 (SD: 4.37)
West	9	30.6 (SD: 3.00)	4.5 (SD: 3.07)	40.3 (SD: 4.37)



Vegetated Medians - Illustration 1.2

GeoLINK environmental management and design

Squirrel Glider Radio Tracking for Post Construction Ecological Monitoring
2885-1046

Information shown is for illustrative purposes only
Drawn by: AB Checked by: RE Reviewed by: DSA
Source of base data: RMS
Date: 12/08/2020

2. Methodology

2.1 Radio Tracking

Radio tracking was undertaken in winter 2019 and comprised three distinct components:

- Initial Squirrel Glider capture and collaring via nest box inspection and Elliott B trapping.
- Radio tracking.
- Squirrel Glider recapture (Elliott B trapping), assessment and collar removal.

The specific methodology for each component is detailed below. A summary of survey dates and effort is provided in **Table 2.1**.

Table 2.1 Summary of Survey Effort

Survey Component	Location	Commencement Date	Completion Date	Total Survey Effort
Initial Squirrel Glider Capture				
Nest box inspection	Impact Site 2 (east, median, west)	3/07/2019	3/07/2019	18 nest boxes inspected
	Impact Site 4 (east, median, west)	2/07/2019	3/07/2019	17 nest boxes inspected (8 nest boxes inspected twice)
Elliott B trapping	Impact Site 2 (east, median, west)	8/07/2019	11/07/2019	10 arboreal Elliott B traps set for 3 nights: 30 trap nights
	Impact Site 4 (east, median, west)	8/07/2019	11/07/2019	10 arboreal Elliott B traps set for 3 nights: 30 trap nights
Radio Tracking				
Radio tracking	Impact Site 2 and Impact Site 4	2/07/2019	27/08/2019	Diurnal den fixes:89 Nocturnal fixes: 287 Total days that fixes were collected: 28
Squirrel Glider Recapture				
Elliott B Trapping	Impact Site 2 and Impact Site 4	5/08/2019	28/08/2019	10-40 arboreal Elliott B (varying configurations): 417 trap nights

2.1.1 Initial Squirrel Glider Capture

Initial Squirrel Glider capture was under using nest box inspection and Elliott B trapping. The 35 Squirrel Glider nest boxes (Hollow Log Home – rear entry timber design) associated with Impact Site 2 and Impact Site 4 were inspected by a tree climber under ecologist direction. The entrance to the nest boxes were blocked prior to opening and inspecting the boxes. **Table 2.2** details the nest box configuration at the relevant sites. Further details on the nest box locations and installation dates are provided in GeoLINK (2018).

Ten Squirrel Gliders were recorded during the nest box inspection (four from Impact Site 2 and six from Impact Site 4). Two adult males and two adult females were fitted with 5.9 g brass loop single stage radio collars (Sirtrack model V1C 116B, Havelock North, New Zealand). The collared gliders were captured from:

- Impact Site 2 (west): One male (referred to as M9) and one female (referred to as F7) captured from the same nest box (Impact Site 2 West Nest Box 6).
- Impact Site 4 (west): One male (referred to as M5) and one female (referred to as F6) captured from the same nest box (Impact Site 4 West Nest Box 5).

The other six gliders were not collared, as five gliders dispersed when establishing climbing ropes during nest box inspection and the other captured glider was a sub-adult and not suitable for collaring. Eight nest boxes from which gliders had escaped or had fresh nesting material (indicated by bright green leaves) were accessed a second time the day after the first inspection but no gliders were present.

Supplementary arboreal Elliott B trapping was undertaken in an attempt to capture and collar more gliders. Specifically, 20 Elliott B traps were set on platforms three metres above the ground along two transects with ten traps each at Impact Site 2 (east) and Impact Site 4 (east). The transects ran parallel to the highway, with the traps set approximately 30-60 m from the road edge and 40-50 m apart. Traps were baited with a rolled oats, peanut butter, honey and apple mix. Trap trees were sprayed with a honey, vanilla essence and water solution as an attractant. The traps were set for three nights (60 trap nights in total) and checked each morning. An additional adult female Squirrel Glider (referred to as F4) was captured and collared from Impact Site 4 (east).

In total five adult Squirrel Gliders were collared. Attribute data of the collared gliders is provided in **Table 2.3**. A photograph of a Squirrel Glider with a fitted radio collar is provided in **Plate 2.1**.

Table 2.2 Inspected Nest Boxes

Site	*No. of Nest Boxes*
Impact Site 2 (east)	6
Impact Site 2 (median)	6
Impact Site 2 (west)	6
Total Impact Site 2	**18**
Impact Site 4 (east)	6
Impact Site 4 (median)	5
Impact Site 4 (west)	6
Total Impact Site 4	**17**
Total (all sites)	**35**

Table 2.3 Attribute Data of Collared Squirrel Gliders

Ref. No.	Sex	Age	Weight (g)	Ventral Fur Colour	Breeding Status	Capture Site	Date Collared
F4	Female	2-3 years	170	Cream	Previously breed. No dependant young present.	Impact Site 4 (east)	9/07/2019
M5	Male	Adult >3 years	231	Yellow	Adult over >3 years	Impact Site 4 (west)	2/07/2019
F6	Female	>2 years	170	Cream	Previously breed. No dependant young present.	Impact Site 4 (west)	2/07/2019
F7	Female	1-2 years	200	Cream	Previously breed. No dependant young present.	Impact Site 2 (west)	3/07/2019
M9	Male	>2 years	195	Yellow	Adult	Impact Site 2 (west)	3/07/2019

Plate 2.1 Female Squirrel Glider (F6) with radio collar fitted

2.1.2 Radio Tracking

2.1.2.1 Radio tracking Protocols

Previous experience with radio tracking Squirrel Gliders had shown that they or their group members chewed off whip (flexible external antennae) antennas, preventing the signal from being transmitted (D. Sharpe personal observations). As GPS collars require a whip antenna, it was not possible to use this approach due to the risk of damage and non-acquisition of data. Therefore, tuned loop single stage VHF transmitters were used. The receiver comprised a yagi three-element directional antennae and Sirtrack Ultra 148-156MHz radio receiver.

Radio tracking was conducted over a five-week period commencing in early July 2019. Radio tracking was conducted on foot four to five times per week during the core study period with additional radio tracking undertaken one to two times per week over the four week glider recapture period. A diurnal den fix was obtained each day. Nightly radio tracking procedures began at dusk after den watches or transmitter signal had shown that gliders were active, terminating between 8:30 pm and 1:00 am (typically 10:30 pm). Generally, three to six location fixes were obtained for each individual per 24 hours. The order of glider tracking was changed each night to avoid systematic bias. The minimum time period between location fixes of each glider was 30 minutes to ensure independence of location fixes (see Sharpe and Goldingay 2007 and Goldingay et al. 2010). On occasions, a shorter period between location fixes was recorded when gliders were actively moving in proximity to the highway edge to capture potential road crossings. Location fixes with less than 30 minutes separation were not used in the home range analysis.

The tree each glider occupied was identified by visually sighting the individual or by circling the tree with the receiver on to pin point the location of the individual. Location data were captured using the ESRI Collector app. This allowed the current location to be viewed on an aerial image. A data entry form captured the location and date and time of each fix. The form also allowed the glider to be individually identified and their behaviour documented if they were visually located and active (e.g. gliding, climbing, nectar feeding). The species, height, DBH and presence and/or number of flowers of each occupied tree was also recorded. Additional comments could also be entered if required (e.g. another glider present). As locations accumulated, Collector enabled real-time viewing of each individual's movement area. Collector operated as a stand-alone application while in the field. Data was synchronised back to the server at the completion of each night's radio tracking. This provided back-up for data and allowed multiple personnel to interact with the database.

2.1.2.1 Glider Movement Analysis

Location data from radio tracking, nest box capture and Elliott B trapping was used to identify potential glider movements across the highway or into the median. ESRI ArcGIS and Microsoft Excel were used during the analysis.

2.1.2.2 Home Range Analysis

Location data from radio tracking, nest box capture and Elliott B trapping were analysed using the Minimum Convex Polygon (MCP) and Fixed Kernel (FK) home range estimators. The FK is generally regarded as the most robust estimator (Worton 1989; Seaman and Powell 1996), while the MCP has been widely used over a long period of time (Mohr 1947), enabling comparisons to other studies. For the MCP, only the 100 per cent home range boundary was estimated. The FK enables various activity contours to be estimated. The 95 per cent boundary is typically used to estimate the home range boundary, while the 50 per cent contour defines the home range core (area of concentrated activity) (e.g. Sharpe and Goldingay 2007).

2.1.2.3 Moon Influence Analysis

To determine whether the moon phase was influencing nocturnal glider behaviour (i.e. whether gliders were active or denning), an analysis with the nocturnal radio tracking results was undertaken using moon rise and set times, and percent illumination information obtained from timeanddate.com for Lismore NSW. Nocturnal fixes were categorised into 'active' or 'denning' based on each individual gliders activity at the time of each fix. Moon illumination (i.e. the percentage of visible moon illuminated) at the time of each fix was identified and defined based on two categories: ≤50 per cent and 51-100 per cent. Moon illumination was nominated as ≤50 per cent where radio tracking fix times were one hour after moonrise and one hour before moon set, or where no moon was present. Location fixes of less than 30 minutes were not used. Nocturnal den fixes from 30 July 2020 were also not included unless that individual had previously been observed as active that night due to a hailstorm that occurred shortly before dusk. A chi square test was performed using the number of active (location fixes) and non-active (nocturnal den fixes) to test for associations between glider activity and the moon illumination categories.

2.1.3 Squirrel Glider Retrieval

Retrieval of collared gliders was undertaken using Elliott B trapping. Nest box inspection was not undertaken as no gliders returned to the nest boxes to den during the entire two month radio tracking and glider retrieval period (this is discussed further in **Sections 3** and **4**). Between 20 and 40 Elliott B traps were used and set on grids located within the core of identified home ranges, adjacent to occupied den trees, or within key observed foraging areas. The trap configuration changed progressively as gliders were captured. Traps were set three metres above the ground and baited as per the initial capture trapping (refer to **Section 2.1.1**). Four hundred and seventeen Elliott B trap nights were undertaken to recapture the five collared gliders.

2.1.4 Timing

The EMP schedules radio tracking in spring/summer of post construction Year 4. The timing was rescheduled to winter of post construction Year 5 for the following reasons:

- Avoid conflicts with W2B clearing and provide a post clearing adjustment period for gliders whose home range were impacted by the W2B main line clearing; and
- Target the period when the highest Squirrel Glider nest box occupation rates had been recorded (i.e. winter 2019a) to maximise animal capture.

This was endorsed by RMS and NSW Environmental Protection Agency (EPA – Peter Higgs – Senior Threatened Species Officer; email correspondence dated 20 December 2018).

2.1.5 Weather Condition

Weather conditions and moon phase during the radio tracking are provided in **Appendix A**. Weather conditions were mostly dry, though moderate rainfall events occurred in early July and early August. The Yamba Pilot Station (located approximately 20 km south-east of the site) recorded a combined mean high temperature of 21.5^{o}C and a mean low of 11.1^{o}C for July and August 2019. Below average rainfall had been recorded during the nine months preceding the radio tracking. July 2019 also received below average rainfall and August rainfall was slightly above average (BoM 2019). Two full moons occurred during the radio tracking period, creating bright nocturnal conditions over the corresponding week.

3. Results

3.1 Results

3.1.1 Location and Road Crossing Results

The results of the radio tracking are provided in **Table 3.1, Table 3.2, Table 3.3** and **Table 3.4**. All recorded glider locations are displayed in **Illustration 3.1**.

Three hundred and seventy-six location fixes were recorded during the radio tracking, including 89 diurnal (mean 17.8 per glider) and 287 nocturnal fixes (mean 57.4 per glider). Glider F6 died 13 days after being collared due to predation (suspected forest owl foraging), therefore limited data was collected for this animal.

Table 3.1 Radio Tracking Results Overview

Glider	Sex	Site	Diurnal Den Fixes	Nocturnal Den	Nocturnal Active	Nocturnal Total	Total Fixes	Fixes used in HR Analysis	Additional Locations Points*
F4	F	Impact Site 4	18	19	40	59	77	69	2
M5	M	Impact Site 4	23	20	48	68	91	77	2
F6	F	Impact Site 4	8	0	20	20	28	27	2
F7	F	Impact Site 2	21	18	55	73	94	72	2
M9	M	Impact Site 2	20	14	52	66	86	70	2
TOTAL	-	-	90	71	215	286	376	315	10

** includes capture and recapture locations (nest box or Elliott B trapping), including recorded mortality location for F6*

Four for the five gliders (M5, F6, F7 and M9) were recorded west of the highway and within the median at the respective site (refer to **Table 3.2**). F4 was only recorded east of the highway. No gliders were recorded on both sides of the highway. M5 was the only glider recorded denning within a median.

Table 3.2 Summary of Glider Locations Relative To Highway

Squirrel Glider	Diurnal Den Fix and Capture*				Nocturnal Fix				
	East	Median	West	Total	East	Median	West	West^	Total
F4	20	0	0	20	59	0	0	0	59
M5	0	17	8	25	0	25	43	0	68
F6	0	0	10	10	0	1	15	4	20
F7	0	0	23	23	0	13	60	0	73
M9	0	0	22	22	0	3	63	0	66
Total	20	17	63	100	59	43	181	4	286

** includes capture and recapture locations (nest box or Elliott B trapping), including recorded mortality location for F6.*

^ site is west of the current Pacific Highway alignment and east of old Pacific Highway/Bundjalung rest area. An approximate 20 m wide road crossing is required to access this site.

Four of the five gliders crossed the Pacific Highway northbound lane, with 48 crossing recorded in total (24 in each direction – refer to **Table 3.3**). Crossings were made at both medians by both male and female gliders. M5 crossed the northbound lane the most (28 occasions), which was associated with denning within the median at Impact Site 4 and foraging predominantly to the west of the highway (refer to **Table 3.4**). F6 crossed the old Pacific Highway at the Bundjalung rest area on eight occasions requiring a horizontal glide distance of approximately 20 m; however this was not captured as a highway lane crossing. No road crossings were recorded for F4. No southbound lane crossings (i.e. movements between the medians and habitat east of the highway) were recorded.

Table 3.3 Number, Location and Direction of Highway Lane Crossings

Squirrel Glider	Site	Northbound Lane		Southbound Lane		Total
		West	East	West	East	
F4	Impact Site 4	0	0	0	0	0
M5	Impact Site 4	14	14	0	0	28
F6	Impact Site 4	1	1	0	0	2
F7	Impact Site 2	6	6	0	0	12
M9	Impact Site 2	3	3	0	0	6
Mean	-	4.8	4.8	0	0	9.6
SD	-	5.63	5.63	0.00	0.00	11.26

Table 3.4 shows the number and frequency of days and nights (when active) that gliders were recorded relative to the highway (west, median, east). Three gliders (F6, F7 and M9) were recorded denning only in habitat west of the highway and visited the median on between 11 to 33 per cent of nights when the gliders were active. One glider (M5) mostly denned within the median at Impact Site 4 (70 per cent of days den fixes were recorded), however was only recorded active within the median on a small number of nights (18 per cent) relative to the number of active nights west of the highway (88 per cent).

Table 3.4 Number of Days/Nights and Frequency (%) Gliders were Recorded in Habitat Relative to Highway

Squirrel Glider	*Site*	*No. of Days Diurnal Denning was Recorded* (%)*				*No. of Nights Active Nocturnal Fixes were Recorded (%)^*			
		Total	*West*	*Median*	*East*	*Total*	*West*	*Median*	*East*
F4	Impact Site 4	18	0 (0%)	0 (0%)	18 (100%)	18	0 (0%)	0 (0%)	18 (100%)
M5	Impact Site 4	23	7 (30%)	16 (70%)	0 (0%)	17	15 (88%)	3 (18%)	0 (0%)
F6	Impact Site 4	9	8 (100%)	0 (0%)	0 (0%)	9	9 (100%)	1 (11%)	0 (0%)
F7	Impact Site 2	22	22 (100%)	0 (0%)	0 (0%)	18	17 (94%)	6 (33%)	0 (0%)
M9	Impact Site 2	21	21 (100%)	0 (0%)	0 (0%)	19	18 (95%)	3 (16%)	0 (0%)
Mean	-	18.6	11.6	3.2	3.6	16.2	11.8	3.3	0.0
SD	-	2.27	3.82	2.86	3.22	1.63	2.99	0.80	0.00

* *Includes nest box denning where relevant and tree denning.*
^ *Excludes nights when only nocturnal denning was recorded.*

Illustration 3.2 shows two tracked northbound lane crossing sequences of glider F7 at Impact Site 2. The sequences comprise:

- 8/07/2019: Sequence of six nocturnal fix locations obtained over a one hour and 45 minute period between 19:26 and 21:11.
- 6/08/2019: Sequence of eight nocturnal fix points obtained over a one hour and 49 minute period between 18:40 and 20:29. The sequence starts with the glider leaving a den tree (D04).

In both sequences F7 starts west of the highway, moves into the median then returns to the western side of the highway.

3.1.2 Den Trees Usage

Fifteen den trees were used during the radio tracking (refer to **Table 3.5** and **Illustration 3.1**), averaging 4.0 den trees per glider (SD: 2.5). Attribute data of each tree is provided in **Appendix C**. A higher number of den trees were used by the gliders at Impact Site 2 (F7 and M9) compared to the gliders at Impact Site 4 (F4, M5 and F7). Fourteen of the den trees were located on land east or west of the highway. One den tree (D13) was located within the median (Impact Site 4). Daytime den usage per tree varied between one and 17 (average 5.8). At Impact Site 2 (west) it was not possible to determine which den tree was being utilised by F7 and M9 on one occasion each. No nest box denning was recorded after the initial glider capture. Nocturnal inspection of nest boxes was observed on two occasions by M5.

Two social groups were identified based on shared den tree occupation and overlapping home ranges (e.g. Sharpe and Goldingay 2007). M5 and F6 shared a den at Impact Site 4 on four days, all within the same den tree (D15). This comprised 50 per cent of the den fixes for F6 prior to the recorded mortality. M5 stopped denning in den tree D15 after F6 died. F7 and M9 shared a den on nine (47 per cent) of the 19 days that den fixes were collected for both gliders at Impact Site 2. Four den trees were shared by F7 and M9 (D5, D6, D8 and D9).

Table 3.5 Diurnal Squirrel Glider Diurnal Den Tree Usage

Tree Location	*Impact Site 2 West*										*Impact Site 4 East*				*Impact Site 4 Median*	*Impact Site 4 West*	*Total Den Fixes*	*No. of Den Trees Used*	*No. Occasions Denning with Another Collared Glider*
Squirrel Glider	*D01*	*D02*	*D03*	*D04*	*D05*	*D06*	*D07*	*D08*	*D09*	*N/A**	*D10*	*D11*	*D12*	*D14*	*D13*	*D15*			
F4	0	0	0	0	0	0	0	0	0	0	6	1	7	4	0	0	18	4	0
M5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	6	22	2	4 (F6)
F6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8	1	4 (M5)
F7	0	0	2	1	2	1	11	2	1	1	0	0	0	0	0	0	21	7	9 (M9)
M9	8	1	0	0	1	0	6	2	1	1	0	0	0	0	0	0	20	6	9 (F7)
Total	8	1	2	1	3	1	17	4	2	2	6	1	7	4	16	14	89	-	-

** On these occasions the den tree was unable to be confirmed due to adverse conditions or variability in signal direction.*

GDA 1994 MGA Zone 56

LEGEND

Impact Site 2 (median)
Den tree

F7 fix
Capture (nest box)
Diurnal den fix
Nocturnal fix

M9 fix
Capture (nest box)
Diurnal den fix
Nocturnal fix

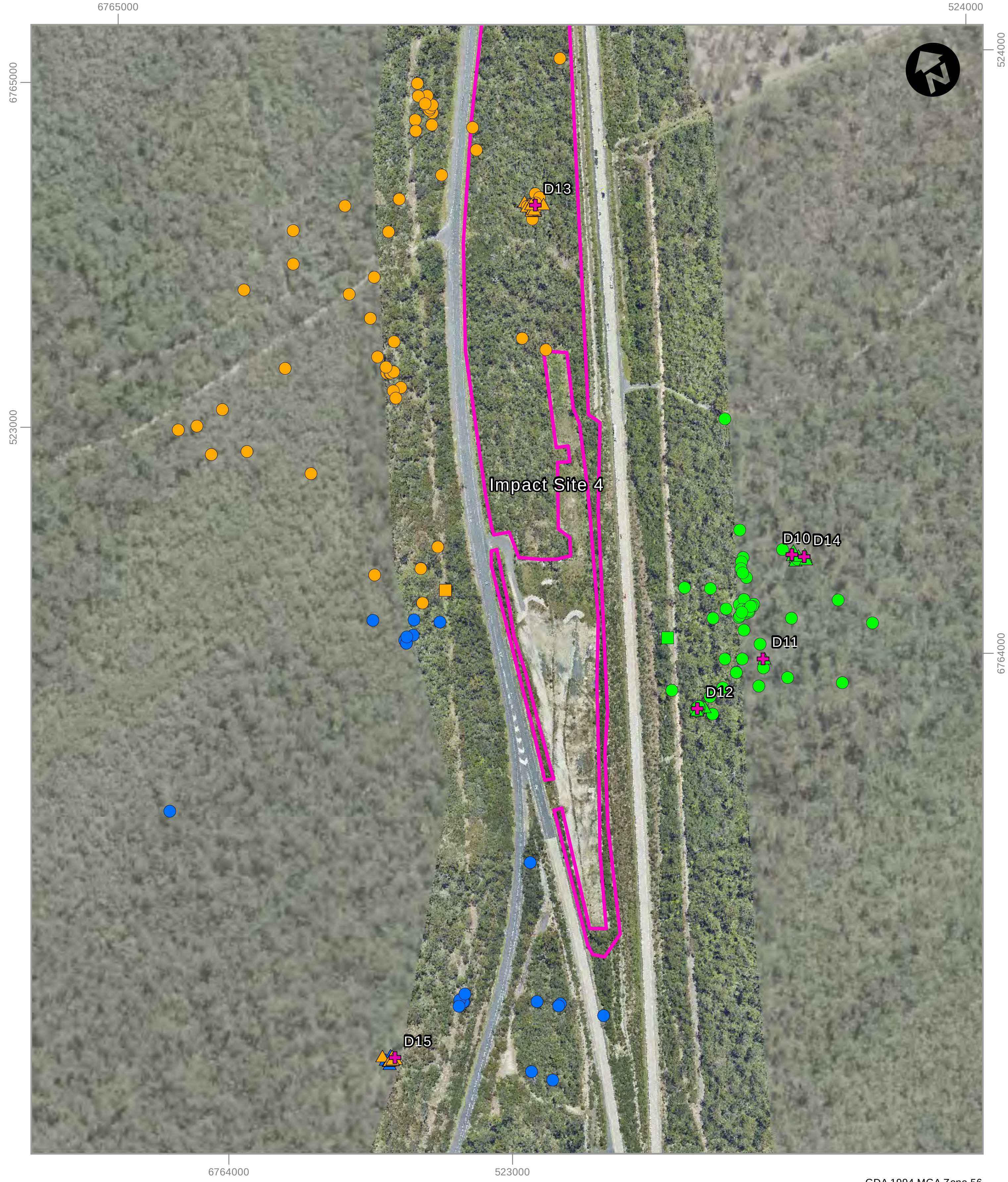
0 100 Metres

Radio Tracking Results
Illustration 3.1 - Sheet 1 of 2

GeoLINK environmental management and design

Squirrel Glider Radio Tracking for Post Construction Ecological Monitoring
2885-1044

Information shown is for illustrative purposes only
Drawn by: AB Checked by: RE Reviewed by: DSA
Source of base data: DFSI
Date: 12/08/2020



LEGEND

Impact Site 4 (median)

Den tree

F4 fix	M5 fix	F6 fix
Capture (Elliott B)	Capture (nest box)	Capture (nest box)
Diurnal den fix	Diurnal den fix	Diurnal den fix
Nocturnal fix	Nocturnal fix	Nocturnal fix

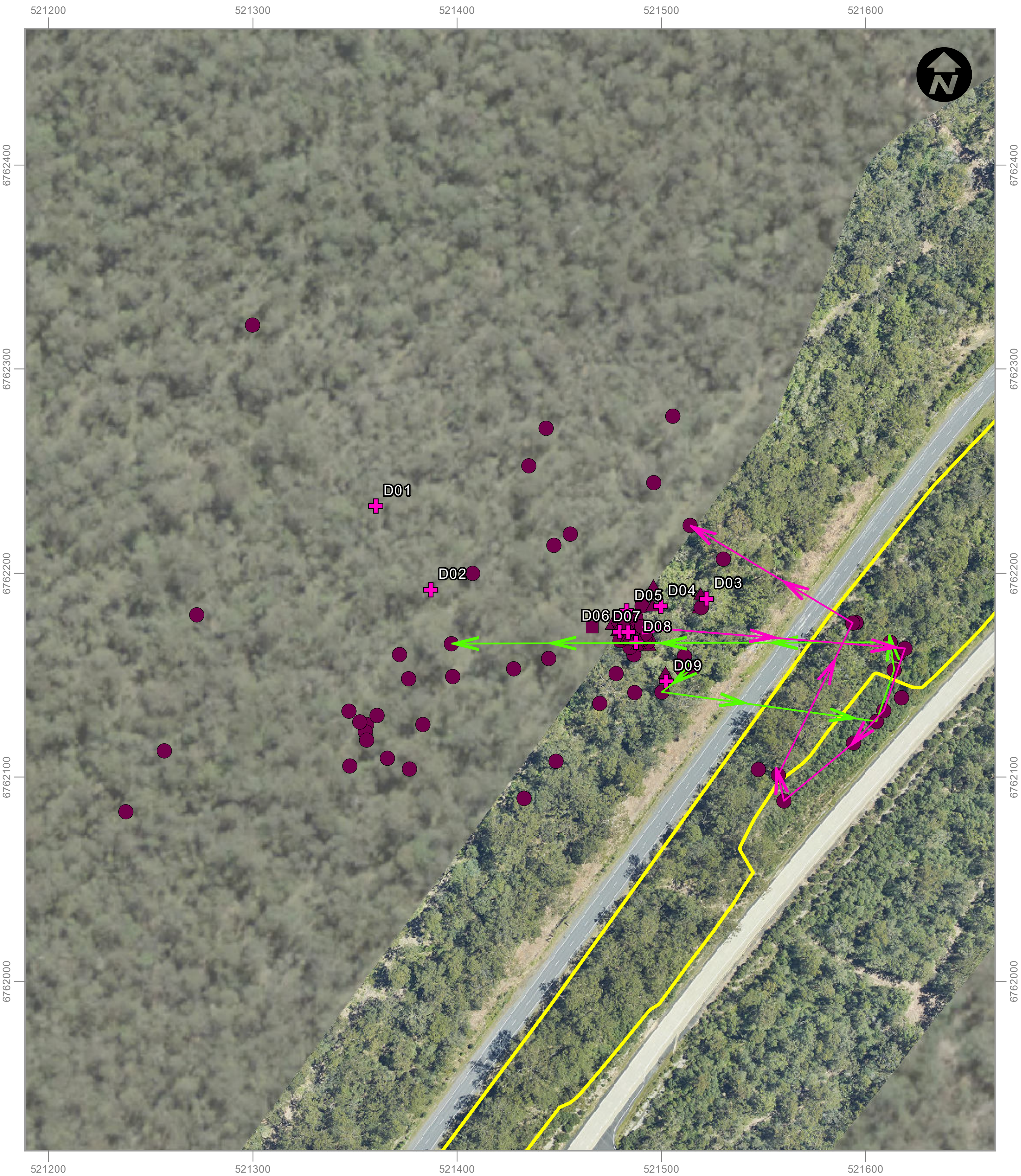
0 100 Metres

Radio Tracking Results
Illustration 3.1 - Sheet 2 of 2

GeoLINK environmental management and design

Squirrel Glider Radio Tracking for Post Construction Ecological Monitoring
2885-1044

Information shown is for illustrative purposes only
Drawn by: AB Checked by: RE Reviewed by: DSA
Source of base data: DFSI
Date: 12/08/2020



LEGEND

- Impact Site 2 (median)
- F7 Crossing 8/07/2019 between 19:26 and 21:11
- F7 Crossing 6/08/2019 between 18:40 and 20:29
- Den tree
- Capture (nest box)
- Diurnal den fix
- Nocturnal fix

0 50 Metres

Glider F7 Crossing Sequence At Impact Site 2 - Illustration 3.2

GeoLINK environmental management and design

Squirrel Glider Radio Tracking for Post Construction Ecological Monitoring
2885-1047

Information shown is for illustrative purposes only
Drawn by: AB Checked by: RE Reviewed by: DSA
Source of base data: RMS
Date: 12/08/2020

3.1.3 Home Range Results

Home range analysis results are provided in **Table 3.6** and displayed in **Illustration 3.3**. Home range sizes varied from 2.54 to 20.49 ha based on the MPC analysis and 2.52 and 14.09 ha based on the Kernel 95 analysis. F4 had the smallest home range which was located exclusively on the eastern side of the highway at Impact Site 4.

M5 and F6 had overlapping home ranges, although the Kernel analysis shows that large portions of their ranges were not overlapping. The mortality of F6 is likely to have influenced this outcome. The home range of both animals included habitat to the west of the highway as well as the median at Impact Site 4. The Kernel 50 home range analysis showed that M5's core home range included the median in the vicinity of den tree D13.

F7 and M9 had overlapping home ranges encompassing land to the west of the highway and the median at Impact Site 2. The Kernel 50 home range analysis results for both animals did not encompass the median.

Table 3.6 Home Range Analysis

Glider	*Days*	*Fixes*				*MCP (ha)*	*Kernel (ha)*			
		*Den**	*Nocturnal*	*Capture*	*Total*		*50*	*95*	*h*	*grid size*
F4	21	18	49	2	69	2.54	0.46	2.52	20	15
M5	26	18	58	1	77	20.49	1.51	14.09	50	15
F6	11	6	20	1	27	13.72	1.25	11.75	55	15
F7	22	12	59	1	72	7.51	0.52	4.76	35	15
M9	22	11	58	1	70	5.23	0.57	6.64	35	15
Mean	20.4	17.4	48.4	1.2	67.0	9.90	0.86	7.95	39	15
S.E.	2.24	1.49	5.33	0.18	4.64	2.89	0.19	1.93	6	0

Includes only independent fix locations used in home range analysis.

3.2 Glider Performance

Tree height and glide performance calculations from GeoLINK (2019b) were overlayed with home range analysis results to provide an indication of minimum highway crossing glide performance (refer to **Appendix C** and **Illustration 3.4**). Horizontal glide distance ranged between 34 m and 50 m (average 40 m). Tree height of potential launch trees ranged between 14 m and 40 m (average 26 m). The findings for each individual glider are summarised in **Table 3.7** and show:

- Numerous potential launch trees occurred within the home ranges of F7 and M9 on both sides of the northbound lane at Impact Site 2. Minimum required glide performance ratio (vertical drop: horizontal plane) was 1:1.5 for west-east glider movement and 1:1.29 for east-west glider movement.
- Several potential launch trees occurred within the home range of F6 on both sides of the northbound lane at Impact Site 4. Minimum required glide performance ratio was 1:2.17 for west-east glider movement and 1:2.47 for east-west glider movement.
- Numerous potential launch trees occurred within the home range of M5 on both sides of the northbound lane at Impact Site 4. Minimum required glide performance ratio (vertical drop: horizontal plane) was 1:1.27 for west-east glider movement and 1:1.30 for east-west glider movement across the northbound lane.

Table 3.7 Summary of Tree Height, Highway Gap and Minimum Glide Performance Calculations for Northbound Lane Crossing at Recorded Home Ranges

Glider Home Range	*Potential Glide Tree Ref.*	*Location Relative to Northbound Lane*	*Tree Height (m)*	*Distance to Closest Landing Tree (m)*	*Minimum Required Glide Ratio (vertical drop: horizontal plane)**	*Minimum Required Glide Angle**	*Frequency of Potential Launch Trees*
F7 and M9	SNW06	West	40.0	50.0	1:1.51	30.2	Numerous launch trees in zone
F7 and M9	SNE06	East (median)	34.0	43.0	1:1.29	37.7	Numerous launch trees in zone
F7 and M9	SNW07	West	31.0	43.0	1:1.66	31.1	Numerous launch trees in zone
F7 and M9	SNE07	East (median)	29.0	43.0	1:1.97	26.9	Numerous launch trees in zone
F6	NNW01	West	20.0	38.5	1:2.17	24.7	Several nearby launch trees
F6	NNE01	East (median)	23.0	42.0	1:2.47	22	Several launch trees present
M5	NNW02	West	25.0	42.0	1:2.08	25.6	Several launching trees available in zone
M5	NNE02	East (median)	14.0	43.0	1:4.14	13.6	Several launching trees available in zone
M5	NNW03	West	31.0	34.0	1:1.27	38.2	Numerous launch tree options available
M5	NNE03	East (median)	21.0	34.0	1:1.91	27.6	Numerous launch tree options available
M5	NNW04	West	25.0	37.0	1:1.70	30.5	Numerous launch options available
M5	NNE04	East (median)	23.0	37.0	1:2.02	26.3	Numerous launch options
M5	NNW05	West	28.0	39.0	1:1.80	29	Various launch options
M5	NNE05	East (median)	20.0	39.0	1:2.22	24.3	Minimal tall launch tree options
M5	NNW06	West	26.0	34.0	1:1.56	32.6	Numerous launch trees available
M5	NNE06	East (median)	20.0	34.0	1:2.13	25.1	Numerous launch trees available
M5	NNW07	West	31.0	39.0	1:1.42	35.1	Several launch options in zone
M5	NNE07	East (median)	33.0	39.0	1:1.30	37.5	Several launch options in zone
Mean	-	-	26.3	39.5	1:1.923	28.78	-
SD	-	-	6.4	4.3	0.657	6.22	-

** Calculations are based on Goldingay and Taylor (2009) where Potential Glide Distance = 1.84 x (tree height – 2 m – 3 m + elevation difference) + 2 m. This allows for gliding 2 m below the tree top; 2 m out from the trunk; and landing 3 m above ground.*

3.3 Moon Influence

Table 3.8 shows the numbers of active and denning nocturnal glider fixes at ≤50 per cent and 51-100 per cent moon illumination. A chi square test showed that there were significant differences in glider activity in the two moon illumination categories ($\chi2 = 92$, < P 0.001). Gliders were often denning during the night when the moon illumination was between 51-100 per cent. In contrast, gliders were more active at night when the moon was absent or illumination was ≤50 per cent.

Table 3.8 Numbers of Active and Denning Glider Nocturnal Fixes and Moon Illumination (the table gives both observed and expected (in brackets) numbers)

Moon Illumination	*Active Nocturnal Fix*	*Denning Nocturnal Fix*	*Total*
0-50%	173 (141)	16 (48)	189
51-100%	31 (63)	53 (21)	84
Total	204	69	273

LEGEND

Impact Site 2 (median)
Den tree
F7 fix
F7 FK home range estimate
M9 fix
M9 FK home range estimate
M9 MCP home range estimate

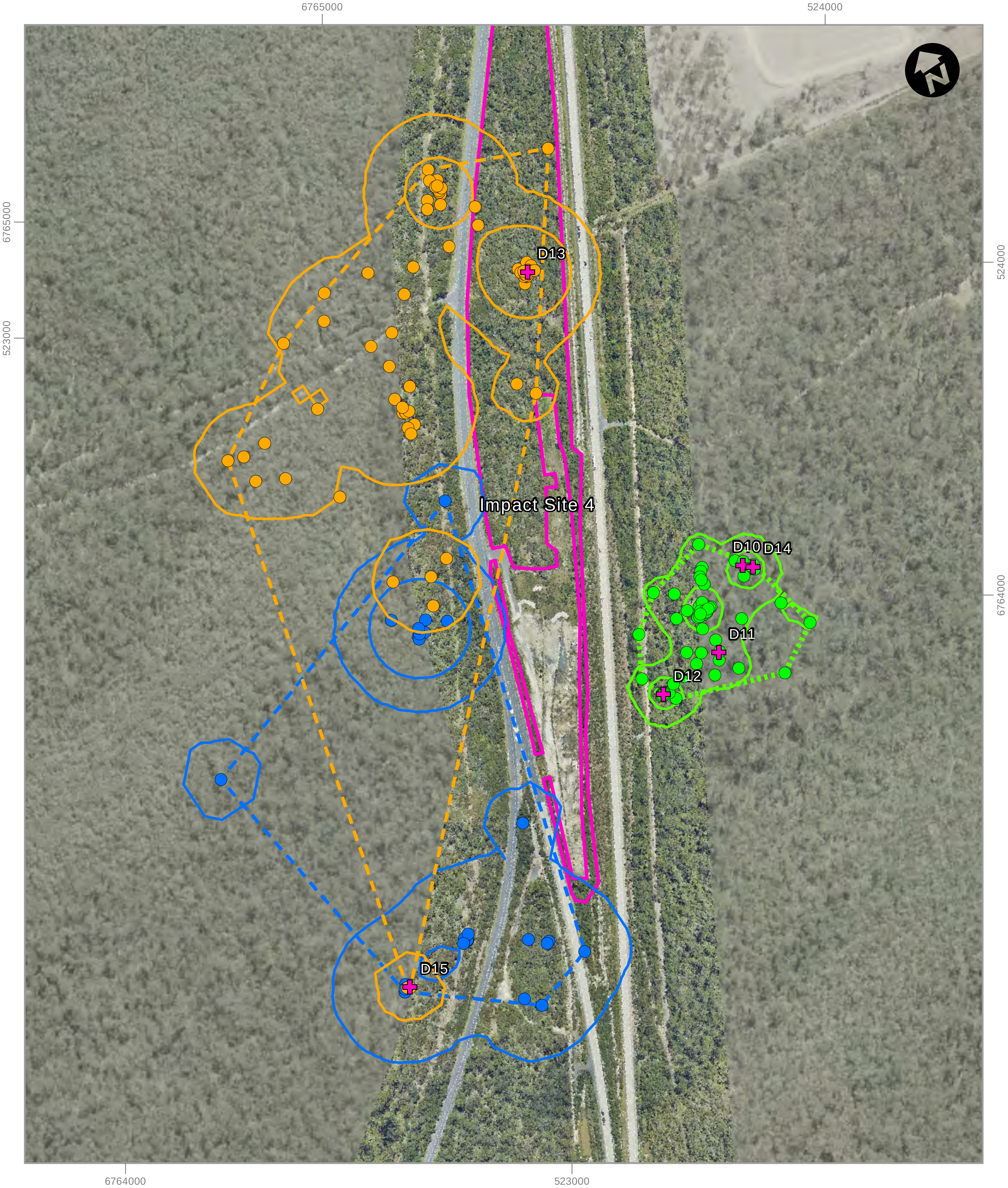
0 120 Metres

Home Range Analysis
Illustration 3.3 - Sheet 1 of 2

GeoLINK environmental management and design

Squirrel Glider Radio Tracking for Post Construction Ecological Monitoring
2885-1045

Information shown is for illustrative purposes only
Drawn by: AB Checked by: RE Reviewed by: DSA
Source of base data: RMS
Date: 12/08/2020



GDA 1994 MGA Zone 56

LEGEND

- Impact Site 4 (median)
- Den tree
- F4 fix
- F4 FK home range estimate
- F4 MCP home range estimate
- M5 fix
- M5 FK home range estimate
- M5 MCP home range estimate
- F6 fix
- F6 FK home range estimate
- F6 MCP home range estimate

0 120 Metres

Home Range Analysis
Illustration 3.3 - Sheet 2 of 2

GeoLINK environmental management and design

Squirrel Glider Radio Tracking for Post Construction Ecological Monitoring
2885-1045

Information shown is for illustrative purposes only
Drawn by: AB Checked by: RE Reviewed by: DSA
Source of base data: RMS
Date: 12/08/2020

GDA 1994 MGA Zone 56

LEGEND

Impact Site 2 (median)

F7 FK home range estimate
F7 MCP home range estimate
M9 FK home range estimate
M9 MCP home range estimate

Potential glide tree based on 1:1.84 glide ratio (GeoLINK 2019b)

Yes
No however within glide angle standard deviation range
No

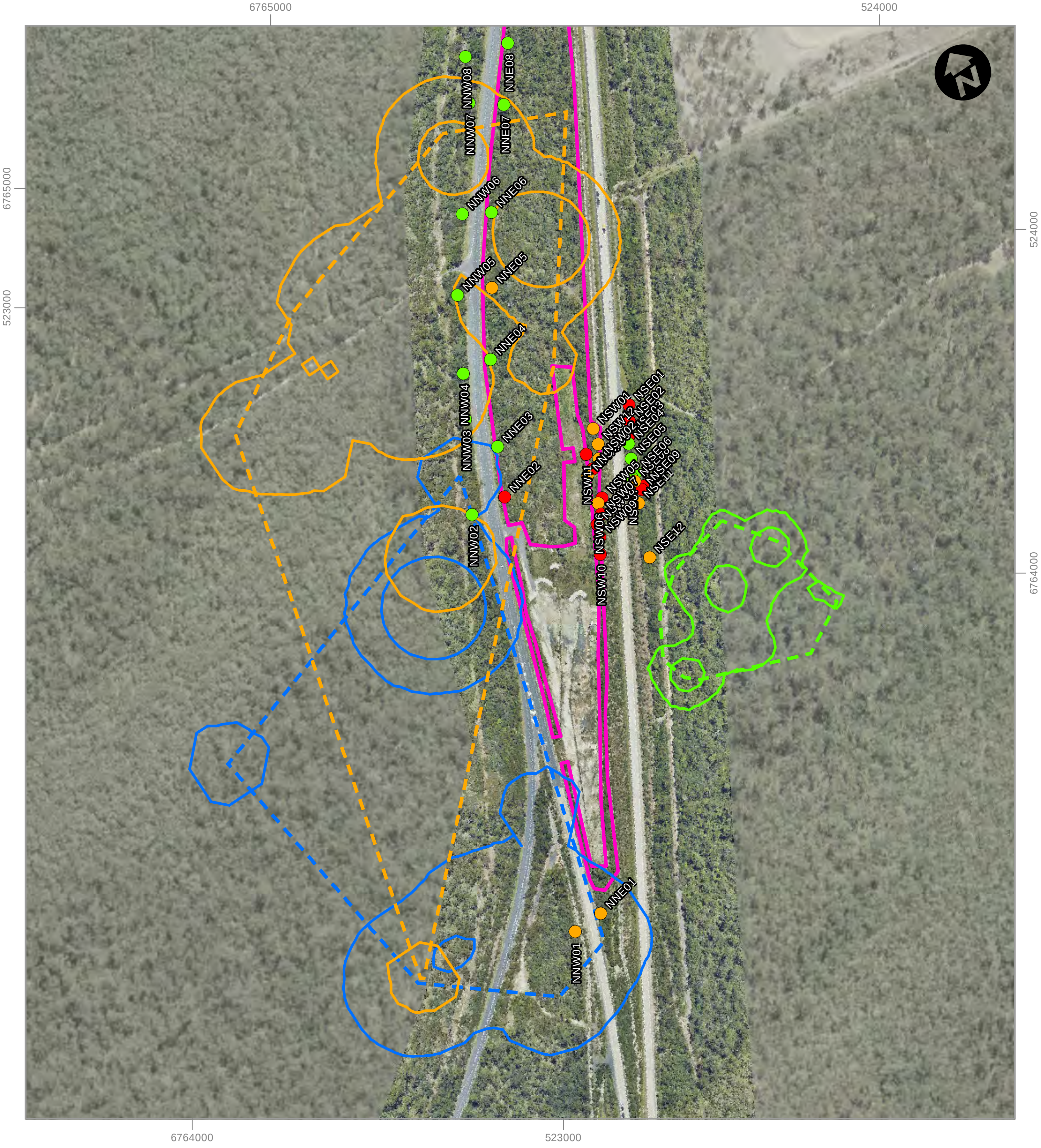
0 120 Metres

Tree Locations for Glide Performance Calculation and Home Range Analysis Results
Illustration 3.4 - Sheet 1 of 2

GeoLINK environmental management and design

Squirrel Glider Radio Tracking for Post Construction Ecological Monitoring
2885-1048

Information shown is for illustrative purposes only
Drawn by: Checked by: Reviewed by:
Source of base data:
Date:
Revision:



LEGEND

- Impact Site 4 (median)
- F4 FK home range estimate
- F4 MCP home range estimate
- M5 FK home range estimate
- M5 MCP home range estimate
- F6 FK home range estimate
- F6 MCP home range estimate

Potential glide tree based on 1:1.84 glide ratio (GeoLINK 2019b)

- Yes
- No however within glide angle standard deviation range
- No

0 120 Metres

Tree Locations for Glide Performance Calculation and Home Range Analysis Results
Illustration 3.4 - Sheet 2 of 2

4. Discussion

4.1 Road Crossings at Vegetated Medians

The radio tracking results demonstrate that both male and female Squirrel Gliders were able to cross the northbound lane of the Pacific Highway at both medians at the Devils Pulpit site under no night traffic conditions. All four gliders that crossed the northbound lane used the medians as part of their home ranges that extend into habitat to the west. The distance between trees on opposite sides of the northbound lane at recorded home ranges was typically <50 m and required a glide performance similar or less than the average Squirrel Glider glide performance recorded by Goldingay and Taylor (2009; i.e. 28.5^{o} (SD7.4^{o})) to cross the lane.

One female glider (F6) crossed the northbound lane in a location requiring an above average glide performance at the southern end of the median at Impact Site 4. A 24.7^{o} glide angle for west-east movement and 22^{o} glide angle for east-west movement was required. This is within the average glide performance standard deviation range recorded in Goldingay and Taylor (2009).

The radio tracking results are consistent with previous studies that have recorded Squirrel Gliders using vegetated medians (van der Ree, et al. 2010) or constructed glider poles (Taylor and Goldingay 2013; Soanes et al. 2013; Goldingay et al. 2018) to cross roads where glide distances are achievable.

No crossings of the southbound lane were recorded, therefore the maintenance of Squirrel Glider movement across this newly constructed carriageway has not been demonstrated. It is unclear if this was due to:

- The radio tracked gliders home range did not encompass habitat on the eastern side of the southbound lane. The vegetation edge along the southbound lane may be used to define the eastern home range extent of radio tracked gliders.
- The small sample of gliders able to be captured and radio tracked as part of this study.
- The southbound lane creating a barrier to glider movement. Clearing width, tree height and glider performance calculations based on conditions at the time of the radio tracking however indicate that Squirrel Gliders could physically cross the southbound lane at both medians. The required glide performance was within the average glide performance standard deviation range recorded in Goldingay and Taylor (2009).

The radio tracking results do not rule out the potential for traffic related behavioural barriers at the site. The northbound lane was closed to traffic and subject to only daytime construction works during the radio tracking. Both lanes of traffic were however open during Years 3 and 4 post construction monitoring spotlighting and nest box monitoring at Devils Pulpit between winter 2017 and summer 2019. Varying occurrences of Squirrel Gliders in the medians were recorded during this period (GeoLINK 2019a, 2018). This suggests that the gliders were crossing with live traffic. These results and records of Squirrel Gliders crossing roads of varying width and traffic volumes within the glide capability (van der Ree 2006; Melton 2007; Goldingay et al. 2018; personal observations); suggests that traffic may not be a factor impacting glider movement across the highway at the site. Further monitoring would be required to determine potential traffic impacts on glider movement.

Overall, based on the clearing widths at the time of the radio tracking it is expected that Squirrel Gliders could cross both the northbound and southbound lanes of the Pacific Highway at the vegetated medians when both lanes are open to traffic. Known habitat occurs on both sides of the highway and the vegetated medians provide crossing opportunities for both resident and dispersing gliders.

4.2 Frequency of Road Crossing

The recorded frequency of glider movement across the northbound lane into the median was greater than Squirrel Glider visits to the Devils Pulpit rope bridge poles during the post construction monitoring undertaken to date (GeoLINK 2019a, 2018). This suggests that the vegetated medians at the Devils Pulpit site provide greater opportunities for Squirrel Glider movement across the highway. Part of the reason for this could be that there are many more crossing opportunities when numerous potential launch trees are available compared to a singular location when artificial crossing structures are used. However, given accumulating evidence of the use of arboreal crossing structures by the Squirrel Glider and other gliding species (e.g. Ball and Goldingay 2008; Soanes et al. 2015, 2018; Goldingay et al. 2018), the use of rope bridges and gliding poles is warranted where clearing gaps exceed gliding ability.

Numerous studies have looked at Squirrel Glider use of vegetated medians, rope bridges and poles to cross roads (e.g. Soanes et al. 2014; Soanes et al. 2013; Taylor 2010). The frequency of use of these crossing structures varies depending on specific site conditions and glider home range configurations. The objective of any glider crossing structure and target frequency of fauna movement should be considered when determining the appropriate glider connectivity structure for a particular site. Site topography, maintenance requirements and clearing impacts should also be considered.

4.3 Home Range and Denning

Recorded home range sizes and den tree numbers were comparable to those recorded in similar Squirrel Glider studies that reported mean kernel estimates of 4.3 - 14.8 ha (Sharpe and Goldingay 2007; Goldingay et al. 2010; Brearley et al. 2011). Two gliders from Impact Site 4 (northern median; one male and one female) and two gliders from the Impact Site 2 (southern median; one male and one female) were from the same family group. They supported overlapping home ranges and were recorded den sharing on multiple occasions. Limited overlap between the two gliders from the northern median (M5 and F6) however suggested the potential polygynous social arrangement.

Polygyny is thought to develop where there are sufficient food resources to enable males to defend the home range of more than one female (Lee and Cockburn 1985). For example, Goldingay (1990) attributed the occurrence of polygyny in the Yellow-bellied Glider (*Petaurus australis*) to the availability of nectar in a coastal forest in southern NSW relative to a nearby hinterland forest where nectar was not important and groups were monogamous (Goldingay and Kavanagh 1990). While members of polygynous groups typically den together, there are unknown reasons for them to den apart in some locations. This situation was observed in the Squirrel Glider at a site on the lower NSW north coast (Dr David Sharpe unpublished data).

4.4 Nest Box Usage

The Squirrel Gliders showed a negative response to nest box inspection and collaring, indicated by:

- None of the radio tracked Squirrel Gliders returning to the nest boxes to den during the radio tracking
- Observations of gliders vacating nest boxes during the day prior to any interaction with the respective nest box during initial nest box inspections (e.g. during establishment of string lines and climbing ropes).

The latter shows a negative response to the nest box inspection, not just from the stress from the handling and collaring process. The observation has implications for other nest box monitoring projects, including:

- Nest box design and inspection ability
- Monitoring methodology and frequency
- Results interpretation.

The availability of tree hollow den sites within the local landscape may also influence post disturbance nest box usage. At the Devils Pulpit site for example, hollow-bearing trees were relatively common and provided alternative denning opportunities not associated with direct human interaction.

4.5 Moon Influence

The behaviour of Squirrel Gliders at the site was observed to be influenced by the moon's illumination. While Squirrel Gliders are known to return to den between feeding bouts (Sharpe and Goldingay 2018), this study found that Squirrel Gliders were:

- More active during no or low moon illumination periods
- Nocturnal denning more when night conditions were bright, corresponding with periods when the moon was present during the first quarter - full - last quarter half of the moon phase.

Linley et. al., (2020) found that moon phase affects the nocturnal activity of mammal species and that, for prey species, there might be trade-offs between predation risk and foraging.

Sharpe and Goldingay (2018) in contrast did not observed any moon phase variation in the percentage of time used for feeding by the Squirrel Glider in Brisbane, however a complex interaction between season, moon phase or sex was observed. The consistent anthropogenic lighting (light pollution) in Brisbane may have influenced this outcome, resulting in the gliders being less influenced by variation in moon illumination. Light pollution is low at the Devils Pulpit site, with anthropogenic lighting being relatively localised to highway and associated with vehicle lights and a rest area.

These findings have implications for:

- Squirrel Glider survey design and results interpretation
- Understanding behaviour in natural and modified (artificial lighting) environments.

5. Recommendations

5.1 Recommendations

The following recommendations are provided for Transport for NSW consideration:

- Ecological monitoring programs developed for future projects should be designed and timed to enable before and after impact trends to be clearly observed. A greater understanding of Squirrel Glider activity and home ranges at the site before impact would have enabled greater interpretation of post construction monitoring results and the overall effectiveness of connectivity measures.
- While the completed radio tracking has satisfied EMP requirements, repeating the Squirrel Glider radio tracking under operational conditions (post Woolgoolga to Ballina construction influences; with two lanes of open traffic and 'normal' traffic volumes) would help determine whether traffic is affecting glider movement across the highway. This is not a requirement of the EMP, however could be encouraged in collaboration with research institutions (e.g. as part of post graduate studies).
- Nest box monitoring programs should consider potential disturbance influences when developing programs and interpreting results.
- Squirrel glider surveys and monitoring programs should be designed with consideration to potential moon phase/illumination influences. Nocturnal surveys targeting active Squirrel Gliders in environments with no or low levels of light pollution should avoid periods of bright moon illumination.

References

Ball, T.M. and Goldingay, R.L. (2008) Can wooden poles be used to connect habitat for a gliding mammal? *Landscape and Urban Planning* **87**: 140-46.

BoM (2019). *Climate Data Online*, for the Yamba Pilot Station (site number: 058012). Australian Government Bureau of Meteorology (BoM) website: www.bom.gov.au/climate/data/, accessed 24/12/2019.

Brearley, G., McAlpine, C., Bell, S. and Bradley, A. (2011) Squirrel glider home ranges near urban edges in eastern Australia. *Journal of Zoology* **285**: 256-65.

GeoLINK (2019a). *Second Annual Report for Post Construction Year 3, 4 and 6 Ecological Monitoring Devils Pulpit Pacific Highway Upgrade.* Unpublished report prepared for NSW Roads and Maritime Services. GeoLINK Consulting, Lennox Head.

GeoLINK (2019b). *W2B Devils Pulpit Widened Median Glider Crossing Ability Assessment.* Unpublished report prepared for BMD Construction. GeoLINK Consulting, Lennox Head.

GeoLINK (2018). *First Annual Report for Post Construction Year 3, 4 and 6 Ecological Monitoring Devils Pulpit Pacific Highway Upgrade.* Unpublished report prepared for NSW Roads and Maritime Services. GeoLINK Consulting, Lennox Head.

GeoLINK (2012a). *Devils Pulpit Highway Class A Upgrade – Rope Bridge Assessment for Target Glider Species at the Northern and Southern Vegetated Medians/Glider Crossings.* Unpublished report prepared for John Holland Group. GeoLINK Consulting, Lennox Head.

GeoLINK (2012b). *Devils Pulpit Pacific Highway Class A Upgrade – Rope Bridge Assessments for Target Glider Species at the Northern and Southern Vegetated Medians/Glider Crossings.* Unpublished report prepared for John Holland Group. GeoLINK Consulting, Lennox Head.

Goldingay, R.L. (1992) Socioecology of the yellow-bellied glider (*Petaurus australis*) in a coastal forest. *Australian Journal of Zoology* **40**: 267-78.

Goldingay, R.L. and Kavanagh, R.P. (1990) Socioecology of the yellow-bellied glider, *Petaurus australis*, at Waratah-Creek, N.S.W. *Australian Journal of Zoology* **38**: 327-41.

Goldingay, R. L. and Taylor, B.D. (2009). Gliding performance and its relevance to gap crossings by the squirrel glider (*Petaurus norfolcensis*)., *Australian Journal of Zoology*, 57, 99-104.

Goldingay, R.L., Sharpe, D.J. and Dobson, M.D.J. (2010) Variation in the home-range size of the squirrel glider (*Petaurus norfolcensis*). *Australian Mammalogy* **32**, 183-88.

Goldingay, R. L., Taylor, B. D., Parkyn, J. L. (2018). Use of tall wooden poles by four species of gliding mammal provides further proof of concept for habitat restoration, in *Australian Mammalogy* https://doi.org/10.1071/AM18008.

Hyder (2012). *Devils Pulpit Upgrade – Ecological Monitoring Program*. Unpublished report prepared for NSW Roads and Maritime Services. Hyder Consulting Pty, Ltd, North Sydney.

Hyder (2011). *Pacific Highway Upgrade – Devils Pulpit Project – Appendix D. Technical Working Paper – Ecology*. Unpublished report prepared for NSW Roads and Traffic Authority. Hyder Consulting Pty, Ltd, North Sydney.

Lee, A.K. and Cockburn, A. (1985) Evolutionary Ecology of Marsupials. Cambridge University Press, Cambridge.

Linley G. D., Pauligk Y., Marneweck C., and Ritchie E. G. (2020). Moon phase and nocturnal activity of native Australian mammals, in *Australian Mammalogy* - https://doi.org/10.1071/AM19070

Sharpe, D.J. and Goldingay, R.L. (2007) Home range of the Australian squirrel glider Petaurus norfolcensis (Diprotodontia). *Journal of Mammalogy* **88**, 1515-22.

Soanes K., Carmody Lobo M., Vesk P. A., McCarthy M. A., Moore J. L. and van der Ree R. (2013). Movement re-established but not restored: inferring the effectiveness of road-crossing mitigation for a gliding mammal by monitoring use, in *Biological Conservation* **159**, 434–441

Soanes K., Vesk P. A. and van der Ree R. (2015). Monitoring the use of road-crossing structures by arboreal marsupials: insights gained from motion-triggered cameras and passive integrated transponder (PIT) tags, in *Wildlife Research* 42, 241-256

Soanes, K., Taylor, A. C., Sunnucks, P., Vesk, P. A., Cesarini, S., and van der Ree, R. (2018). Evaluating the success of wildlife crossing structures using genetic approaches and an experimental design: lessons from a gliding mammal, in *Journal of Applied Ecology* **55**, 129–138.

Soanes, K., Taylor, A.C., Sunnucks, P., Vesk, P.A., Cesarini, S., van der Ree, R. and Wiersma, Y. (2018) Evaluating the success of wildlife crossing structures using genetic approaches and an experimental design: Lessons from a gliding mammal. *Journal of Applied Ecology* **55**: 129-38.Taylor, B. D. (2010). *Use and effectiveness of engineered road crossing-structures for wildlife in eastern Australia*. Thesis, Griffith School of Environment Science, Environment, Engineering and Technology, Griffith University.

Taylor, B. D. and Goldingay, R. L. (2013). Squirrel glider use of roadside glide poles to cross a road gap, in *Australian Mammalogy* **35**;119.

van der Ree, R. (2006). Road upgrade in Victoria a filter to the movement of the endangered squirrel glider (Petaurus norfolcensis): results of a pilot study, in *Ecological Management and Restoration* **7**, 226-228.

van der Ree R., Cesarini S., Sunnucks P., Moore J. L., and Taylor A. (2010). Large gaps in canopy reduce road crossing by a gliding mammal, in *Ecology and Society* **15**, 35.

Copyright and Usage

Appendix A

Weather Conditions and Moon Phase

Table A1 Weather Conditions and Moon Phase During July and August 2019

Date	Temperature		Rainfall (mm)*	Moon Phase^	Moon Rising Time^	Moon Set Time^	Illumination (%)^
	High*	Low*					
1/07/2019	19.7	13.7	0.2		4:42 am	3:33 pm	4.3
2/07/2019	21.8	12.5	0		5:45 am	4:27 pm	0.8
3/07/2019	20.8	11.9	0.2	New moon	6:47 am	5:27 pm	0.1
4/07/2019	21.5	13.5	4.4		7:46 am	6:32 pm	2.5
5/07/2019	20.7	15.9	25.8		8:41 am	7:40 pm	7.8
6/07/2019	20.5	16.2	6.4		9:30 am	8:47 pm	15.7
7/07/2019	19.5	12.7	4		10:13 am	9:53 pm	25.7
8/07/2019	18.1	14.1	10.4		10:54 am	10:57 pm	36.9
9/07/2019	20.5	11.2	1.2	First quarter	11:31 am	-	48.6
10/07/2019	21.6	10.2	0.2		12:08 pm	12:00 am	60.2
11/07/2019	23.4	11.2	0		12:46 pm	1:01 am	70.9
12/07/2019	24.8	11.2	0		1:25 pm	2:01 am	80.4
13/07/2019	23.1	13.1	0		2:06 pm	3:01 am	88.3
14/07/2019	17.9	8	0		2:51 pm	4:00 am	94.3
15/07/2019	19.4	8.2	0		3:39 pm	4:58 am	98.2
16/07/2019	22	7.3	0		4:30 pm	5:52 am	99.9
17/07/2019	19.8	7.7	0		5:23 pm	6:42 am	-
18/07/2019	19.2	9.8	0	Full moon	6:18pm	7:27 am	99.5
19/07/2019	21.9	7.4	0		7:11 pm	8:08 am	97.2
20/07/2019	21	8.1	0		8:05 pm	8:46 am	93.0
21/07/2019	23.3	9.4	0		8:57 pm	9:20 am	87.2
22/07/2019	23.2	9.6	0		9:49 pm	9:52 am	80.0
23/07/2019	23.3	11.2	0		10:41 pm	10:23 am	71.6
24/07/2019	25	9.3	0		11:34 pm	10:54 am	62.4
25/07/2019	17.6	10.5	0	Third quarter	-	11:26 am	52.5
26/07/2019	22.6	11.8	2.4		12:28 am	12:00 pm	42.2
27/07/2019	20.9	13.4	0		1:25 am	12:38 pm	32.0
28/07/2019	20.6	10.8	0		2:24 am	1:22 pm	22.2
29/07/2019	21.6	10.5	0		3:26 am	2:11 pm	13.5
30/07/2019	21.6	11.4	0		4:28 am	3:08 pm	6.4
31/07/2019	14.6	11.1	5.8		5:29 am	4:12 pm	1.8
Monthly	**Mean: 21**	**Mean: 11.1**	**Total: 61**	-	-	-	-

Date	Temperature		Rainfall (mm)*	Moon Phase^	Moon Rising Time^	Moon Set Time^	Illumination (%)^
	High*	Low*					
1/08/2019	19.1	11.1	43.2	New moon	4:42 am	3:33 pm	4.3
2/08/2019	19.2	10.7	21		5:45 am	4:27 pm	0.8
3/08/2019	20.1	10.1	12		6:47 am	5:27 pm	0.1
4/08/2019	20.4	10.1	0.6		7:46 am	6:32 pm	2.5
5/08/2019	23.2	10.8	0.2		8:41 am	7:40 pm	7.8
6/08/2019	22	11.1	0		9:30 am	8:47 pm	15.7
7/08/2019	20.2	12.3	0		10:13 am	9:53 pm	25.7
8/08/2019	26.8	13	0	First quarter	10:54 am	10:57 pm	36.9
9/08/2019	23.6	11.8	0		11.31 am	-	48.6
10/08/2019	21.2	12.3	0		12:08 pm	12:00 am	60.2
11/08/2019	19.1	10.1	0		12:46 pm	1:01 am	70.9
12/08/2019	18.8	7.4	0		1:25 pm	2:01 am	80.4
13/08/2019	20.2	8.8	0		2:06 pm	3:01 am	88.3
14/08/2019	20.5	11.3	0.2		2:51 pm	4:00 am	94.3
15/08/2019	22.7	10.2	0	Full moon	3:39 pm	4:58 am	98.2
16/08/2019	25.3	11.4	0		4:30 pm	5:52 am	99.8
17/08/2019	26	10.3	0		5.23 pm	6:42 am	-
18/08/2019	21.8	11.4	0		6:18 pm	7:27 am	99.5
19/08/2019	26.7	14.1	0		7:11 pm	8:08 am	97.2
20/08/2019	19.1	7.7	0		8:05 pm	8:46 am	93.0
21/08/2019	25.9	8.9	0		8:57 pm	9:20 am	87.2
22/08/2019	26.5	11.9	0		9:49 pm	9:52 am	80.0
23/08/2019	20	12.1	0		10:41 pm	10:23 am	71.6
24/08/2019	22.8	9.1	0	Third quarter	11:34 pm	10:54 am	62.4
25/08/2019	23.7	10.9	0		-	11:26 am	52.5
26/08/2019	22.1	13	0		12:28 am	12:00 pm	42.2
27/08/2019	23.5	14.9	0		1:25 am	12:38 pm	32.0
28/08/2019	19.8	15.9	0		2:24 am	1:22 pm	22.2
29/08/2019	21	12.6	0		3:26 am	2:11 pm	13.5
30/08/2019	19.3	10.9	0.6	New moon	4:28 am	3:08 pm	6.4
31/08/2019	19.2	10.7	1.2		5:29 am	4:12 pm	1.8
Monthly	**Mean: 26.8**	**Mean: 11.2**	**Total: 79**	-	-	-	-

** Weather data is from Australian Government Bureau of Meteorology (BoM), Climate Data Online website: www.bom.gov.au/climate/data/, for the Yamba Pilot Station (site number: 058012). Accessed 24/12/2019.*

^ Moon phase data is from timeanddate.com for Lismore, NSW. Accessed 24/12/2019.

Appendix B

Den Tree Attribute Data

Table B1 Den Tree Attribute Data

HBT No.	Site	Common Name	Scientific Name	Comment	Tree Height (m)	DBH (cm)	Easting	Northing	Total Hollows	Small Limb Hollow (<5cm)	Medium Limb Hollow (5-15cm)	Large Limb Hollow (>15cm)	Small Trunk Hollow (<5cm)	Medium Trunk Hollow (5-15cm)	Large Trunk Hollow (>15cm)
D01	Impact 2 west	Stag	-	Hollow not visible from the ground.	20	35	521360	6762233	1	0	0	0	0	1	0
D02	Impact 2 west	Stag	-	Dead Swamp Box (*L. suaveolens*)	22	95	521387	6762192	-	-	-	-	-	-	-
D03	Impact 2 west	Forest Red Gum	*Eucalyptus tereticornis*	Possible den tree only. Hollows not visible on the ground and signal was variable.	39	120	521522	6762188	2	1	1	0	0	0	0
D04	Impact 2 west	Northern Grey Ironbark	*Eucalyptus siderophloia*	Trunk hollow has vertical opening	26	45	521499	6762184	2	0	1	0	0	1	0
D05	Impact 2 west	Northern Grey Ironbark	*Eucalyptus siderophloia*	Possible den tree only. No visible hollows. Possible cavity in folk.	30	85	521483	6762181	0	0	0	0	0	0	0
D06	Impact 2 west	Forest Red Gum	*Eucalyptus tereticornis*	Medium limb hollow is in a termitaria.	20	40	521479	6762171	4	1	2	0	0	1	0
D07	Impact 2 west	Broad-leaved Paperbark	*Melaleuca quinquenervia*	Vertical pipe.	15	60	521484	6762171	1	0	0	0	0	1	0
D08	Impact 2 west	Northern Grey Ironbark	*Eucalyptus siderophloia*	Possible den tree only. Not used often and variable signal.	32	90	521487	6762166	2	1	1	0	0	0	0
D09	Impact 2 west	Stag	-	Vertical hollow opening	18	110	521502	6762147	2	0	0	0	0	0	2
D10	Impact 4 east	Scribbly Gum	*Eucalyptus signata*	-	24	120	523563	6764187	3	1	2	0	0	0	0

HBT No.	Site	Common Name	Scientific Name	Comment	Tree Height (m)	DBH (cm)	Easting	Northing	Total Hollows	Small Limb Hollow (<5cm)	Medium Limb Hollow (5-15cm)	Large Limb Hollow (>15cm)	Small Trunk Hollow (<5cm)	Medium Trunk Hollow (5-15cm)	Large Trunk Hollow (>15cm)
D11	Impact 4 east	Smudgy Apple	*Angophora woodsiana*	-	24	65	523481	6764117	2	1	0	0	0	1	0
D12	Impact 4 east	Stag	-	-	20	60	523399	6764112	3	0	2	0	0	1	0
D13	Impact 4 median	Tallowwood	*Eucalyptus microcorys*	-	26	120	523542	6764620	10	6	4	0	0	0	0
D14	Impact 4 west	Smudgy Apple	*Angophora woodsiana*	-	20	60	523572	6764179	1	0	0	0	0	1	0
D15	Impact 4 west	Smudgy Apple	*Angophora woodsiana*	-	24	60	522955	6763988	4	1	3	0	0	0	0

Appendix C

Glider Performance Calculations

Tree height data from GeoLINK (2019)b

Median	W2B Chainage Zone	Lane	Potential Glide Tree Ref. No.	Location	Ground Elevation at Tree Base (m)	Tree Height (m)	Distance to Closest Landing Tree (m)	Species	DBH (mm)	Road Elevation (m)	Tree Base Elevation to Road Elevation Difference (m)	Ground Elevation at Landing Tree (m)	Elevation Difference Between Launch and Landing Tree Bases (m)	Field Survey Date	Frequency of Potential Launch Trees	Frequency of Potential Landing Trees	Potential Glide Distance (m)	Potential Glide Distance minus Distance to Launch Tree	Potential for Successful Glide?	Distance for Glide Angle Calculation	Height for Glide Angle Calculation	Required Glide Ratio	Required Glide Angle	Greater Than Lower Standard Deviation (>21.1)	Glider Home Range
Southern Median	105900-106000	Northbound	SNW06	West	31.7	40.0	50.0	Grey Gum	1200	37.8	-6.1	35	-3.3	12/03/2019	Numerous other closer launch tree of slightly shorter in height	Less than five potential landing trees	60.33	10.3	Yes	48	31.70	1.51	30.2	Yes	F7 and M9
Southern Median	105900-106000	Northbound	SNE06	East	34.7	34.0	43.0	Spotted Gum	700	37.8	-3.1	32	2.7	12/03/2019	Numerous launch trees in zone	Landing trees mostly obscured by regrowth; approximately 5 available	60.33	17.3	Yes	41	31.70	1.29	37.7	Yes	F7 and M9
Southern Median	106000-106100	Northbound	SNW07	West	27.7	31.0	43.0	Red Gum	650	28.8	-1.1	29	-1.3	12/03/2019	Numerous launch trees in zone	Numerous landing trees	47.45	4.4	Yes	41	24.70	1.66	31.1	Yes	F7 and M9
Southern Median	106000-106100	Northbound	SNE07	East	27.8	29.0	43.0	Red Gum	800	28.8	-1.0	31	-3.2	12/03/2019	Numerous launch trees in zone	Numerous landing trees	40.27	-2.7	No however within glide angle standard deviation range	41	20.80	1.97	26.9	Yes	F7 and M9
Northern Median	108400-108500	Northbound	NNW01	West	26.8	20.0	38.5	Bloodwood	450	25.6	1.2	25	1.8	12/03/2019	Several nearby launch trees	Only one suitable landing trees on the eastern side	32.91	-5.6	No however within glide angle standard deviation range	36.5	16.80	2.17	24.7	Yes	F6
Northern Median	108400-108500	Northbound	NNE01	East	25.2	23.0	42.0	Bloodwood	750	25.6	-0.4	27	-1.8	12/03/2019	Several launch trees present	Regrowth on western side will eventually obscure landing trees	39.17	-2.8	No however within glide angle standard deviation range	40	16.20	2.47	22	Yes	F6
Northern Median	108800-108900	Northbound	NNW02	West	17.2	25.0	42.0	Red Mahogany	750	17.290001	-0.1	18	-0.8	12/03/2019	Several launching trees available in zone	Several landing trees available in zone	44.69	2.7	Yes	40	19.20	2.08	25.6	Yes	M5
Northern Median	108800-108900	Northbound	NNE02	East	17.9	14.0	43.0	White Mahogany	400	18.578	-0.7	17	0.9	12/03/2019	Several launching trees available in zone	Several landing trees available in zone	20.22	-22.8	No	41	9.90	4.14	13.6	No	M5
Northern Median	108900-109000	Northbound	NNW03	West	16.2	31.0	34.0	Blackbutt	1200	15.773001	0.4	17	-0.8	12/03/2019	Numerous launch tree options available	Numerous landing tree options available	55.73	21.7	Yes	32	25.20	1.27	38.2	Yes	M5
Northern Median	108900-109000	Northbound	NNE03	East	16.8	21.0	34.0	White mahogany	210	16.053	0.7	16	0.8	12/03/2019	Numerous launch tree options available	Numerous landing tree options available	40.20	6.2	Yes	32	16.76	1.91	27.6	Yes	M5
Northern Median	109000-109100	Northbound	NNW04	West	15.6	25.0	37.0	Blackbutt	700	15.65	0.0	15	0.6	12/03/2019	Numerous launch options available	Numerous landing options available	47.32	10.3	Yes	35	20.63	1.70	30.5	Yes	M5
Northern Median	109000-109100	Northbound	NNE04	East	15.3	23.0	37.0	White Mahogany	300	15.65	-0.3	16	-0.7	12/03/2019	Numerous launch options	Only one or two landing options due to scrubby regrowth	41.25	4.2	Yes	35	17.33	2.02	26.3	Yes	M5
Northern Median	109100-109200	Northbound	NNW05	West	14.6	28.0	39.0	Red Mahogany	1000	14.74	-0.2	17	-2.5	12/03/2019	Various launch options	Few landing options due to dense regrowth on east side	47.17	8.2	Yes	37	20.55	1.80	29	Yes	M5
Northern Median	109100-109200	Northbound	NNE05	East	16.7	20.0	39.0	Blackbutt	210	14.74	2.0	15	1.7	12/03/2019	Minimal tall launch options	Several landing options on west side.	32.71	-6.3	No however within glide angle standard deviation range	37	16.69	2.22	24.3	Yes	M5
Northern Median	109200-109300	Northbound	NNW06	West	13.5	26.0	34.0	Ironbark	700	13.87	-0.4	14	-0.5	12/03/2019	Numerous launch trees available	Numerous landing trees available	47.08	13.1	Yes	32	20.50	1.56	32.6	Yes	M5
Northern Median	109200-109300	Northbound	NNE06	East	14.0	20.0	34.0	Bloodwood	700	13.87	0.1	14	0.0	12/03/2019	Numerous launch trees available	Numerous landing trees available	36.96	3.0	Yes	32	15.00	2.13	25.1	Yes	M5
Northern Median	109300-109400	Northbound	NNW07	West	13.0	31.0	39.0	Blackbutt	1000	13.22	-0.2	13	0.0	12/03/2019	Several launch options in zone	Several landing options in zone	57.20	18.2	Yes	37	26.00	1.42	35.1	Yes	M5
Northern Median	109300-109400	Northbound	NNE07	East	13.4	33.0	39.0	Blackbutt	1000	13.22	0.2	13	0.4	12/03/2019	Several launch options in zone	Several landing options in zone	61.62	22.6	Yes	37	28.40	1.30	37.5	Yes	M5