Woolgoolga to Ballina Pacific Highway upgrade

Invertebrate Monitoring Program Annual Report 2023

Operation Phase Year 3 Report

NSW GOVERNMENT

THIS PAGE LEFT INTENTIONALLY BLANK

Document Control Sheet

File Number: 0180-020f

Project Manager/s: Dr Penn Lloyd

Client: Jacobs on behalf of Transport for NSW (TfNSW)

Project Title: Woolgoolga to Ballina Pacific Highway Upgrade Invertebrate Monitoring Program Annual Report 2023, Year 3 Operation Phase Report

Project Author/s: Dr Penn Lloyd

Project Summary: This report presents the results of the third operation phase season of monitoring for threatened invertebrates for the Woolgoolga to Ballina Pacific Highway Upgrade Project. Monitoring of invertebrate activity and habitat condition was performed for Southern Pink Underwing Moth and Atlas Rainforest Ground Beetle at impact sites close to the new highway and at two control sites in Victoria Park Nature Reserve and Davis Scrub Nature Reserve from November 2022 to March 2023 for comparison with baseline pre-construction and construction phase monitoring results.

Draft Preparation History:

Draft No.	Date draft completed	Reviewed by	Issued by
0108-020f Draft A	18/04/2023	Paulette Jones	Dr Penn Lloyd

Revision/ Checking History Track:

Version	Date of Issue	Checked by	Issued by
0108-020f Version 0	31/05/2023	Paulette Jones	Dr Penn Lloyd

Document Distribution:

Destination	Revision							
	1	Date Dispatched	2	Date Dispatched	3	Date Dispatched	4	Date Dispatched
Client Copy 1 - digital	A	18/04/2023	0	31/05/2023				
Client Copy 1- hard copy								
PDF & MS Word doc – cloud storage	A	18/04/2023	0	31/05/2023				

NOTICE TO USERS OF THIS REPORT

Purpose of Report

Biodiversity Assessment and Management Pty Ltd has produced this report in its capacity as {consultants} for and on the request of Jacobs on behalf of Transport for NSW (TfNSW) (the "Client") for the sole purpose of documenting the results of the third operation phase survey and monitoring for two threatened invertebrate species for the Woolgoolga to Ballina Pacific Highway Upgrade Project (the "Specified Purpose"). This information and any recommendations in this report are particular to the Specified Purpose and are based on facts, matters and circumstances particular to the subject matter of the report and the Specified Purpose at the time of production. This report is not to be used, nor is it suitable, for any purpose other than the Specified Purpose. Biodiversity Assessment and Management Pty Ltd disclaims all liability for any loss and/or damage whatsoever arising either directly or indirectly as a result of any application, use or reliance upon the report for any purpose other than the Specified Purpose.

This report has been produced solely for the benefit of the Client. Biodiversity Assessment and Management Pty Ltd does not accept that a duty of care is owed to any party other than the Client. This report is not to be used by any third party other than as authorised in writing by Biodiversity Assessment and Management Pty Ltd and any such use shall continue to be limited to the Specified Purpose. Further, Biodiversity Assessment and Management Pty Ltd does not make any warranty, express or implied, or assume any legal liability or responsibility for any third party's use in whole or in part of the report or application or use of any other information or process disclosed in this report and to the full extent allowed by law excludes liability in contract, tort or otherwise, for any loss or damage sustained by any person or body corporate arising from or in connection with the supply or use of the whole part of the report through any cause whatsoever.

Biodiversity Assessment and Management Pty Ltd has used information provided to it by the Client and Government registers, databases, departments and agencies in the preparation of this report. Biodiversity Assessment and Management Pty Ltd does not know, nor does it have any reason to suspect, that the information provided to it was false, inaccurate, incomplete or misleading at the time of its receipt. This report is supplied on the basis that while Biodiversity Assessment and Management Pty Ltd believes all the information in it is deemed reliable at the time of publication, it does not warrant its accuracy or completeness and to the full extent allowed by law excludes liability in contract, tort or otherwise, for any loss or damage sustained by any person or body corporate arising from or in connection with the supply or use of the whole or any part of the information in this report through any cause whatsoever.

Copyright and reproduction

Signed on behalf of Date: 31/05/2023

Biodiversity Assessment and Management Pty Ltd

Dr Penn Lloyd
Principal Ecologist and Director

EXECUTIVE SUMMARY

Background and objectives

Biodiversity Assessment and Management (BAAM) has prepared this report for Jacobs on behalf of Transport for NSW (TfNSW) to document the results of the third operation phase survey and monitoring for two threatened invertebrate species for the Woolgoolga to Ballina Pacific Highway Upgrade Project. Construction was completed in late December 2019 and operation of the Woodburn to Pimlico section of the highway that adjoins the study area commenced when this section was opened to all traffic in September 2020. The objectives of the study are to:

1. Undertake four monthly monitoring surveys (November, December, January, February) for Southern Pink Underwing Moth *Phyllodes imperialis smithersi* eggs and larvae during daylight hours at a network of monitoring sites, including two control transect sites, five impact transect sites and 11 additional impact sites close to the highway footprint.
2. Undertake five monthly monitoring surveys (November-March) for Atlas Rainforest Ground Beetle *Nurus atlas* populations at two control transect sites and five impact transect sites.
3. Undertake a single habitat assessment survey for the moth and beetle in March, including a survey for Southern Pink Underwing Moth larvae during daylight hours at all habitat assessment monitoring sites, as well as a survey for Southern Pink Underwing Moth larvae at an additional eight impact sites.
4. Monitor host plant populations (and their condition) for the moth at the monitoring transects and additional nearby sites.
5. Check the outcomes of the monitoring against the performance measures relevant to construction outlined in the Threatened Invertebrates Management Plan (TIMP) for the Project.

Methodology

The methodology used in this study was designed to be consistent with the approach and objectives outlined in the TIMP. Monitoring of Southern Pink Underwing Moth larval abundance, which is indicative of breeding activity was conducted once each month from November 2022 to March 2023 (five survey events) and involved searching for eggs and larvae on the foliage of the species' host plant *Carronia multisepalea*. Monthly monitoring for Atlas Rainforest Ground Beetle (five survey events) involved: (1) searching during daylight hours for burrows consistent with those constructed and maintained by Atlas Rainforest Ground Beetle within a 50 x 20 m transect at each monitoring site; and (2) returning in the early evening to all burrows found during the daytime survey, to confirm whether the burrows were occupied by Atlas Rainforest Ground Beetles, which typically only become active at their burrow entrances at night.

Results and Discussion

A total of 81 Southern Pink Underwing Moth larvae were found at multiple sites during the initial survey in mid-November 2022, indicating a good early-season breeding event. No Southern Pink Underwing Moth larvae were found in December 2022 or January 2023, but a single pupa was found in January. On 20-21 February 2023, unusually large numbers of Southern Pink Underwing Moth eggs (847: 800 at impact sites, 47 at control sites) and early-instar larvae (579: 507 at impact sites, 72 at control sites) were found, with large numbers of eggs (249 at impact sites, 6 at control sites) and larvae of all ages (400 at impact sites, 20 at control sites) again present 17 days later, on 9-10 March 2023. No adult Southern Pink Underwing Moths were observed during the nocturnal monitoring for Atlas Rainforest Ground Beetle. This unusually high level of breeding activity of Southern Pink Underwing Moth occurred to a greater extent at impact sites than control sites, confirming that the initial three years of operation of the new highway have had no indirect

impact on the breeding success of Southern Pink Underwing Moth in retained rainforest habitats close to the highway.

Across all surveys during 2022/23, the greatest numbers of Atlas Rainforest Ground Beetles confirmed at burrow entrances along monitoring transects were as follows: T1 (2 beetles, 2 burrows); between T1 and T5 (1 burrow); C1 in Davis Scrub NR (beetles in 50% of burrows checked, with up to 73 burrows detected on the 50 x 20m transect); and C2 Victoria Park NR (5 burrows). These are all locations where Atlas Rainforest Ground Beetle has been confirmed on previous surveys. No burrows consistent with Atlas Rainforest Ground Beetle were found at any of the other monitoring sites, which is consistent with the results of previous surveys. These results confirm that a low-density population of Atlas Rainforest Ground Beetle occurs in retained rainforest habitats close the highway construction footprint. There has been no evidence of a decline in beetle abundance in this population during the three years of highway construction or during the first three years of operation in comparison with pre-construction abundance.

Richmond Birdwing was found at five different impact sites (total of 25 eggs, 50 larvae, 1 pupa, 3 butterflies) as well as in planted host vines near site C2 in Victoria Park Nature Reserve (total of 10 larvae), with larvae found during all five surveys through the 2022/23 season. The incidental observations from the current survey confirm ongoing breeding by the species in the study area, with no evidence of a decline in the population of the species or its host plant.

Measures of habitat condition in the third year of operation have remained stable since the 2021/22 monitoring in the second year of operation.

Conclusions

No evidence of a decline attributable to the project in numbers of either Southern Pink Underwing Moth or Atlas Rainforest Ground Beetle was detected during the third year of operation of the highway. The record high abundance of Southern Pink Underwing Moth larvae in 2022/23 by comparison with previous years may be attributable to natural variation in the response of this species to environmental conditions, which are not yet well understood.

Incidental observations of Richmond Birdwing from the current survey confirm ongoing breeding by the species in the study area, with no evidence of a decline in the population of the species or its host plant Richmond Birdwing Vine *Pararistolochia praevenosa*.

This report represents the final report at the conclusion of the monitoring program that the TIMP specified would continue for three years post-construction. There is no evidence that the Project has had a negative indirect impact on Southern Pink Underwing Moth, Atlas Rainforest Ground Beetle or the condition of their habitats or host plants adjacent to the Project during either construction or the first three years of operation of the highway bypass. Consequently, no additional management measures or continued monitoring are recommended to facilitate the long-term survival of the threatened invertebrates and habitats adjacent to the Project.

INVERTEBRATE MONITORING PROGRAM ANNUAL REPORT 2023
YEAR 3 OPERATION PHASE REPORT

WOOLGOOLGA TO BALLINA PACIFIC HIGHWAY UPGRADE

Table of Contents

Table of Figures

Table of Appendices

Table of Terms and Abbreviations

BAAM	Biodiversity Assessment and Management Pty Ltd
BC Act	New South Wales *Biodiversity Conservation Act 2016*
Conservation significant	Includes species listed as Critically Endangered, Endangered, Vulnerable and Near Threatened under the EPBC Act and/or BC Act and species listed as Regionally Significant under the Byron Biodiversity Conservation Strategy, which have been identified in association with rainforest communities in the Study Area
EPBC Act	Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*
SKM	Sinclair Knight Merz
Study Area	The area encompassing a network of monitoring sites close to the Woolgoolga to Ballina Pacific Highway Upgrade Corridor between Pimlico and Buckombil Mountain southwest of Ballina, northern New South Wales
TfNSW	Transport for NSW
TIMP	Woolgoolga to Ballina Threatened Invertebrate Management Plan

1.0 INTRODUCTION

1.1. BACKGROUND AND PURPOSE

Biodiversity Assessment and Management (BAAM) has prepared this report for Jacobs on behalf of Transport for NSW (TfNSW) to document the results of surveys and monitoring for conservation significant invertebrates on properties close to Section 10 of the Woolgoolga to Ballina Pacific Highway Upgrade at Coolgardie Road near Wardell in northern New South Wales during the third year of the operation phase of the new highway. The scope of work also required monitoring at control locations in two national park estates to the north-west of Section 10 for comparative purposes.

This report fulfils obligations specified under the Woolgoolga to Ballina Threatened Invertebrate Management Plan (TIMP) (NSW Roads and Maritime Services 2015), which prescribes management and monitoring approaches for values protected by the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the *Biodiversity Conservation Act 2016* (BC Act). Key objectives of the TIMP with regards to monitoring include the following:

- Monitor breeding activity, age (eggs, larvae, adults) and numbers of Southern Pink Underwing Moth *Phyllodes imperialis smithersi* sufficient to detect population change in comparison with the baseline population, including whether a decline in numbers occurs over a three-year post-construction survey period, controlling for natural seasonal variability
- Monitor the presence and abundance of Atlas Rainforest Ground Beetle *Nurus atlas* in known and potential habitat areas sufficient to detect population change in comparison with the baseline population, including whether a decline in numbers occurs over a three-year post-construction survey period, controlling for natural seasonal variability
- Monitor habitat condition for Southern Pink Underwing Moth and Atlas Rainforest Ground Beetle in known habitat retained outside the project clearing boundary sufficient to detect change in habitat condition in comparison with the baseline condition, including whether a decline in habitat condition occurs after each monitoring event
- Monitor the abundance of host plants for Southern Pink Underwing Moth larvae in known habitat retained outside the project clearing boundary sufficient to detect change in host plant abundance in comparison with the baseline abundance, including whether a decline in host plant abundance occurs after each monitoring event.

To meet the monitoring objectives of the TIMP, this study specifically aims to:

- Monitor Southern Pink Underwing Moth *Phyllodes imperialis smithersi* and Atlas Rainforest Ground Beetle *Nurus atlas* populations at five established monitoring transects close to Section 10 of the Project (referred to as ‘impact sites’ due to their potential to experience indirect impacts due to their close proximity to the highway construction footprint) and two nearby control sites
- Monitor habitat condition for the moth and beetle at the monitoring transects and additional nearby sites
- Monitor host plant populations (and their condition) for the moth at the monitoring transects and additional nearby sites
- Check the outcomes of the monitoring against the performance measures relevant to construction outlined in the TIMP (NSW Roads and Maritime Services 2015).

The area encompassing the complete network of impact and control monitoring sites included in this study is hereafter referred to as the ‘study area’.

1.2. SITE DESCRIPTION

The portion of the Woolgoolga to Ballina Pacific Highway Upgrade that passes through the study area partially follows the footprint of the existing Pacific Highway near Pimlico in the north, then diverting to the west from the intersection of Coolgardie Road southwest to Lumleys Lane, Wardell (**Figure 1.1**). The five impact transect monitoring sites as well as other habitat monitoring sites are located in vegetation types that include Lowland Rainforest of Subtropical Australia, listed as a Threatened Ecological Community (TEC) under the EPBC Act and an Endangered Ecological Community under the BC Act, as well as rainforest regrowth that does not meet the condition thresholds for recognition as the TEC (BAAM 2012, 2013). The rainforest regrowth includes patches dominated by Camphor Laurel *Cinnamomum camphora*, an introduced tree species. Almost all patches of these habitats close to Section 10 are restricted to steep rocky slopes or lower slopes on dark basaltic soils (Sheringham *et al.* 2008). However, red basaltic soils transition abruptly to lighter coloured soils, presumably kurosols derived from metamorphic rocks (Jenkins and Morand 2002) on some parts of Buckombil Mountain. Furthermore, one habitat monitoring site north of Coolgardie Road occurs in rainforest on the alluvial plain.

The two control sites are situated north-west of Section 10, in Victoria Nature Reserve and Davis Scrub Nature Reserve. Both these reserves contain remnant Lowland Rainforest on rich red ferrosols formed on a basaltic plateau (Jenkins and Morand 2002).

1.3. CONSTRUCTION WORK

The highway upgrade involved the construction of a partly raised, multi-lane highway, with interchanges, lighting and temporary construction infrastructure located at appropriate points. This development required clearing of vegetation and earthwork along a linear corridor through the study area; however, the position of the road corridor was sited to avoid direct impact to rainforest habitats close to the road corridor that contain populations of the conservation significant invertebrates targeted in this study. More specific details on the Project are available in NSW Roads and Maritime Services (2013). The start of vegetation clearing for the highway upgrade close to the impact monitoring sites commenced in November 2017. By March 2018, the highway construction footprint had been cleared and substantial road-base had been laid down, and by March 2019 the highway construction was well progressed but not yet complete. The final components of construction were completed in late December 2019.

1.4. COMMENCEMENT OF HIGHWAY OPERATION

Operation of the Woodburn to Pimlico section of the highway that adjoins the study area commenced when this section was opened to all traffic in September 2020 and it has remained operational since then.

1.5. TARGET SPECIES

The target species for this monitoring program are the two threatened invertebrate species that are known to occur in rainforest habitats in the study area:

- Southern Pink Underwing Moth *Phyllodes imperialis smithersi* (listed as endangered under the EPBC Act and the BC Act) and its host plant *Carronia multisepalea* (not threatened)
- Atlas Rainforest Ground Beetle *Nurus atlas* (listed as endangered under the BC Act).

Incidental observations of a third species, Richmond Birdwing *Ornithoptera richmondia*, listed as Regionally Significant under the Byron Biodiversity Conservation Strategy, and its host plant Richmond Birdwing Vine *Pararistolochia praevenosa* (not threatened), were also included as a component of the assessment.

BAAM ECOLOGICAL CONSULTANTS

Client	Jacobs on behalf of TfNSW	
Project	Woolgoolga to Ballina Pacific Highway Upgrade Invertebrate Monitoring	
Design	BAAM	4.05.2017
Drawn	Bentline | MP	4.05.2017
Scale	1:600,000	# 0108-020
Cad File	BAAM_PacHWY01.dwg	NTP 87
Title	Location of the Study Area	FIGURE 1.1

1.6. MODIFICATIONS TO THE MONITORING METHODOLOGY FOR PINK UNDERWING MOTH

The initial three seasons of monitoring for Southern Pink Underwing Moth between March 2014 and March 2018 incorporated two methods: (1) nocturnal monitoring for adult Southern Pink Underwing Moths attracted to baits of over-ripe bananas placed on transects through each of the five impact and two control monitoring sites, undertaken once per month within the period November to March, including incidental searches for larvae; and (2) habitat assessment and intensive searches for Southern Pink Underwing Moth larvae on host plants at each of 18 habitat assessment sites within the study area, undertaken once each year in February/March.

While a variety of moth species that feed on ripe fruit were detected during the nocturnal monitoring surveys between March 2014 and March 2018, no Southern Pink Underwing Moth adults were positively detected despite considerable survey effort (588 bait-nights) and evidence of extensive breeding by the species in the study area (BAAM 2014, 2017, 2018). This led to the conclusion that the nocturnal monitoring method is ineffective in detecting adult Southern Pink Underwing Moths due to the high mobility, unpredictability and apparent rarity of the adult moths (BAAM 2018). A recommendation was made to modify the monitoring approach for Pink Underwing Moth to provide more effective monitoring of habitat use, breeding activity and population change (BAAM 2018). The recommended change to the monitoring approach was to discontinue the monitoring of adult moths and allocate the survey effort previously expended on this method to improving the survey effort coverage of larval-stage monitoring. Larval surveys offer the best method for monitoring habitat use and population change in Southern Pink Underwing Moth due to the predictable association of the larval stages with a single host plant species and the relative ease with which larvae can be surveyed on host plants. Recommendations for a revised survey approach for Southern Pink Underwing Moth were as follows (BAAM 2018):

- Four monthly surveys (November, December, January, February) for Southern Pink Underwing Moth eggs and larvae during daylight hours at an expanded network of monitoring sites, including the two control transect sites, five impact transect sites and 11 additional sites close to the highway construction footprint.
- A single habitat assessment survey in March, including a survey for Southern Pink Underwing Moth larvae during daylight hours at all habitat assessment monitoring sites, as well as a survey for Southern Pink Underwing Moth larvae at an additional eight sites identified during the March 2018 survey. This survey replicates the habitat assessment survey as originally outlined in the TIMP but expands the number of Southern Pink Underwing Moth larvae monitoring sites for the assessment of total larval population size. While larval abundance is typically greatest in March, the timing of the habitat assessment survey should be flexible such that if larvae are detected earlier in the season than normal, then the habitat assessment survey could be switched with one of the monthly surveys to ensure that the habitat assessment survey is conducted at the anticipated time of greatest larval abundance.

The recommended revision to the survey approach for Southern Pink Underwing Moth was adopted by Transport for NSW prior to the start of Year 2 of the construction phase. The recommended revised approach is therefore implemented in this report as set out in the following section.

2.0 METHODOLOGY

The methodology used in this study was designed to be consistent with the approach and objectives outlined in the Threatened Invertebrates Management Plan (NSW Roads and Maritime Services 2015). It included monitoring of threatened invertebrates and host plants during the months November 2022 to March 2023 (five monitoring events in total), and a single habitat assessment survey in February/March 2023. Surveys were performed by Dr Penn Lloyd (Principal Ecologist) and Emma Green (Project Ecologist) at monthly intervals. All surveys were performed under BAAM's NSW Scientific Licence number SL100704.

2.1. MONITORING SOUTHERN PINK UNDERWING MOTH LARVAL ABUNDANCE

Monitoring of Southern Pink Underwing Moth larval abundance, which is indicative of breeding activity, was conducted at a network of 18 monitoring sites, including two control transect sites (C1 and C2), five impact transect sites (T1 to T5) and 11 other impact sites in retained habitat close to the highway footprint. The locations of the monthly monitoring sites are shown in **Figure 2.1**.

During each monitoring event, the undersides of the leaves and stems of most of the *Carronia multisepalea* host plants present at each site were searched for eggs and larvae during daylight hours. Wherever eggs or larvae were found, the position of the observation was recorded using a hand-held GPS and the number and age of the larvae were noted. Larval ages were characterised on the basis of the five stages of growth that larvae (caterpillars) go through, referred to as larval instars, between the time they hatch from eggs and the time they become a pupa. These stages are illustrated in the photos below. Incidental searches for Southern Pink Underwing Moth adults were also undertaken during the nocturnal surveys for Atlas Rainforest Ground Beetle described in the next section.

Photo 2.1. Pink Underwing Moth egg.

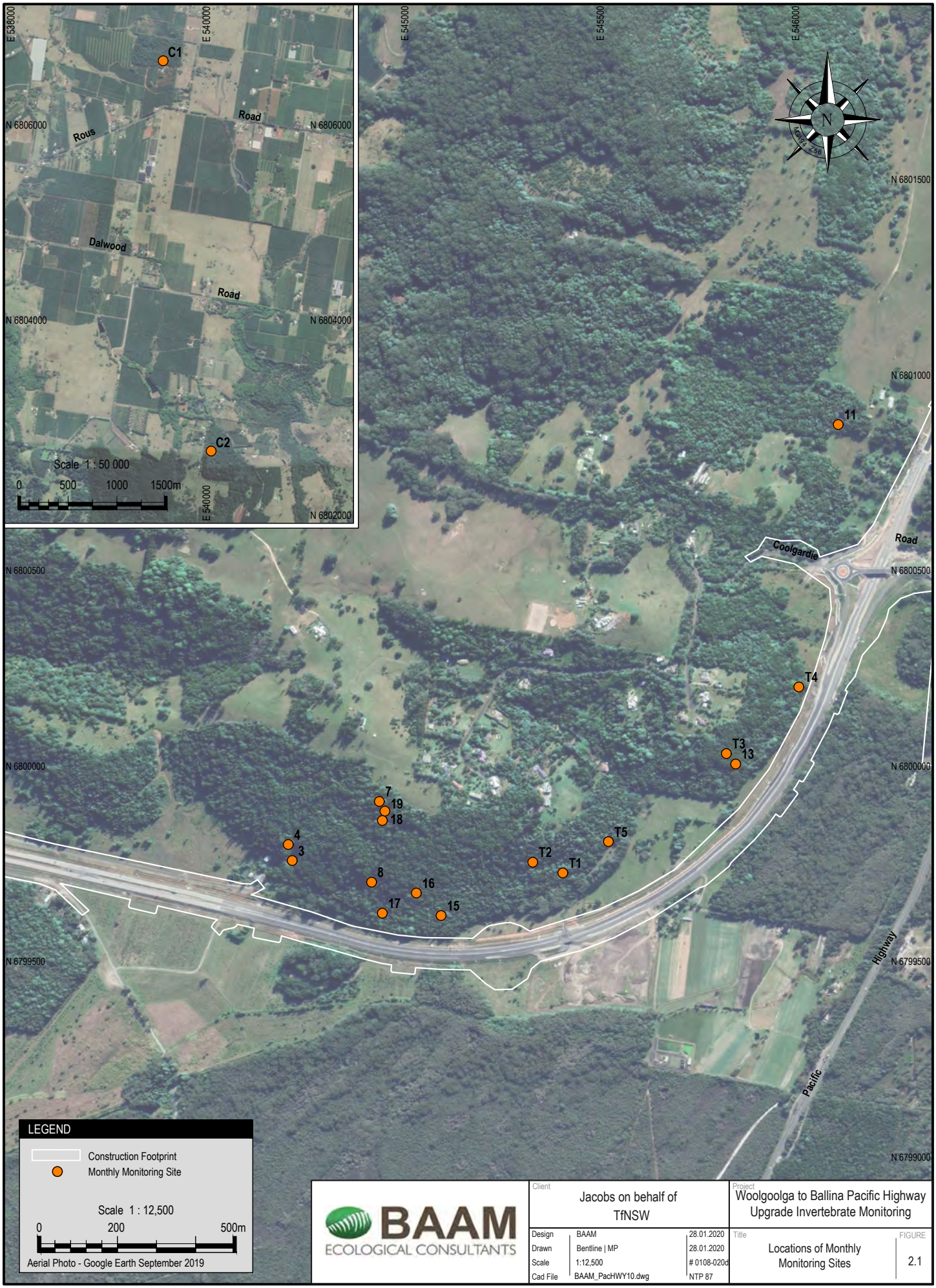
Photo 2.2. Pink Underwing Moth 1st instar larva.

Photo 2.3. Pink Underwing Moth 2nd instar larva.

Photo 2.4. Pink Underwing Moth 3rd instar larva.

Photo 2.5. Pink Underwing Moth 4th instar larvae.

Photo 2.6. Pink Underwing Moth 5th instar larva.



BAAM ECOLOGICAL CONSULTANTS

Client	Jacobs on behalf of TfNSW	Project	Woolgoolga to Ballina Pacific Highway Upgrade Invertebrate Monitoring
Design	BAAM	28.01.2020	
Drawn	Bentline | MP	28.01.2020	
Scale	1:12,500	# 0108-020d	
Cad File	BAAM_PacHWY10.dwg	NTP 87	
Title	Locations of Monthly Monitoring Sites	FIGURE	2.1

2.2. MONITORING ATLAS RAINFOREST GROUND BEETLE ABUNDANCE

Monitoring of Atlas Rainforest Ground Beetle abundance was conducted in conjunction with the Southern Pink Underwing Moth monitoring. This monthly monitoring was conducted at an expanded network of monitoring sites, including two control transect sites (C1 and C2), five impact transect sites (T1 to T5) and 11 additional impact sites close to the highway construction footprint. Each monitoring survey involved: (1) searching during daylight hours for burrows consistent with those constructed and maintained by Atlas Rainforest Ground Beetle within a 50 x 20 m transect at each monitoring site; and (2) returning in the early evening to all burrows found during the daytime survey, to confirm whether the burrows were occupied by Atlas Rainforest Ground Beetles, which typically only become active at their burrow entrances at night. During the nocturnal survey starting approximately 45 minutes after sunset, burrows were approached as quietly as possible and LED head-torches were used to first check for the presence of a beetle at each burrow entrance from a short distance away before shining the torch down the burrow to check for the presence of a beetle deeper in the burrow.

2.3. MONITORING HABITAT CONDITION

The habitat condition survey, conducted over two days 20-21 February 2023, included assessment of habitat condition at a network of habitat assessment sites for each of the two invertebrate species as well as searches for Southern Pink Underwing Moth larvae and Atlas Rainforest Ground Beetle burrows. The habitat condition assessment sites included the five impact transect sites, two control transect sites and additional sites (11 for Southern Pink Underwing Moth and eight for Atlas Rainforest Ground Beetle) located more broadly within the study area close to the highway construction footprint (**Figure 2.2**). The habitat condition assessment methods for each of the two invertebrate species are outlined in the following two sections.

2.3.1. Southern Pink Underwing Moth

In accordance with the preconstruction survey, the following data were collected at each of the 18 fixed habitat condition assessment sites for Southern Pink Underwing Moth:

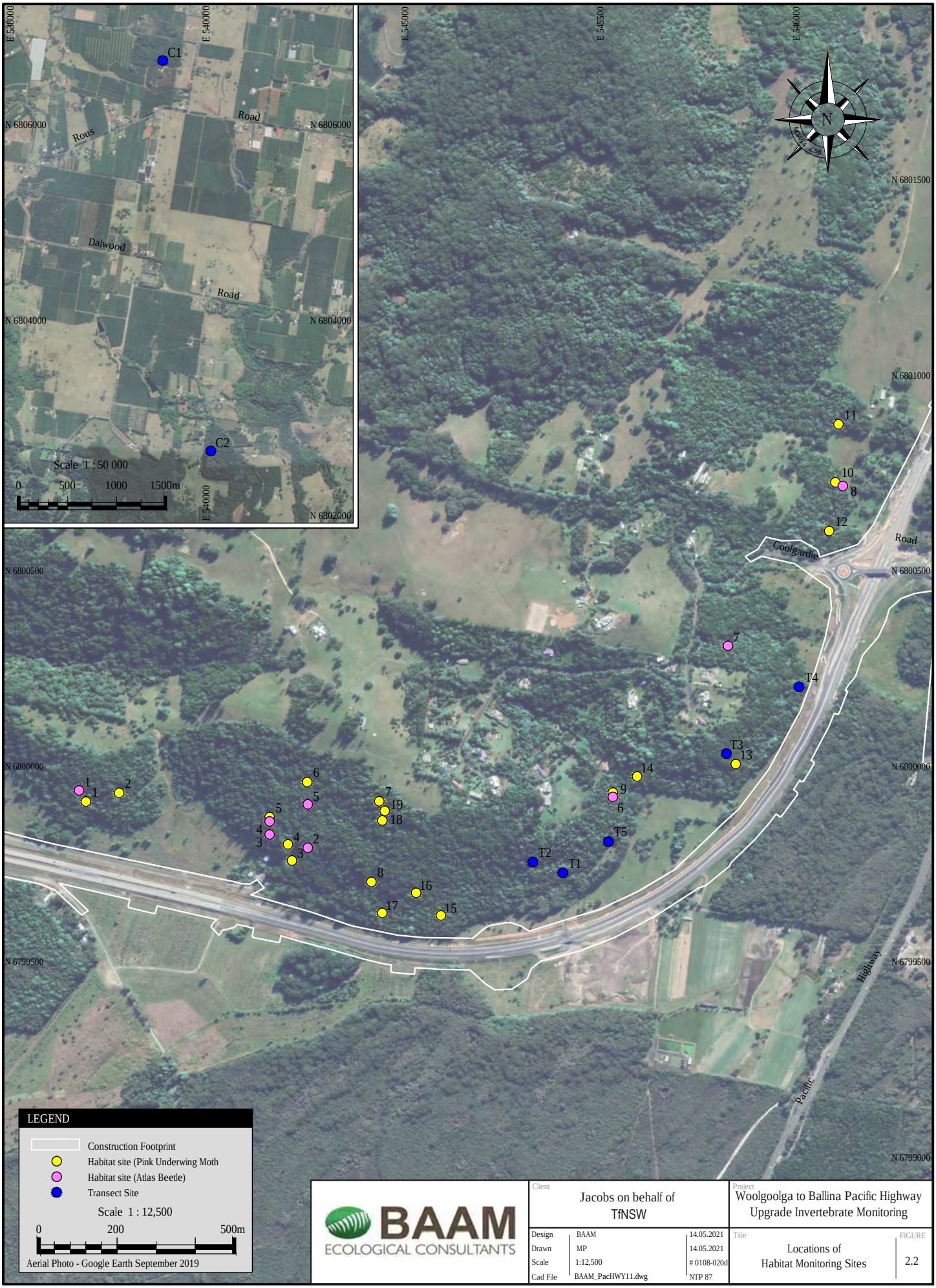
- Presence or absence of host plants (*Carronia multisepalea*)
- Number of fleshy-fruited native tree species in the habitat surrounding the site
- Percent cover of native and exotic plant species in each stratum of the habitat surrounding the site, estimated by eye
- Percent canopy cover of the habitat surrounding the site, estimated by eye.

At each of the five impact site transects and two control site transects, photographs were taken at each cardinal compass point at the centre of each transect for comparison with baseline condition photographs.

2.3.2. Atlas Rainforest Ground Beetle

In accordance with the preconstruction survey, the following data were collected at each of the 15 fixed habitat assessment sites for Atlas Rainforest Ground Beetle:

- Percentage cover of rocks in the ground layer
- Percentage cover of logs in the ground layer
- Percentage cover of overhangs in the ground layer
- Total number of active burrows consistent with the size and shape of those inhabited by Atlas Rainforest Ground Beetle found during a meandering search in areas of suitable habitat at the site, searching the bases of rocks, logs and plant roots for burrow entrances; surveys focussed particularly on areas where burrows have previously been recorded.



BAAM ECOLOGICAL CONSULTANTS

Client	Jacobs on behalf of TfNSW	
Project	Woolgoolga to Ballina Pacific Highway Upgrade Invertebrate Monitoring	
Design	BAAM	14.05.2021
Drawn	MP	14.05.2021
Scale	1:12,500	# 0108-020d
Cad File	BAAM_PacHWY11.dwg	NTP 87
Title	Locations of Habitat Monitoring Sites	FIGURE 2.2

2.4. HABITAT MAPPING AND CONDITION SCORES FOR SOUTHERN PINK UNDERWING MOTH

The first preconstruction survey (BAAM 2014) mapped patches of habitat for Southern Pink Underwing Moth into three categories:

1. Known habitat where the host plant occurs and the adult moth or larvae have been recorded
2. Potential habitat where the host plant occurs but the adult moth or larvae have not been recorded
3. Potential habitat where neither the host plant nor the adult moth or larvae have yet been detected.

Areas of potential and known habitat were scored by 'habitat condition' relative to the ecological requirements of Southern Pink Underwing Moth as far as they are understood. Polygons were given a score of between 0 and 6, with a point being awarded for each one of these criteria (modified from BAAM 2013):

- Host plant (*Carronia multisepalea*) was detected during the surveys
- Number of native fleshy-fruited tree species detected during the survey was >20
- Patch exhibited natural canopy gaps, allowing for potential recruitment of the host plant
- Canopy cover comprised >50% native species
- Number of rainforest indicator species (from TSSC 2011) was >30
- Included areas where canopy cover was dominantly ≥65%.

This mapping was designed to be updated based on the survey results following each year of monitoring. The results of the present study required no amendments to the mapping based on the application of the criteria listed above.

2.5. MONITORING HOST PLANT POPULATIONS

In accordance with the preconstruction survey, the following data were collected at each of the 18 fixed habitat condition assessment sites for Southern Pink Underwing Moth:

- Total number of *Carronia multisepalea* plants
- Dominant leaf characteristics (broad-leaved or narrow-leaved) of *Carronia multisepalea* plants at the site, including presence of soft, pale, new leaf growth, and any evidence of leaf damage consistent with the feeding of Southern Pink Underwing Moth larvae
- Presence, total number and age of any Southern Pink Underwing Moth eggs or larvae found on *Carronia multisepalea* host plants.

Wherever additional patches of *Carronia multisepalea* were encountered during meandering traverses of the study area between the previously identified fixed monitoring sites, the foliage of the plants was thoroughly searched to identify the presence, total number and age of any Southern Pink Underwing Moth eggs or larvae.

2.6. OPPORTUNISTIC SURVEY FOR RICHMOND BIRDWING

Opportunistic observations and records of Richmond Birdwing butterflies and larvae were made during each of the monthly daytime surveys. This included searching the foliage of host plants (Richmond Birdwing Vine *Pararistolochia praevenosa*) for the distinctive Richmond Birdwing larvae.

3.0 RESULTS AND DISCUSSION

3.1. RAINFALL CONDITIONS DURING THE MONITORING PERIOD

Rainfall from January to May 2022 in the preceding wet season was substantially above average. During the 2022/23 wet season, rainfall was again above average in September-October but slightly below average November 2022 to March 2023 (**Figure 3.1**). These rainfall conditions resulted in good vegetation growth and condition throughout the 2022/23 summer season.

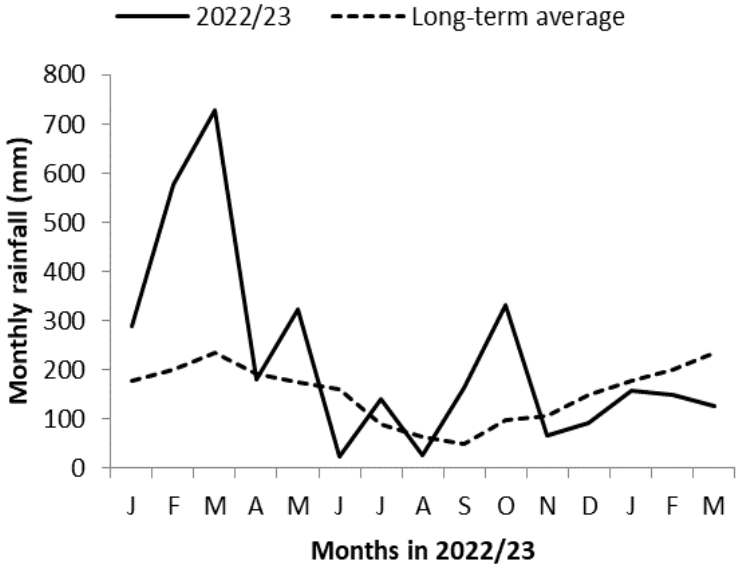


Figure 3.1. Monthly rainfall at Meerschaum Vale weather station during 2022/23 compared to the long-term average (BoM 2023).

3.2. SOUTHERN PINK UNDERWING MOTH ABUNDANCE

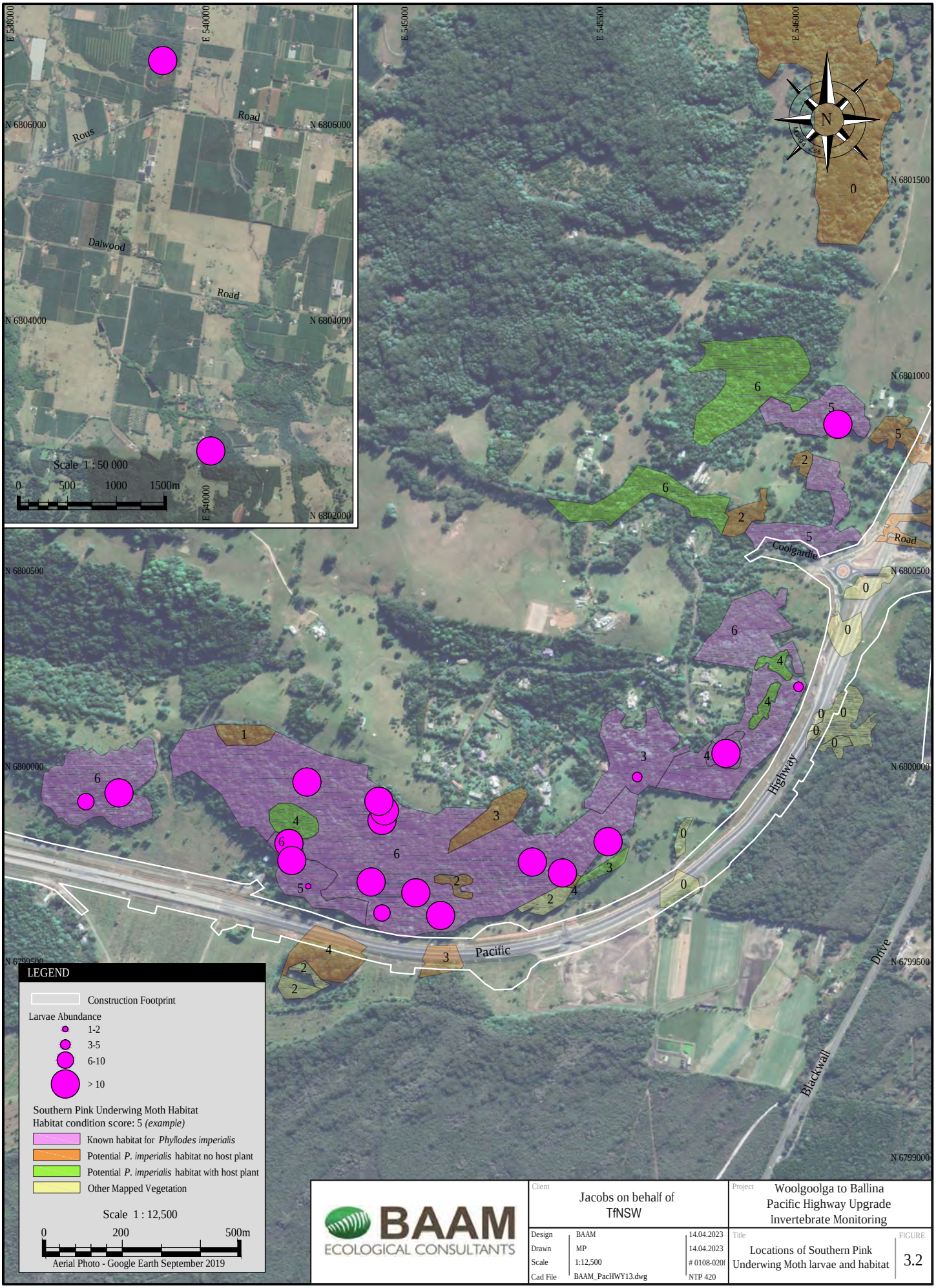
A summary of the monthly monitoring results is provided in **Table 3.1**. A total of 81 Southern Pink Underwing Moth larvae were found at multiple sites during the initial survey in mid-November 2022, indicating a good early-season breeding event. No Southern Pink Underwing Moth larvae were found in December 2022 or January 2023, but a single pupa was found in January. On 20-21 February 2023, unusually large numbers of Southern Pink Underwing Moth eggs (847: 800 at impact sites, 47 at control sites) and early-instar larvae (579: 507 at impact sites, 72 at control sites) were found, with large numbers of eggs (249 at impact sites, 6 at control sites) and larvae of all ages (400 at impact sites, 20 at control sites) again present 17 days later, on 9-10 March 2023 (**Figure 3.2, Table 3.1**). No adult Southern Pink Underwing Moths were observed during the nocturnal monitoring for Atlas Rainforest Ground Beetle.

The finding of relatively large numbers of Southern Pink Underwing Moth larvae during the various surveys (see **Table 3.2** for a summary) has confirmed that the study area is a significant breeding area for Southern Pink Underwing Moth, particularly during favourable seasonal rainfall conditions. The large and dispersed population of *Carronia multisepalea* plants at impact sites T1 and T2 consistently supported the greatest numbers of Southern Pink Underwing Moth larvae in different seasons prior to 2021/22. Inadvertent herbicide treatment that reduced the cover of *Carronia multisepalea* plants at site T1 by around 50%, combined with a substantial reduction in the forest canopy cover at T1 following the control of weed trees during forest rehabilitation works conducted by the private landholder had reduced the suitability of site T1 for Southern Pink Underwing Moth during the 2021/22 season. Consequently, whereas site T1 had supported between 25% and 32% of larvae at impact sites in previous years, it supported only 1% of larvae in 2021/22. Monitoring site T1 is located on private land adjacent to the Pacific Highway easement and is therefore not managed by Transport for NSW (TfNSW).

Table 3.1. Summary of the results of monitoring for Southern Pink Underwing Moth and Atlas Rainforest Ground Beetle.

Date	Rainfall	General Notes	Atlas Rainforest Ground Beetle	Southern Pink Underwing Moth
16 November 2022	July-October rainfall of 660 mm, substantially greater than the long-term average of 303 mm over this period.	Mild (27°C) partly cloudy day with light winds; no rain.	Burrows consistent with Atlas Rainforest Ground Beetle were found during the day at C1 only (73 burrows within 50x10 m plot; 50% of 20 burrows checked in the evening were confirmed to have a beetle present).	Pink Underwing Moth larvae (total of 81) were detected at multiple sites: T1 (2), T3 (30), PUM03 (6), PUM06 (7), PUM07 (11), PUM11 (5), PUM 15 (3), PUM16 (14) and PUM19 (3). Two fruit-piercing moth larva were found at PUM03. Carronia host plants had good fresh growth at most sites. Richmond Birdwing were detected at multiple sites: T2 (7 eggs, 22 larvae, 1 pupa); T5 (1 larva); PUM04 (1 egg, 13 larvae, 1 butterfly); PUM11 (1 egg, 2 larvae); and on planted vines near C2 (1 larva).
22 December 2022	A further 131 mm through November to 22 December, below average for that period.	Mild (25°C) partly cloudy day with light winds; no rain.	Burrows consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (two burrows) and C1 (42 burrows within 50x10 m plot).	No Pink Underwing Moth or fruit-piercing moth larvae were found. Carronia host plants had good fresh growth at most sites. Richmond Birdwing were detected at: T5 (1 egg); and on planted vines near C2 (8 larvae).
18 January 2023	Approximately 50mm since the previous survey, below average for this period.	Mild (26°C) partly cloudy day with light winds; no rain.	Burrows consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (one burrow) and C1 (37 burrows within 50x10 m plot).	No Pink Underwing Moth or fruit-piercing moth larvae or eggs were found. A single Pink Underwing Moth pupa was found at PUM19. Carronia host plants had good fresh growth at most sites. Richmond Birdwing were detected at a single site: PUM11 (2 larvae).
20-21 February 2023	Approximately 200mm since the previous survey.	Warm (26-28°C) partly cloudy days with light winds; light showers in the early morning.	Burrows consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (1 burrows), C2 (1 burrow) and C1 (35 burrows within 50x10 m plot).	Southern Pink Underwing Moth eggs (total of 847) and larvae (total of 579) were detected at nearly all monitoring sites: C1, C2, T1 to T5, PUM01-04, PUM06-08, PUM11, PUM13, PUM15-19. Larvae of fruit-piercing moth species were present at five monitoring sites, with a total of 6 larvae found. Richmond Birdwing eggs (12), larvae (10) or butterflies (2) were detected at six sites.

Date	Rainfall	General Notes	Atlas Rainforest Ground Beetle	Southern Pink Underwing Moth
9-10 March 2023	Approximately 85mm since the previous survey.	Warm (26-28°C), humid, overcast days with light winds; no rain.	Burrows consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (2 burrows), between T1 and T5 (1 burrow), C2 (5 burrows) and C1 (58 burrows within 50x10 m plot).	Southern Pink Underwing Moth eggs (total of 255) and larvae (total of 420) were detected at nearly all monitoring sites: C1, C2, T1 to T5, PUM03-04, PUM06-08, PUM11, PUM13-19. Larvae of fruit-piercing moth species were present at three monitoring sites, with a total of 5 larvae found. Richmond Birdwing eggs (3) and larvae (3) were detected at three sites.



BAAM ECOLOGICAL CONSULTANTS

Client: Jacobs on behalf of TfNSW

Project: Woolgoolga to Ballina Pacific Highway Upgrade Invertebrate Monitoring

Design	BAAM	14.04.2023
Drawn	MP	14.04.2023
Scale	1:12,500	# 0108-020f
Cad File	BAAM_PacHWY13.dwg	NTP 420

Title: Locations of Southern Pink Underwing Moth larvae and habitat

FIGURE 3.2

Table 3.2. Summary of the numbers of Southern Pink Underwing Moth larvae found during recent targeted surveys for the species in north-eastern NSW.

Survey	Summary of larvae found
Pre-construction: Six days 6-10 February and four days 13-16 March 2012, focussed on habitats close to the highway construction footprint, including sites further north and south of the current monitoring area (BAAM 2012).	No larvae found during the February survey, but **22 larvae** found during the March survey, 15 at what later became monitoring site T1 and 7 around T3.
Pre-construction: A broader habitat and population assessment survey 11-15 February 2013 at impact sites (BAAM 2013)	A total of **45 larvae** and **9 eggs** recorded, all at sites T1 and T2.
Pre-construction: Six nocturnal monitoring surveys between 5 March and 9 April and a broader habitat and population assessment survey 18-20 March 2014 at impact and control sites (BAAM 2014).	No larvae found at impact monitoring sites, but **one larva** found in late March at Davis Scrub Nature Reserve control site C1.
Two surveys 5-9 December 2016 and 19-24 February 2017 at 63 sites with host plant populations across north-eastern NSW between Tweed Heads and Wardell (Richards and Andren 2017).	A total of **56 larvae** recorded from 22 sites at seven discrete localities, 9 during the early December survey and 47 during the late February survey, but none at Davis Scrub or Victoria Park Nature Reserves.
Pre-construction: Two nocturnal monitoring surveys 1 and 30 March 2017 and a broader habitat and population assessment survey 28-31 March 2017 at impact and control sites (BAAM 2017).	No larvae found.
Construction Year 1: Six nocturnal monitoring surveys between 8 November 2017 and 7 March 2018 and a broader habitat and population assessment survey 6-8 March 2018 at impact and control sites (BAAM 2018).	No larvae found November to January but **21 larvae** and **1 egg** found during brief surveys on 20 February and **75 larvae** found during more extensive survey 6-8 March, including 70 at impact sites and 5 at Davis Scrub Nature Reserve control site C1.
Construction Year 2: Six monthly surveys between 27 November 2018 and 5 March 2019 at impact and control sites (BAAM 2019).	A total of **41 larvae** found in late November, **14 larvae** in mid-December, **3 larvae** in early February and **18 larvae** in early March, all at impact sites.
Construction Year 3: Two monthly surveys 26 November and 17 December 2019 at impact and control sites (BAAM 2020).	A **single larva** found in November at Davis Scrub Nature Reserve control site C1; no larvae found at impact monitoring sites.
Operation Year 1: Five monthly surveys between 17 November 2020 and 17 March 2021 at impact and control sites (BAAM 2021).	**Two larvae** found at control site C1 in February and a total of **13 larvae** found in March: 12 at four impact sites; and one at control site C1.
Operation Year 2: Six monthly surveys between 12 October 2021 and 10 March 2022 at impact and control sites (BAAM 2022).	A total of **24 larvae** found on 24 November 2021, **233 eggs and 170 larvae** on 7-8 February 2022 and **1 egg and 137 larvae** on 10 March 2022. A total of **52 eggs and 69 larvae** at control sites C1 and C2, and **119 eggs and 325 larvae** at impact sites through 2021/22.
Operation Year 3: Five monthly surveys between 16 November 2022 and 10 March 2023 at impact and control sites (this study).	A total of **81 larvae** found on 16 November 2022, **847 eggs and 579 larvae** on 20-21 February 2023 and **255 eggs and 420 larvae** on 9-10 March 2023. A total of **53 eggs and 92 larvae** at control sites C1 and C2, and **756 eggs and 988 larvae** at impact sites through 2022/23.

The surveys conducted to date show that both the timing of breeding and the relative abundance of larvae during each breeding event are variable (**Table 3.2, Figure 3.3**). Breeding events appear to occur in early summer (November/December) and/or late summer (February/March). Although breeding activity was greater in early summer in the 2018/19 season, in most years breeding activity is greater in late summer than in early summer. This pattern of breeding activity is consistent with the species having two generations per year and a lifespan of about 80 days: egg 8 days, larva 18 days, pupa 25 days and adult 30 days (Andren *et al*. 2021). Thus, adults emerge in early summer from pupae that have remained dormant through winter, to lay eggs that develop into larvae in November/December. The adults produced by this first generation then emerge in mid- to late-summer to lay eggs that develop into larvae in February/March.

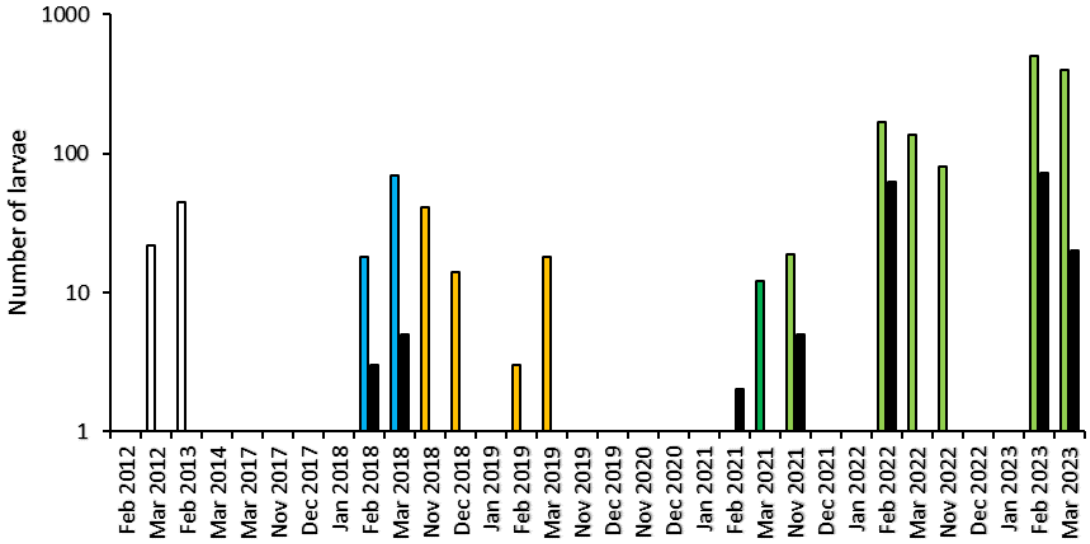


Figure 3.3. Southern Pink Underwing Moth total larval abundance (on logarithmic scale) at impact monitoring sites during pre-construction (February 2012 to March 2017, white bars), construction year 1 (November 2017 to March 2018, blue bars), construction year 2 (November 2018 to March 2019, orange bars), construction year 3 (November to December 2019), and operation years 1 to 3 (November 2020 to March 2023, dark green bar) surveys. Black bars show total larval abundance at control sites.

The abundance of Southern Pink Underwing Moth larvae across the network of impact monitoring sites during the first two construction-year survey periods was equivalent to or greater than larval abundance during the pre-construction surveys (**Figure 3.3**). This result demonstrates that the initial two years of construction works on the highway upgrade had no indirect impact on the breeding success of Southern Pink Underwing Moth in retained rainforest habitats close to the highway construction footprint. Due to the short duration of monitoring in Year 3 of the construction phase, which covered only the early portion of the species' potential breeding season, as well as the prevailing dry conditions that may have inhibited early-season breeding, it is not possible to make meaningful comparisons of that year with previous seasons. The relatively lower abundance of Southern Pink Underwing Moth larvae detected during the full season of surveys during Year 1 of the operation phase was a little unexpected given that ideal conditions were experienced with above-average summer rainfall that resulted in a substantially greater abundance of fruit-piercing moth and Richmond Birdwing Butterfly larvae than detected during any previous monitoring surveys at the site. However, the relatively low breeding activity of Southern Pink Underwing Moth occurred at both the control and impact sites; therefore, it could represent natural variability. There is also the potential for a negative relationship between Southern Pink Underwing Moth and fruit-piercing moth breeding activity since their larvae feed on the same host plant species; during the seasons of high Southern Pink Underwing Moth breeding activity in 2017/18, 2018/19, 2021/22 and 2022/23, larvae of fruit-piercing moths were either absent or present in low numbers (BAAM 2018, 2019, 2022).

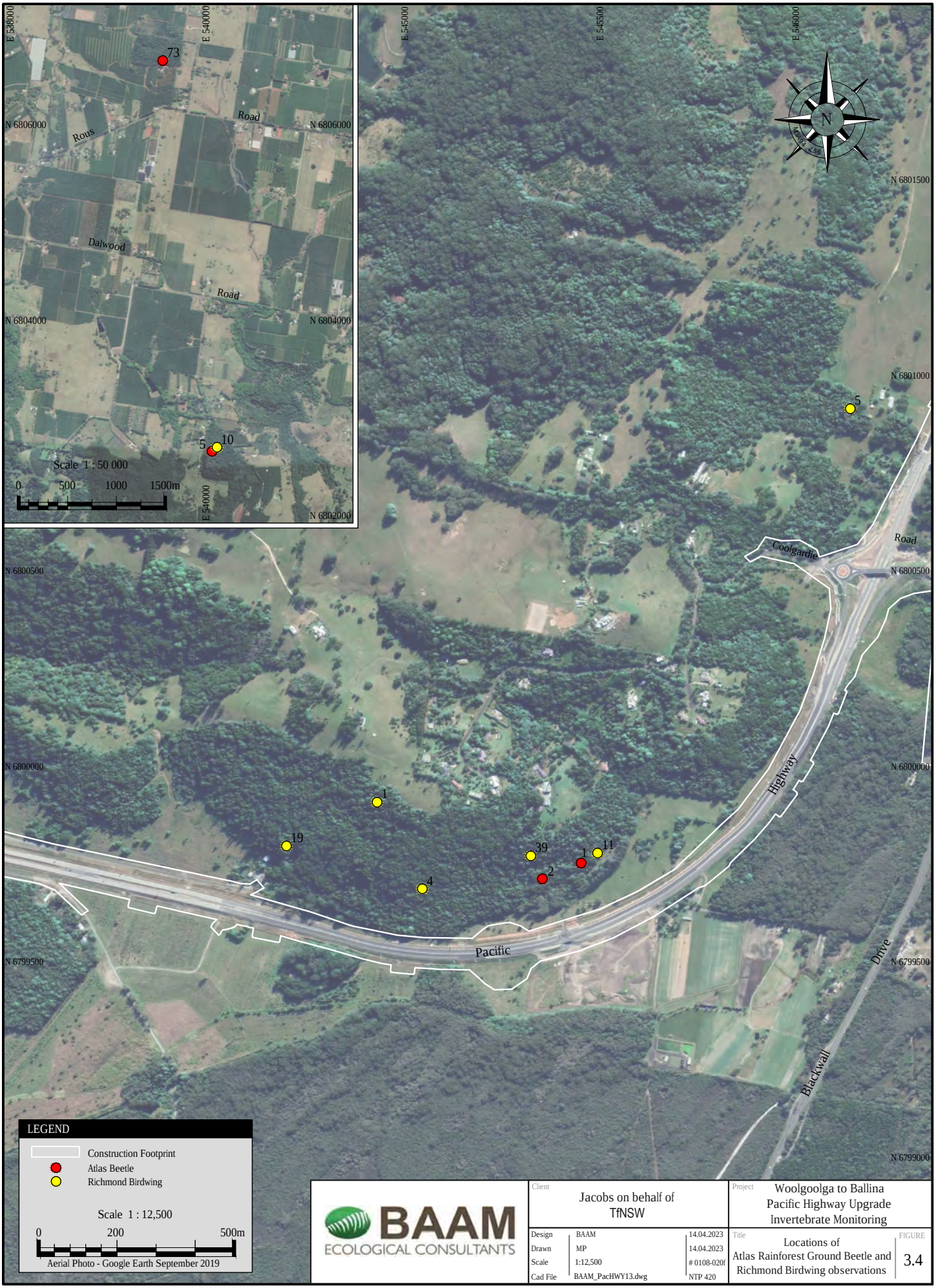
The substantially increased abundance of Southern Pink Underwing Moth larvae in the second year of operation in 2021/22 and even greater abundance of larvae in the third year of operation in 2022/23 coincided with consecutive seasons of above-average rainfall and low breeding activity of fruit-piercing moths. A survey of 143 sites in suitable habitat across northern NSW over 64 days across five summer seasons between November 2016 and March 2021 recorded a total of 132 eggs and 396 larvae of Southern Pink Underwing Moth (Andren *et al*. 2021). Thus, the total of 1,102 eggs and 999 larvae over four days in February and March 2023 reported here, mostly from sites located within several hundred metres of the new highway bypass represents the most significant breeding event of this species recorded to date. This unusually high level of breeding activity of Southern Pink Underwing Moth occurred to a greater extent at impact sites than control sites, confirming that the initial three years of operation of the new highway have had no indirect impact on the breeding success of Southern Pink Underwing Moth in retained rainforest habitats close to the highway.

3.3. ATLAS RAINFOREST GROUND BEETLE ABUNDANCE

Across all surveys during 2022/23, the greatest numbers of Atlas Rainforest Ground Beetles confirmed at burrow entrances along monitoring transects were as follows: T1 (2 beetles, 2 burrows); between T1 and T5 (1 burrow); C1 in Davis Scrub NR (beetles in 50% of burrows checked, with up to 73 burrows detected on the 50 x 20m transect); and C2 Victoria Park NR (5 burrows) (**Table 3.1, Figure 3.4**). These are all locations where Atlas Rainforest Ground Beetle has been confirmed on previous surveys. No burrows consistent with Atlas Rainforest Ground Beetle were found at any of the other monitoring sites, which is consistent with the results of previous surveys.

Table 3.3. Summary of the numbers of Atlas Rainforest Ground Beetles or burrows found during surveys for the species in the study area.

Survey	Summary of beetles or burrows found
Pre-construction: Six days 6-10 February and four days 13-16 March 2012, focussed on habitats close to the highway construction footprint, including sites further north and south of the current monitoring area (BAAM 2012).	**One beetle** in a burrow at what later became monitoring site T1.
Pre-construction: Six nocturnal monitoring surveys between 5 March and 9 April and a broader habitat and population assessment survey 18-20 March 2014 at impact and control sites (BAAM 2014).	Up to **three beetles** in burrows at Davis Scrub Nature Reserve control site C1, **one beetle** in a burrow at Victoria Park control site C2, many more potential burrows at C1 and C2, one potential burrow at T3.
Pre-construction: Two nocturnal monitoring surveys between 1 and 30 March 2017 and a broader habitat and population assessment survey 28-31 March 2017 at impact and control sites (BAAM 2017).	Up to six beetle burrows with up to **four beetles** at C1, up to **two beetles** at C2, and **one beetle** at T1.
Construction Year 1: Six nocturnal monitoring surveys between 8 November 2017 and 7 March 2018 and a broader habitat and population assessment survey 6-8 March 2018 at impact and control sites (BAAM 2018).	Up to **nine beetles** at C1 but no burrows found at C2, **one beetle** at T1 and two new locations with up to **two beetles** at T5 and up to **four beetles** 45m south-east of T1.
Construction Year 2: Six daytime and nocturnal monitoring surveys between 29 November 2018 and 5 March 2019 and a broader habitat and population assessment survey 12-13 December 2018 at impact and control sites (BAAM 2019).	Up to **44 beetles** at C1, no burrows found at C2 but up to eight beetles in burrows nearby**, two beetles** at T1, **three beetles** at T5 and **three beetles** between T1 and T5.
Construction Year 3: Two daytime and nocturnal monitoring surveys 26 November and 17 December 2019 (BAAM 2020).	Up to 37 burrows with 50% confirmed activity at C1, no burrows at C2, 2 burrows (no beetles) at T1, 1 burrow (**1 beetle**) at T5 and 3 burrows (no beetles) between T1 and T5.
Operation Year 1: Five monthly surveys between 17 November 2020 and 17 March 2021 at impact and control sites (BAAM 2021).	Up to 50 burrows with 75% confirmed activity at C1, no burrows at C2, 2 burrows (2 beetles) at T1, 1 burrow (**1 beetle**) at T5, no burrows between T1 and T5.
Operation Year 2: Six monthly surveys between 12 October 2021 and 10 March 2022 at impact and control sites (this study).	Up to 137 burrows with 71% confirmed activity at C1, no burrows at C2, 2 burrows (2 beetles) at T1, no burrow at T5, up to 5 burrows between T1 and T5, 2 burrows at PUM07.
Operation Year 3: Five monthly surveys between 16 November 2022 and 10 March 2023 at impact and control sites (this study).	Up to 73 burrows with 50% confirmed activity at C1, up to 5 burrows at C2, 2 burrows at T1, no burrow at T5, 1 burrow between T1 and T5.



BAAM ECOLOGICAL CONSULTANTS

Client	Jacobs on behalf of TfNSW		
Project	Woolgoolga to Ballina Pacific Highway Upgrade Invertebrate Monitoring		
Design	BAAM	14.04.2023	
Drawn	MP	14.04.2023	
Scale	1:12,500	# 0108-020f	
Cad File	BAAM_PacHWY13.dwg	NTP 420	
Title	Locations of Atlas Rainforest Ground Beetle and Richmond Birdwing observations	FIGURE	3.4

The 2021/22 surveys detected similar numbers of Atlas Rainforest Ground Beetles at the impact monitoring sites as were found during previous surveys (**Table 3.3, Figure 3.5**), confirming the presence of small numbers of beetles at two different locations at or close to the T1 impact monitoring site, an ongoing healthy population at Davis Scrub Nature Reserve control site C1 and the appearance of a small population at Victoria Park control site C2. The increase in the total number of beetles at Davis Scrub Nature Reserve control site C1 since 2018/19 is largely due to the changed Southern Pink Underwing Moth survey protocol that allows more time for searching for beetle burrows during the day.

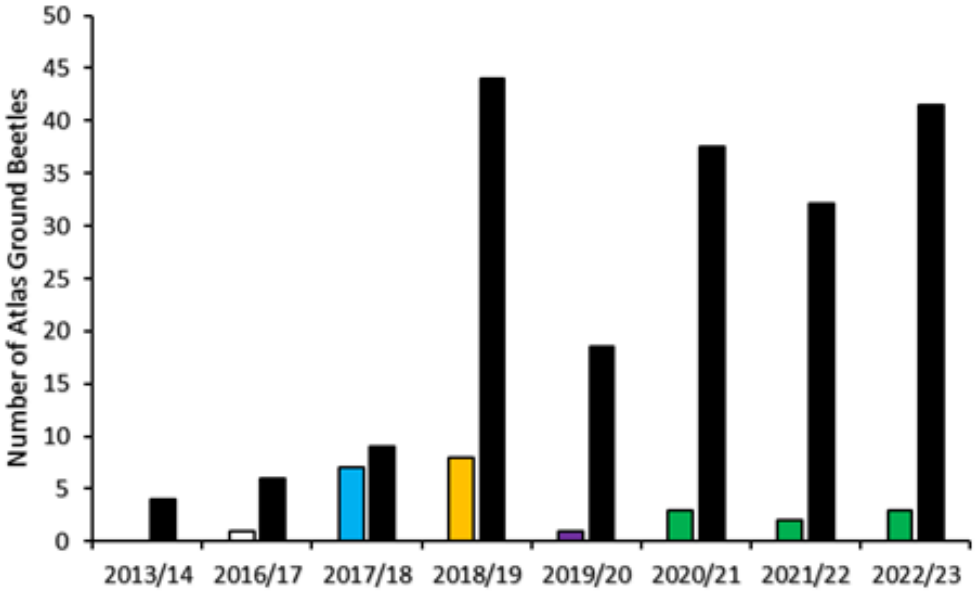


Figure 3.5. Atlas Rainforest Ground Beetle total maximum abundance at impact monitoring sites during pre-construction (2013/14 and 2016/17, white bars), construction year 1 (2017/18, blue bar), construction year 2 (2018/19, orange bar), construction year 3 (2019/20, purple bar) and operation years 1 to 3 (2020/21 to 2022/23, green bars) surveys. Black bars show maximum beetle abundance at control sites.

These results confirm that a low-density population of Atlas Rainforest Ground Beetle occurs in retained rainforest habitats close the highway construction footprint. There has been no evidence of a decline in beetle abundance in this population during the three years of highway construction or during the first three years of operation in comparison with pre-construction abundance (**Figure 3.5**).

3.4. RICHMOND BIRDWING

Richmond Birdwing was found at five different impact sites (total of 25 eggs **Photo 3.1**, 50 larvae (**Photo 3.2**), 1 pupa, 3 butterflies) as well as in planted host vines near site C2 in Victoria Park Nature Reserve (total of 10 larvae), with larvae found during all five surveys through the 2022/23 season (**Table 3.1**). The locations of these observations are shown in **Figure 3.4**.

Previous surveys identified an active breeding population of Richmond Birdwing together with relatively large numbers of its larval host plant *Pararistolochia praevenosa* in rainforest habitats close to the highway construction footprint (BAAM 2012, 2014, 2017, 2018, 2019, 2020, 2021, 2022). The incidental observations from the current survey confirm ongoing breeding by the species in the study area, with no evidence of a decline in the population of the species or its host plant.

Photo 3.1. Richmond Birdwing egg on the underside of a Birdwing Vine leaf.

Photo 3.2. Richmond Birdwing larva.

3.5. HABITAT CONDITION

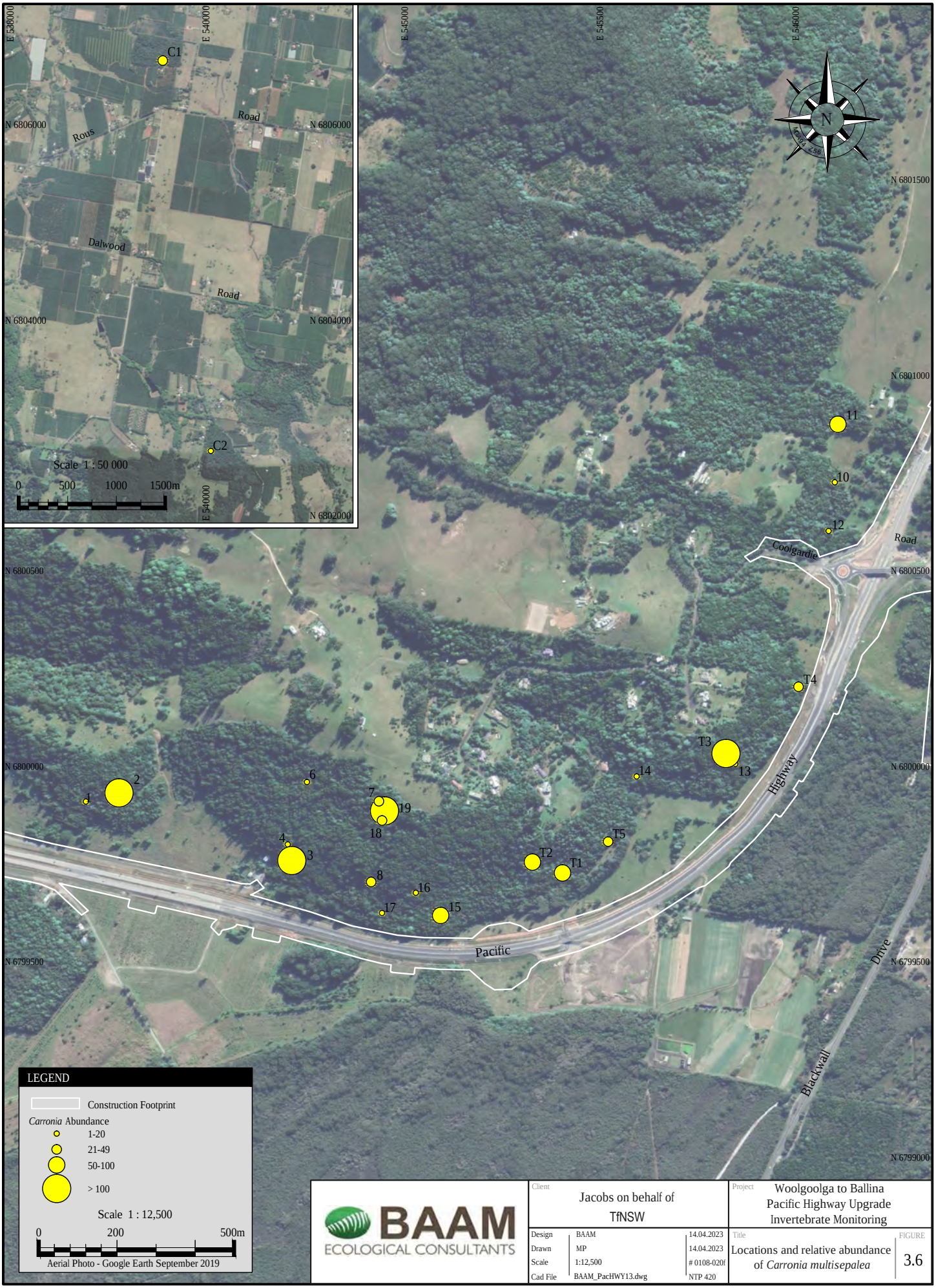
Detailed data from the habitat condition assessments are presented in **Appendices A** and **B**. Measures of habitat condition have generally remained stable since the March 2018 first construction survey, with one exception. The canopy tree layer at site T1 was substantially modified through 2020/21 as a result of herbicide treatments conducted by the private landholder to kill invasive trees at this site in accordance with the Threatened Invertebrates Management Plan (TIMP) objectives of restoring degraded rainforest habitat areas adjacent to the highway. The tree canopy at site T1 had previously been dominated by invasive Camphor Laurel (*Cinnamomum camphora*), Broad-leaved Privet (*Ligustrum lucidum*) and introduced Mango (*Mangifera indica*) trees, but most of these trees had been killed but left standing by November 2020. The increased light had facilitated the growth and spread of the invasive Mile-a-minute vine (*Ipomoea cairica*), which, together with vigorous growth of the native Burny Bean vine (*Mucuna gigantea*) had smothered a portion of the carronia shrub population at this site in 2020/21. Spraying of the Mile-a-minute vine with herbicide by the private landholder before the start of the 2021/22 season inadvertently killed around half of the cover of carronia host plant at site T1, substantially reducing the suitability of this site for Southern Pink Underwing Moth. Nonetheless, ongoing growth of the abundant native tree saplings present in the understorey of the treated areas is expected to improve habitat condition over the long term if the spread of Mile-a-minute vine is effectively controlled during the rehabilitation works being undertaken by the private landholder with the aim of restoring the native tree canopy layer.

3.5.1. Southern Pink Underwing Moth

Patches of the host plant *Carronia multisepalea* were found at all Southern Pink Underwing Moth habitat monitoring sites where the host plant had been previously recorded i.e. the five impact transect sites, two control transect sites, nine of the 11 additional habitat assessment sites and eight additional sites located more broadly near the highway construction footprint (**Figure 3.6**).

Host plant population sizes at each of the monitoring sites were generally stable since the previous survey in 2022 (**Figure 3.7**). Host plants in all populations were found to be in good health, typically with signs of substantial new growth following above-average early summer rainfall.

Southern Pink Underwing Moth larvae from the 2021/22 season were recorded at all but three of the sites where larvae have previously been recorded as well as being recorded for the first time at two additional sites, including at site PUM14 in a polygon of habitat in which the species has not previously been recorded. Consequently, the extent of known habitat for the species increased by 3.55 ha to 49.1 ha. **Table 3.4** summarises the extents of known and potential habitat scored and ranked based on habitat condition (with a score of “6” being the highest ranking of habitat condition). The habitat condition scores remain unchanged.



BAAM ECOLOGICAL CONSULTANTS

Client	Jacobs on behalf of TfNSW		
Design	BAAM	14.04.2023	
Drawn	MP	14.04.2023	
Scale	1:12,500	# 0108-020f	
Cad File	BAAM_PacHWY13.dwg	NTP 420	

Project: Woolgoolga to Ballina Pacific Highway Upgrade Invertebrate Monitoring

Title: Locations and relative abundance of *Carronia multisepalea*

FIGURE 3.6

Table 3.4. Extent of Southern Pink Underwing Moth habitat ranked according to condition.

Habitat condition ranking (see Section 2.3)	Area (hectares)		
	Known habitat	Potential habitat (where host plant is present)	Potential habitat (where host plant was not detected)
0	0	0	0.3
1	0	0	3.7
2	0	0	1.2
3	3.6	0.3+	3.0
4	0.5	3.0	4.2
5	6.5	0	11.6
6	38.6	7.8	0
No ranking[1]	0	0	16.6
TOTAL AREA	49.1	11.2	40.6

[1] Rankings were allocated only to polygons visited as part of this study or previous surveys (BAAM 2012, 2013, 2014, 2017, 2018, 2019, 2020, 2021,2022)

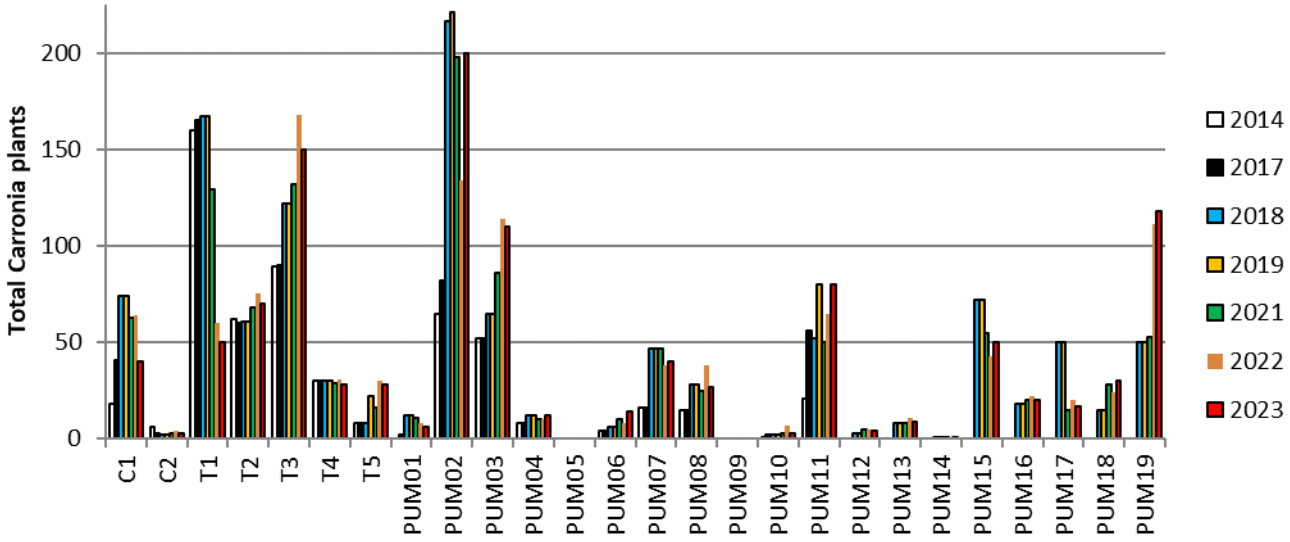


Figure 3.7. Comparison of *Carronia multisepalea* counts between surveys during pre-construction (2014 and 2017), construction year 1 (2018), construction year 2 (2019) and operation years 1 to 3 (2021 to 2023).

The habitat mapping and condition scores for Southern Pink Underwing Moth are presented in **Figure 3.2**.

3.5.2. Atlas Rainforest Ground Beetle

Habitat condition for Atlas Rainforest Ground Beetle has remained stable since the 2017 preconstruction survey (**Appendices A** and **B**).

3.6. CONCLUSIONS ON OUTCOMES RELATIVE TO PERFORMANCE INDICTORS

The Threatened Invertebrates Management Plan (TIMP) is intended to be a dynamic document subject to continual improvement (NSW Roads and Maritime Services 2015). The TIMP specifies performance indicators and corrective actions if monitoring finds poor outcomes, as outlined in **Table 3.5** below. Also included in **Table 3.5** is an assessment of whether corrective actions are triggered by the monitoring results of the 2022/23 season.

Table 3.6. Summary of monitoring outcomes relative to the performance indicators and corrective actions specified in the TIMP.

Monitoring element	Trigger for corrective action	Corrective actions	Assessment of 2021/22 monitoring outcomes
Southern Pink Underwing Moth annual surveys Atlas Rainforest Ground Beetle annual surveys	Evidence of a decline in numbers over a three-year post-construction survey period.	• If decline is noted in invertebrate numbers at a monitoring event from the baseline evaluate potential causes. • Review monitoring locations and cross reference with monitoring results of rehabilitation areas and monitoring of Lowland Rainforest communities in Section 10 and Section 11. • Evaluate population numbers at the control sites and investigate additional areas of habitat beyond the project and consider options to improve habitat condition and connectivity. • If a decline is still noted after three consecutive years of monitoring engage with OEH and EPA and consider provisional measures. • This may include a review and update of the monitoring program to consider more intense monitoring or different techniques to identify if the decline is as a result of the Project. • If there is an additional residual impact to threatened invertebrates Roads and Maritime will evaluate the need for additional offsets.	No evidence of a decline attributable to the project in numbers of either Southern Pink Underwing Moth or Atlas Rainforest Ground Beetle during the third year of operation. Instead, record high numbers of Southern Pink Underwing Moth eggs and larvae were observed, including at sites close to the operational highway, confirming the occurrence of an exceptionally good breeding event. No corrective actions triggered.
Invertebrate habitat condition monitoring (known habitat retained outside the project clearing boundary)	Evidence of a decline in habitat condition after each monitoring event. Less than 100% survival rate of retained host plants.	• Evaluate reasons for the decline such as weed incursion, edge effects or natural event. • Review and revise management techniques as appropriate. • Continue monitoring program to evaluate effectiveness of revised management actions.	No evidence of a decline in invertebrate habitat condition besides a reduction in tree canopy cover at site T1 in 2021/22 due to herbicide treatment of tree weeds during forest rehabilitation works undertaken by the private landholder that will improve habitat quality over the longer term. No further decline in tree canopy cover in 2022/23 or evidence of a decline in invertebrate habitat condition elsewhere in the study area. No corrective actions triggered.
Host plant condition monitoring	Evidence of a decline in host plant quantity or habitat condition.	• If decline in host plant numbers or habitat condition is noted during any annual period of monitoring, review and revise management techniques as appropriate. • Erect temporary shade cloth adjacent to host plants where these occur in edge areas to minimise dust impacts and increased exposure until plants have stabilised. • If decline noted after three years post-construction monitoring, cross reference with monitoring of threatened invertebrates. • Investigate additional areas of habitat beyond the project and consider options to improve habitat condition and connectivity. • If decline still noted in subsequent two monitoring periods engage with OEH and consider provisional measures. • Further monitoring of provisional measures would be planned at this stage.	No evidence of a decline in host plant condition besides a reduction in host plant cover at site T1 in 2021/22 due to inadvertent death of plants after herbicide treatment of invasive Mile-a-minute Vine smothering those plants. No further decline in host plant cover at site T1 in 2022/23 and no evidence of reduced survival of host plants elsewhere in the study area. No corrective actions triggered.

Corrective action investigation was triggered in 2021/22 by the observation of the reduction in cover of host plants at monitoring site T1 following the death of host plants. Subsequent investigation of the causes of this localised reduction in the number and cover of host plants found that it was due to inexperienced contractors engaged in forest rehabilitation works who sprayed herbicide on invasive Mile-a-minute Vine that was smothering the host plants, inadvertently killing the host plants at the same time. These forest rehabilitation works are being undertaken by the private landholder. Transport NSW has no jurisdiction over the management of the land; consequently, the impact is not a result of the Project and no corrective action under the TIMP is required. Nonetheless, the impact of the herbicide treatment was brought to the attention of the private landholder as soon as it was observed at the start of the 2021/22 monitoring season in October 2021. In response, the private landholder immediately implemented controls to avoid a recurrence of inadvertent spraying of host plants with herbicide during weed control works. No recurrence occurred through the remainder of the 2021/22 or during the 2022/23 monitoring season. There was no further decline in tree canopy cover or host plant cover at site T1 through 2022/23.

This report represents the final report at the conclusion of the monitoring program that the TIMP specified would continue for three years post-construction. As outlined in the previous sections, there is no evidence that the Project has had a negative indirect impact on Southern Pink Underwing Moth, Atlas Rainforest Ground Beetle or the condition of their habitats or host plants adjacent to the Project during either construction or the first three years of operation of the highway bypass. Consequently, no additional management measures or continued monitoring are recommended to facilitate the long-term survival of the threatened invertebrates and habitats adjacent to the Project.

4.0 REFERENCES

Biodiversity Assessment and Management (BAAM) (2012). Ballina to Woodburn Pacific Highway Upgrade Targeted Threatened Invertebrate Study. Report prepared for Sinclair Knight Merz.

Biodiversity Assessment and Management (BAAM) (2013). Supplementary survey for Pink Underwing Moth. Report prepared for Sinclair Knight Merz.

Biodiversity Assessment and Management (BAAM) (2014). Preconstruction Survey and Nocturnal Monitoring for Conservation Significant Invertebrates. Report prepared for NSW Roads and Maritime Services.

Biodiversity Assessment and Management (BAAM) (2017). Woolgoolga to Ballina Pacific Highway Upgrade Preconstruction Invertebrate Monitoring Report 2017. Report prepared for Jacobs on behalf of Pacific Complete.

Biodiversity Assessment and Management (BAAM) (2018). Woolgoolga to Ballina Pacific Highway Upgrade Year 1 Construction Phase Invertebrate Monitoring Report 2018. Report prepared for Jacobs on behalf of Pacific Complete.

Biodiversity Assessment and Management (BAAM) (2019). Woolgoolga to Ballina Pacific Highway Upgrade Year 2 Construction Phase Invertebrate Monitoring Report 2019. Report prepared for Jacobs on behalf of Pacific Complete.

Biodiversity Assessment and Management (BAAM) (2020). Woolgoolga to Ballina Pacific Highway Upgrade Year 3 Construction Phase Invertebrate Monitoring Report 2020. Report prepared for Jacobs on behalf of Pacific Complete.

Biodiversity Assessment and Management (BAAM) (2021). Woolgoolga to Ballina Pacific Highway Upgrade Year 1 Operation Phase Invertebrate Monitoring Report 2021. Report prepared for Jacobs on behalf of Pacific Complete.

BoM (2022). Weather data from Meerschaum Vale weather station number 58171. Available at: http://www.bom.gov.au/climate/data/

Common I.F.B. (1990). *Moths of Australia*. Melbourne University Press, Melbourne.

Jenkins B. and Morand D. (2002). A comparison of basaltic soils and associated vegetation patterns in contrasting climatic environments. In: Roach I.C. (ed) *Regolith and landscapes in eastern Australia*. CRCLEME (Cooperative Research Center for Landscape Environments and Mineral Exploration), Australia.

Monteith, G. B. and Turco, F. (n. d.). A Guide to Species of the Ground Beetle Genus *Nurus* (Coleoptera: Caribidae) in the Lismore District, NSW. Queensland Museum, Brisbane.

NSW Roads and Maritime Services (2013). *Woolgoolga to Ballina Appendix E Supplementary Biodiversity Assessment of Submissions/Preferred Infrastructure Report.*

NSW Roads and Maritime Services (2015). *Woolgoolga to Ballina Pacific Highway Threatened Invertebrates Management Plan. Version 3.*

Richards, P. and Andren, M. (2017). Southern Pink Underwing Moth *Phyllodes imperialis smithersi* Sands (Erebidae): Surveys to identify key habitats and breeding sites. Report prepared for the NSW Office of Environment and Heritage.

Sands, D. P. A. (2012). Review of Australian *Phyllodes imperialis* Druce (Lepidoptera: Prebidae) with description of a new subspecies from subtropical Australia. *Australian Entomologist* 39: 281-292.

Sheringham P.R., Dr. Benwell A., Gilmour, P., Graham M.S., Westaway J., Weber L., Bailey, D., and Price, R. (2008). *Targeted Vegetation Survey of Floodplains and Lower Slopes on the Far North Coast. A report prepared by the Department of Environment and Climate Change for the Comprehensive Coastal Assessment.* Department of Environment and Climate Change (NSW), Coffs Harbour, NSW.

Threatened Species Scientific Committee (TSSC) (2011). Commonwealth Listing Advice on Lowland Rainforest of Subtropical Australia. Department of Sustainability, Environment, Water, Population and Communities.

APPENDIX A

Descriptions and photo-monitoring results for impact and control site transects

Transect name, target species and position		**Comparative photographs**			
		North	**East**	**South**	**West**
T1. Confirmed location for Southern Pink Underwing Moth and Atlas Rainforest Ground Beetle. Start: 28.9296°S 153.4652°E. End: 28.9294°S 153.4657°E.	2014				
	2017				
	2018				
	2019				

Transect name, target species and position		Comparative photographs			
		North	East	South	West
	2021				
	2022				
	2023				
T2. Confirmed location for Southern Pink Underwing Moth. Suitable for Atlas Rainforest Ground Beetle. Start: 28.9293°S 153.4649°E. End: 28.9292°S 153.4653°E.	2014				

Transect name, target species and position		Comparative photographs			
		North	East	South	West
	2017				
	2018				
	2019				
	2021				

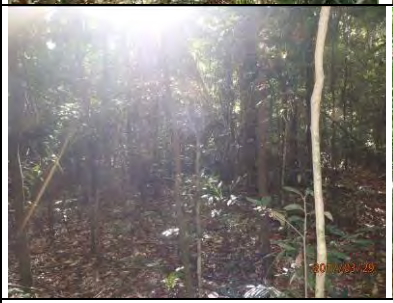
Transect name, target species and position		Comparative photographs			
		North	East	South	West
	2022				
	2023				
T3. Suitable for Southern Pink Underwing Moth and Atlas Rainforest Ground Beetle. Start: 28.9268°S 153.4698°E. End: 28.9266°S 153.4701°E.	2014				
	2017				

Transect name, target species and position		Comparative photographs			
		North	East	South	West
	2019				
	2021				
	2022				
	2023				

Transect name, target species and position		Comparative photographs			
		North	East	South	West
T4. Confirmed location for Southern Pink Underwing Moth. Suitable for Atlas Rainforest Ground Beetle. Start: 28.9253°S 153.4718°E. End: 28.9248°S 153.4719°E.	2014				
	2017				
	2019				
	2021				

Transect name, target species and position		Comparative photographs			
		North	East	South	West
	2022				
	2023				
T5. Suitable for Southern Pink Underwing Moth and Atlas Rainforest Ground Beetle. Start: 28.9286°S 153.4669°E. End: 28.9290°S 153.4665°E.	2014				
	2017				

Transect name, target species and position		Comparative photographs			
		North	East	South	West
	2018				
	2019				
	2021				
	2022				

Transect name, target species and position		Comparative photographs			
		North	East	South	West
	2023				
C1. Confirmed site for Atlas Rainforest Ground Beetle. Suitable for Southern Pink Underwing Moth. Start: 28.8665°S 153.4051°E. End: 28.8668°S 153.4048°E.	2014				
	2017				
	2018				

Transect name, target species and position		Comparative photographs			
		North	East	South	West
	2019				
	2021				
C2. Confirmed site for Atlas Rainforest Ground Beetle. Suitable for Southern Pink Underwing Moth. Start: 28.9028°S 153.4102°E. End: 28.9030°S 153.4100°E.	2014				
	2017				

Transect name, target species and position		Comparative photographs			
		North	East	South	West
	2018				
	2019				
	2021				
	2022				

Transect name, target species and position		Comparative photographs			
		North	East	South	West
	2023				

APPENDIX B

Monitoring survey data for habitat condition and relevant invertebrates in lowland rainforest habitats in the study area

Table B.1. Summary of data from Southern Pink Underwing Moth habitat assessment sites close to the highway footprint (T1 to T5 and PUM01 to PUM11) and control sites at Davis Scrub Nature Reserve (C1) and Victoria Park Nature Reserve (C2) in February 2023, together with a total count of moths, eggs and larvae counted at each site over the whole season.

Site name	Latitude	Longitude	Count of moths	Count of eggs	Count of larval instars					Count of Carronia	Leaf type	Count of fleshy fruit trees
					1st	2nd	3rd	4th	5th			
T1	-28.929457	153.465693		17	5	7	3	5	1	50	Mixed	71
T2	-28.929211	153.464903		213	66	85	32	14	1	70	Mixed	71
T3	-28.926688	153.469976		11	3	34	1	1		150	Mixed	54
T4	-28.925143	153.471871		2		2	1			28	Broad	54
T5	-28.92873	153.466887		54	4	4	7		1	28	Narrow	71
PUM01	-28.927856	153.453179		25	7	1				6	Narrow	69
PUM02	-28.927654	153.454049		46	9	1	1			200	Narrow	69
PUM03	-28.929196	153.458586		162	51	97	26	13	2	110	Narrow	46
PUM04	-28.928825	153.458482		14	7	8	8	3		12	Narrow	47
PUM05	-28.9282	153.458								0	NA	39
PUM06	-28.927382	153.458982		37	8	17	13	2		14	Narrow	71
PUM07	-28.927823	153.460869		33	23	16	16	6	2	40	Narrow	71
PUM08	-28.929688	153.460674		43	14	8	10	2	1	27	Narrow	71
PUM09	-28.9276	153.467								0	NA	
PUM10	-28.920415	153.472801								3	Narrow	13
PUM11	-28.91908	153.472878		37	4	27	15	16	1	80	Broad	50
PUM12	-28.921539	153.472647								4	Narrow	
PUM13	-28.926927	153.470222		8						9	Narrow	
PUM14	-28.927228	153.467632		13				1	2	1	Narrow	
PUM15	-28.930453	153.462502		143	9	12	4	1		50	Narrow	
PUM16	-28.929934	153.46185		32	15	23	16	2		20	Narrow	
PUM17	-28.930402	153.460959		42	2	5				17	Narrow	
PUM18	-28.928264	153.46095		35	8	17	16	11	3	30	Narrow	
PUM19	-28.928045	153.461016		83	26	59	34	9	1	118	Narrow	
C1	-28.866728	153.405019		37	15	28	9	1	1	40	Narrow	47
C2	-28.902754	153.410189		16	31	5	1	1		3	Narrow	50
Total				1103	307	456	213	88	16			

Table B.2. Summary of data from Atlas Rainforest Beetle habitat assessment sites close to the highway footprint (T1 to T5 and ARB1 to ARB8) and control sites at Davis Scrub Nature Reserve (C1) and Victoria Park Nature Reserve (C2) in February 2023, together with the maximum number of beetles and beetle burrows counted at each site over the whole season.

Site name	Latitude	Longitude	Count of Beetle	Count of burrows	Log cover	Rock cover	Overhang cover	Canopy cover (exotic)	Subcanopy cover (exotic)
T1	-28.9294	153.466	2	2	5%	63%	5%	24.4% (0%)	17.2% (0%)
T2	-28.9292	153.465	0	0	1%	19%	5%	95% (0%)	62.2% (0%)
T3	-28.9265	153.47	0	0	1%	71%	5%	0% (100%)	13% (41%)
T4	-28.9253	153.472	0	0	1%	35%	1%	38% (62%)	18% (5%)
T5	-28.9286	153.467	0	0	1%	15%	0%	24.4% (0%)	17.2% (0%)
ARB1	-28.9276	153.453	0	0	5%	30%	1%		
ARB2	-28.9289	153.459	0	0	1%	45%	1%		
ARB3	-28.9286	153.458	0	0	5%	30%	5%		
ARB4	-28.9283	153.458	0	0	1%	40%	5%		
ARB5	-28.9279	153.459	0	0	5%	30%	5%		
ARB6	-28.9277	153.467	0	0	1%	40%	5%		
ARB7	-28.9242	153.47	0	0	5%	30%	5%		
ARB8	-28.9205	153.473	0	0	5%	5%	0%		
C1	-28.8665	153.405	37	73	5%	0%	5%	100% (0%)	80.8% (0%)
C2	-28.9028	153.41	5	5	10	3%	5%	100% (0%)	84% (0%)