Woolgoolga to Ballina Pacific Highway upgrade

Invertebrate Monitoring Program Annual Report 2021

Operation Phase Year 1 Report

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Document Control Sheet

File Number: 0180-020d

Project Manager/s: Dr Penn Lloyd

Client: Jacobs on behalf of Pacific Complete

Project Title: Woolgoolga to Ballina Pacific Highway Upgrade Invertebrate Monitoring Program Annual Report 2021, Year 1 Operation Phase Report

Project Author/s: Dr Penn Lloyd

Project Summary: This report presents the results of the first 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 2020 to March 2021 for comparison with baseline pre-construction and construction phase monitoring results.

Draft Preparation History:

Draft No.	Date draft completed	Reviewed by	Issued by
0108-020d Draft A	14/05/2021	Paulette Jones	Dr Penn Lloyd

Revision/ Checking History Track:

Version	Date of Issue	Checked by	Issued by
0108-020d Version 0	22/09/2021	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	14/05/2021	0	22/09/2021				
Client Copy 1- hard copy								
PDF & MS Word doc – cloud storage	A	14/05/2021	0	22/09/2021				

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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 Pacific Complete to document the results of the first 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 2020 to March 2021 (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

No Pink Underwing Moth larvae were found during the November 2020 to January 2021 surveys despite large numbers of fruit-piercing moth larvae being found from January 2021. During the February 2021 survey, two small 2nd instar Pink Underwing Moth larvae were found at control site C1 (Davis Scrub Nature Reserve). During the March 2021 survey, a total of 13 Pink Underwing Moth larvae were detected at several sites. 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 and 2018/19, larvae of fruit-piercing moths were either absent or present in low numbers.

Atlas Rainforest Ground Beetles were active at one or more sites during all surveys through the 2020/21 season. Across all surveys, the greatest numbers of Atlas Rainforest Ground Beetles confirmed at burrow entrances along monitoring transects were as follows: T1 (2 beetles, 2 burrows); T5 (1 beetle, 1 burrow); and C1 in Davis Scrub NR (18 beetles in 24 burrows checked, with up to 57 burrows detected on the 50 x 20m transect). These are all locations where Atlas Rainforest Ground Beetle has been confirmed on previous surveys. No burrows were detected at a location between T1 and T5 where up to 3 to 4 burrows and beetles had been detected in some previous years. 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.

Richmond Birdwing *Ornithoptera richmondia* larvae were found at five different impact sites (total of 28 larvae) and were particularly abundant in planted host vines near site C2 in Victoria Park Nature Reserve (total of 63 larvae, 5 pupae), with larvae found during all five surveys through the 2020/21 season. Adult butterflies were observed at control site C2 and impact site T2.

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 has been substantially modified since the previous surveys in 2019 as a result of herbicide treatments to kill invasive trees in the vicinity of this location in accordance with the Threatened Invertebrates Management Plan (TIMP) objectives of restoring degraded rainforest habitat areas adjacent to the highway. The reduced canopy cover and increased light 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. While this has resulted in a short-term negative impact on Southern Pink Underwing Moth host plants at this site where the highest larvae densities have previously been found, there will be longer term benefits resulting from the forest restoration activities; good recruitment of native rainforest tree saplings was evident throughout the areas of canopy and subcanopy tree weed control. Furthermore, overall habitat condition has been improved through the reduction in weed tree cover, which will facilitate the growth of a native rainforest tree canopy over time.

Conclusions

No definitive 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 first year of the post-construction survey period. The relatively lower abundance of Southern Pink Underwing Moth larvae in comparison with some previous years may be attributable to natural variation in the response of this species to environmental conditions, which are not yet well understood. There was also no evidence of a decline in invertebrate habitat condition besides a minor impact of vine weeds on carronia plants at site T1, and no evidence of reduced survival of retained host plants.

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*.

The construction phase monitoring conducted to date has not identified an exceedance of any trigger for corrective action; consequently, no corrective actions are triggered. Since no indirect impacts of the Project on any threatened invertebrate species have been detected, adaptive management of the mitigation measures set out in the TIMP is not required.

INVERTEBRATE MONITORING PROGRAM ANNUAL REPORT 2021
YEAR 1 OPERATION PHASE REPORT

WOOLGOOLGA TO BALLINA PACIFIC HIGHWAY UPGRADE

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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*
RMS	Roads and Maritime Services
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
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 Pacific Complete 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 first 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.

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 Pacific Complete	
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. HABITAT IMPROVEMENT

In January 2020, Pacific Complete introduced five large tree-trunk logs on basaltic soil on sloping terrain at the edges of rainforest regrowth in the study area as an action to improve habitat for Atlas Rainforest Ground Beetle. This action implements one of the management measures recommended under Section 6.3.7 of the TIMP.

1.7. 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 2020 to March 2021 (six monitoring events in total), and a single habitat assessment survey in March 2021. Surveys were performed by Dr Penn Lloyd (Principal Ecologist) and Lizzy Buckby (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.

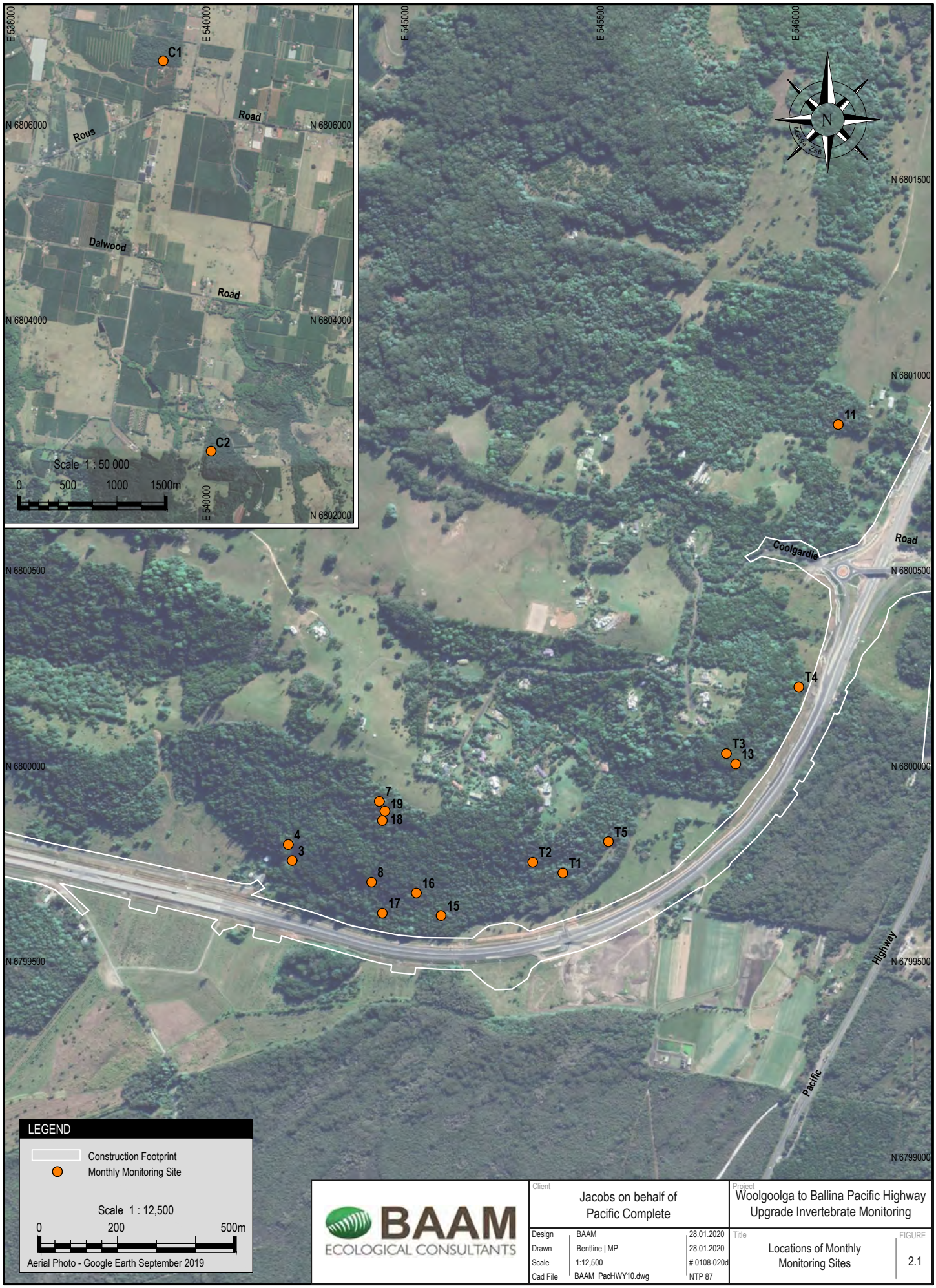
Photo 2.2. Pink Underwing Moth 1st instar larva (reproduced from Sands (2012)).

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.



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Client	Jacobs on behalf of Pacific Complete	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 each 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 16-17 March 2021, 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.

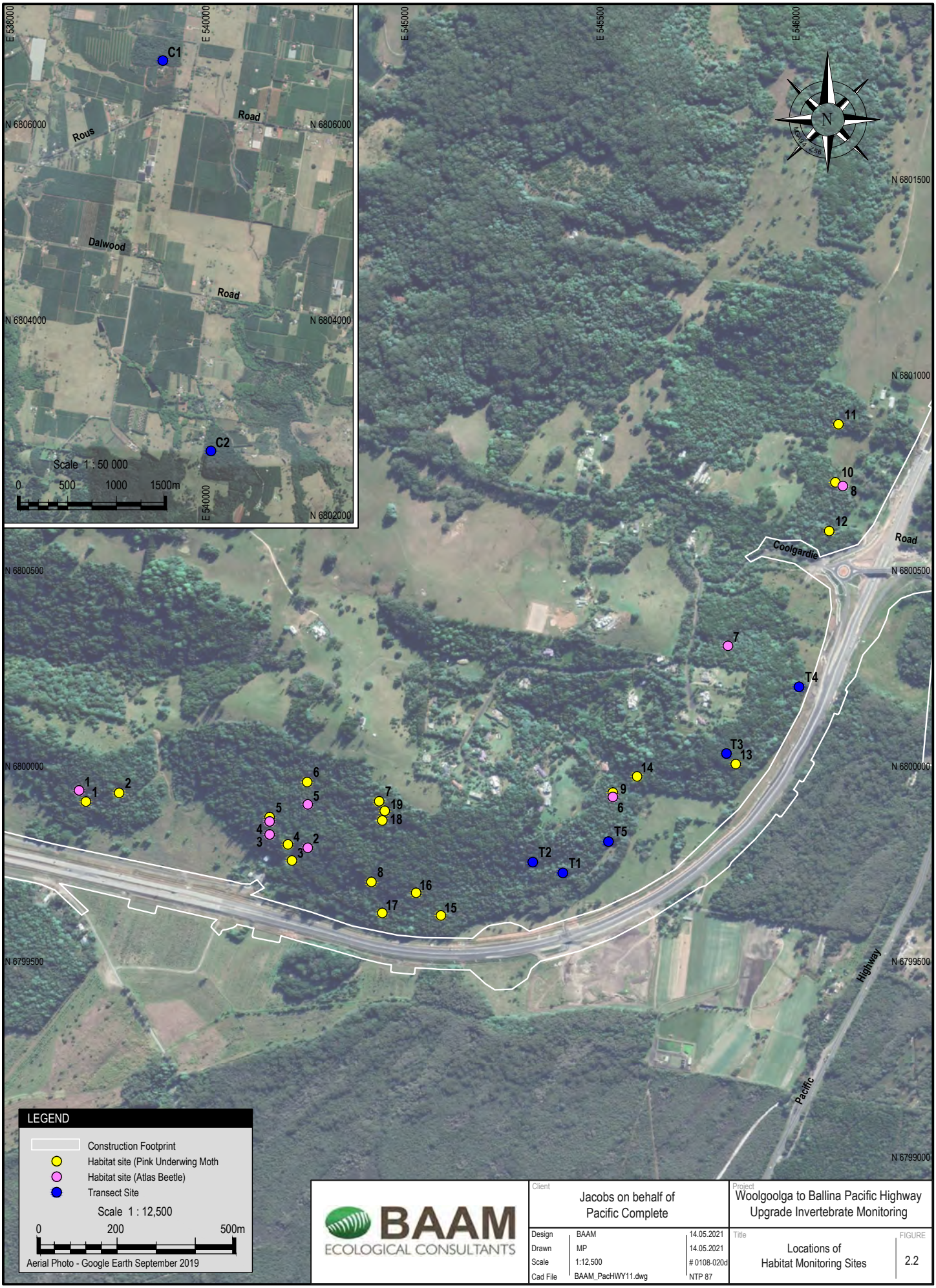
2.3.1. Southern Pink Underwing Moth

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. In addition, the following parameters were measured within a 50m x 20m plot transect marked using a 50m measuring tape down the centre of each of the five impact site transects and two control site transects:

- Percentage cover of native and exotic canopy, subcanopy and shrub cover, using the line-intercept method along the length of the 50m tape
- Percentage cover of native and exotic grasses and forbs as well as bare ground, litter and rocks in the groundcover layer within each of five 1m x 1m quadrats spaced at 10m intervals along the 50m tape
- Total length of logs lying on the ground (with a minimum length of 0.5m and minimum diameter of 10cm) within the 50m x 20m plot i.e. within 10m either side of the 50m tape.



BAAM ECOLOGICAL CONSULTANTS

Client	Jacobs on behalf of Pacific Complete	
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

2.3.2. 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.

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, sex (where apparent) and form (seedling, shrub or vine) 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 March to November 2020 was below average, but rainfall through the summer months of December 2020 to March 2021 was substantially above average (**Figure 3.1**).

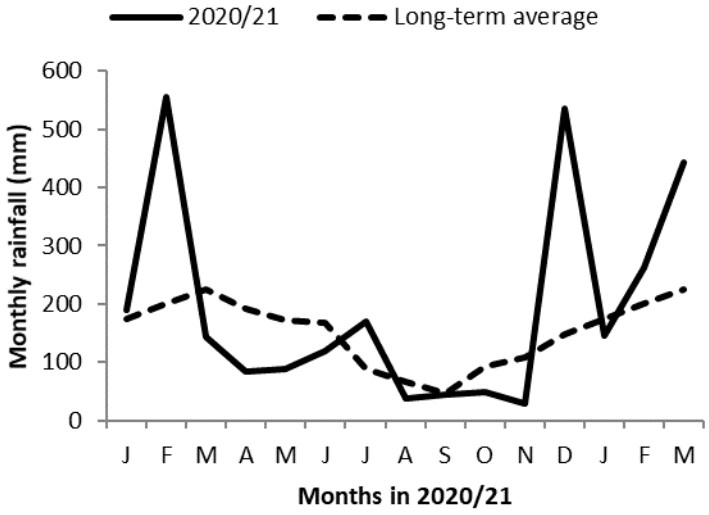


Figure 3.1. Monthly rainfall at Meerschaum Vale weather station during 2020/21 compared to the long-term average (BoM 2021).

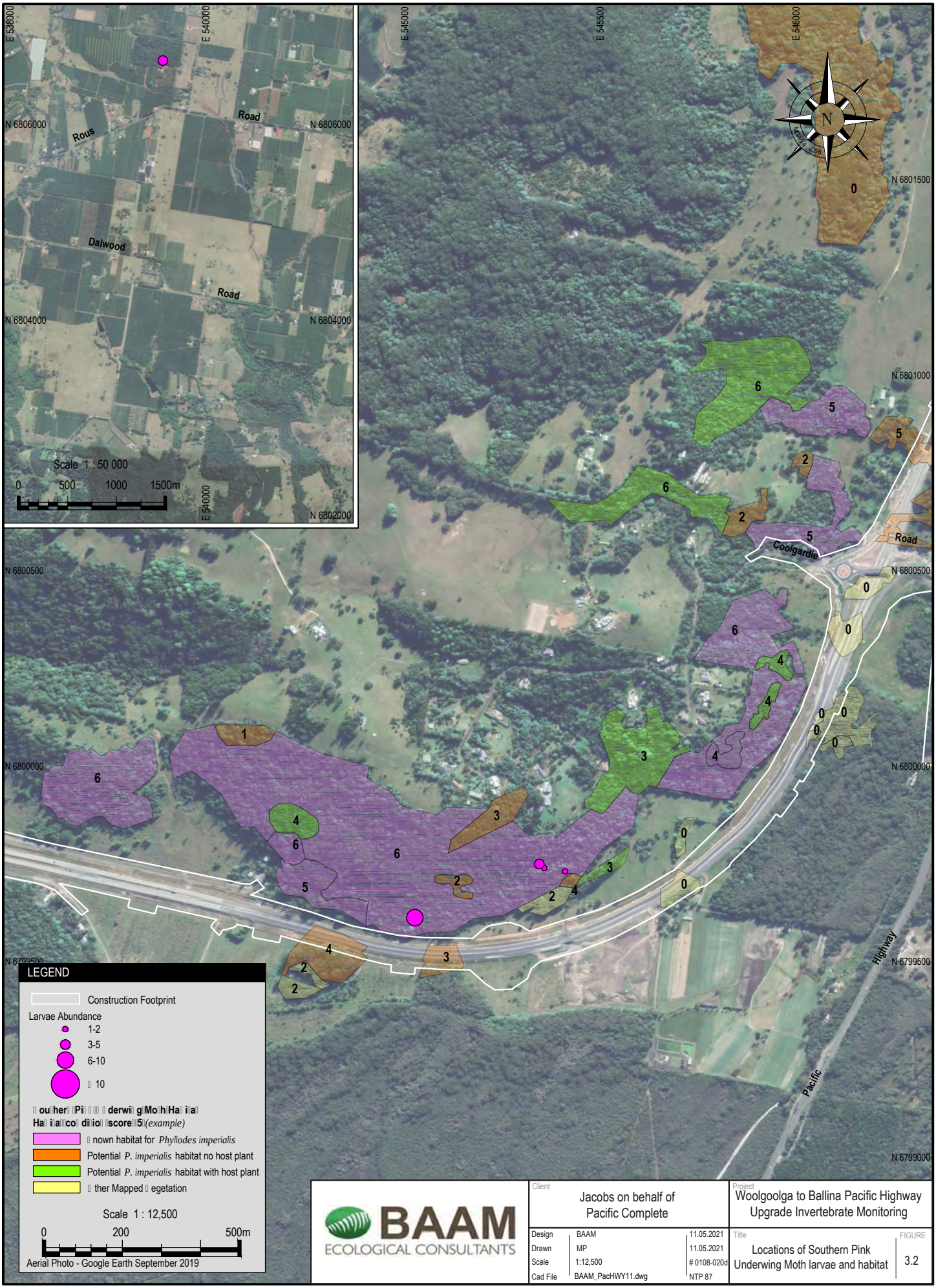
3.2. SOUTHERN PINK UNDERWING MOTH ABUNDANCE

A summary of the monthly monitoring results is provided in **Table 3.1**. No Pink Underwing Moth larvae were found during the November 2020 to January 2021 surveys despite large numbers of fruit-piercing moth larvae being found from January 2021. During the February 2021 survey, two small 2nd instar Pink Underwing Moth larvae were found at control site C1 (Davis Scrub Nature Reserve) (**Figure 3.2**). During the March 2021 survey, a total of 13 Pink Underwing Moth larvae were detected at several sites (**Figure 3.2, Table 3.1**). No adult Pink Underwing Moths were observed during the nocturnal monitoring for Atlas Rainforest Ground Beetle.

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

Date	Rainfall	General Notes	Atlas Rainforest Ground Beetle	Southern Pink Underwing Moth
18 November 2020	July-October 2020 rainfall of 301 mm, approximately equal to the long-term average of 303 mm for this period, with an additional 29 mm in November 2020 prior to the survey.	Mild (24°C), dry and partly cloudy with a moderate breeze during the day; mild (20°C), dry with a light breeze during the evening survey.	Burrows consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (2 burrows), T5 (1 burrow), C1 (46 burrows within 50x10 m plot) and C2 (2 burrows). Beetles were detected at burrow entrances during the evening survey in 14 of 24 burrows checked as a sample at C1, but no beetles were detected at burrow entrances at the other sites.	No Pink Underwing Moth larvae detected at any of the monitoring sites. No larvae of fruit-piercing moth species were found. Carronia host plants had good fresh growth. Richmond Birdwing larvae were detected at multiple sites: 51 larvae and 2 pupae on planted vines near C2; 2 larvae at T2 and 1 larva at T5.
21 December 2020	Approximately 429 mm rainfall since the previous survey, most of it falling in the week prior to the survey.	Partly cloudy, warm, humid, conditions with no rainfall.	Burrows consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (2 burrows), T5 (1 burrow), between T1 and T5 (2 burrows) and C1 (57 burrows within 50x10 m plot). Beetles were detected at burrow entrances during the evening survey in the two burrows at T1, the single burrow at T5, and in 16 of 22 burrows checked as a sample at C1.	No Pink Underwing Moth larvae detected at any of the monitoring sites. No larvae of fruit-piercing moth species were found. Richmond Birdwing larvae were detected at multiple sites: 5 larvae, 2 pupae and 1 nearly emerged butterfly at planted vines near C2; 1 larva at T5 and 1 larva at PUM11.
19 January 2021	Approximately 127 mm rainfall since the previous survey.	Partly cloudy, warm, humid, conditions with no rainfall.	Burrows consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (1 burrow, beetle present), T5 (1 burrow, beetle present), and C1 (47 burrows within 50x10 m plot).	No Pink Underwing Moth larvae detected at any of the monitoring sites. Carronia plants in excellent condition with flush of new growth following good recent rainfall. Larvae of fruit-piercing moth species were present at most monitoring sites, with a total of 156 larvae found. Richmond Birdwing larvae were detected at multiple sites: 5 larvae, 1 pupa and 1 nearly emerged butterfly at planted vines near C2; 11 larvae and 1 adult at T2, 9 larvae at T5 and 2 larvae at PUM07.
22 February 2021	A total of 145 mm in January and a further 274 mm in February prior to the survey; rainfall above average for the wet season.	Clear sunny, humid day with light winds.	Active burrows consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (1 burrow, beetle present), and C1 (50 burrows within 50x10 m plot).	Pink Underwing Moth larvae were detected at a single site: 2 small 2nd instar larvae at C1. Larvae of fruit-piercing moth species were present at seven sites, with a total of 45 larvae found. Richmond Birdwing larvae were detected at four sites: 2 larvae at planted vines near C2; 2 larvae at T2, 2 larvae at T5 and 3 larvae at PUM11.

Date	Rainfall	General Notes	Atlas Rainforest Ground Beetle	Southern Pink Underwing Moth
16-17 March 2021	A total of 128 mm since the previous survey. Carronia plants in good condition after above average wet season.	Partly cloudy, mild with scattered showers.	Active burrows consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (1 burrow, beetle present), and C1 (43 burrows within 50x10 m plot). Beetles were detected at burrow entrances during the evening survey in 18 of 24 burrows checked as a sample at C1.	Pink Underwing Moth larvae (total of 13) were detected at several sites: two 4th instar larvae at T1, one 5th instar larva between T1 and T2, three 3rd instar larvae at PUM03, six 3rd instar larvae between PUM15 and PUM17, and one 4th instar larva at C1. Larvae of fruit-piercing moth species were present at ten sites, with a total of 75 larvae found. Two Richmond Birdwing larvae were detected at a single site: PUM03.



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Title: Locations of Southern Pink Underwing Moth larvae and habitat

FIGURE 3.2

The finding of relatively large numbers of Southern Pink Underwing Moth larvae during the construction Year 2 and earlier surveys (see **Table 3.3** for a summary) 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 have consistently supported the greatest numbers of Southern Pink Underwing Moth larvae in different seasons.

Table 3.3. 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 (this study).	**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.

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 3.3, Figure 3.3**). While at least some Southern Pink Underwing Moth larvae appear to be consistently produced in February/March each year, a larger number of larvae were produced in November than in February/March in the study area during the 2018/19 season. The environmental factors responsible for inter-annual and intra-seasonal variation in breeding activity remain poorly understood; while the November 2018 early-season breeding followed above-average rainfall in September-October after below-average rainfall through winter, similar conditions the previous year did not result in early-season breeding.

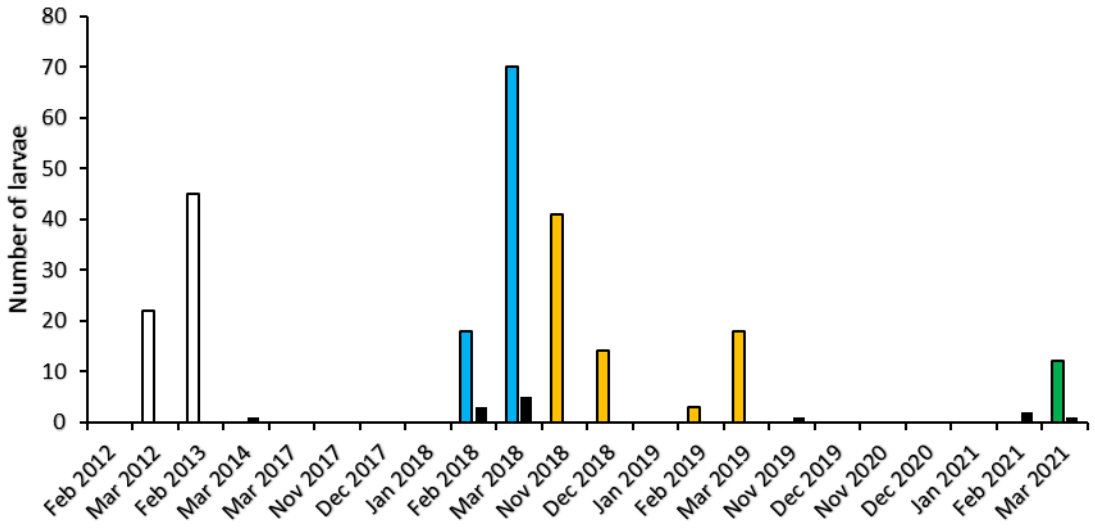

Figure 3.3. Southern Pink Underwing Moth total larval abundance at impact monitoring sites during pre-construction (February 2012 to March 2017, white bars), construction year 1 (November 2017 to March 2018, blue bars), construction year 2 (November 2018 to March 2019, orange bars), construction year 3 (November to December 2019) and operation year 1 (November 2020 to March 2021, 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 (see **Table 3.1**) and Richmond Birdwing Butterfly larvae (see **Table 3.1, Figure 3.4**) 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 and 2018/19, larvae of fruit-piercing moths were either absent or present in low numbers (BAAM 2018, 2019).

3.3. Atlas Rainforest Ground Beetle Abundance

Atlas Rainforest Ground Beetles were active at one or more sites during all surveys through the 2020/21 season (**Table 3.1, Figure 3.4**). Across all surveys, the greatest numbers of Atlas Rainforest Ground Beetles confirmed at burrow entrances along monitoring transects were as follows: T1 (2 beetles, 2 burrows); T5 (1 beetle, 1 burrow); and C1 in Davis Scrub NR (18 beetles in 24 burrows checked, with up to 57 burrows detected on the 50 x 20m transect). These are all locations where Atlas Rainforest Ground Beetle has been confirmed on previous surveys. No burrows were detected at a location between T1 and T5 where up to 3 to 4 burrows and beetles had been detected in some previous years. 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.

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Title: Locations of Atlas Rainforest Ground Beetle and Richmond Birdwing observations

FIGURE 3.4

The 2018/19 surveys detected similar numbers of Atlas Rainforest Ground Beetles at the impact monitoring sites as were found during 2017/18 (**Table 3.4, Figure 3.5**), confirming the presence of small numbers of beetles at three different locations at or close to the T1 and T5 impact monitoring sites. The apparent loss of 3-4 burrows at a location between sites T1 and T5 between the 2019/20 and 2020/21 coincided with a reduction in tree canopy cover at this location as a result of weed control activities that killed Broad-leaved Privet and Camphor Laurel trees (both introduced weeds) as part of the native rainforest rehabilitation and management at the property. 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.

Table 3.4. 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 (**19 beetles**) 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 (this study).	Up to 50 burrows with 75% confirmed activity (**18 beetles**) at C1, no burrows at C2, 2 burrows (2 beetles) at T1, 1 burrow (**1 beetle**) at T5, no burrows between T1 and T5.

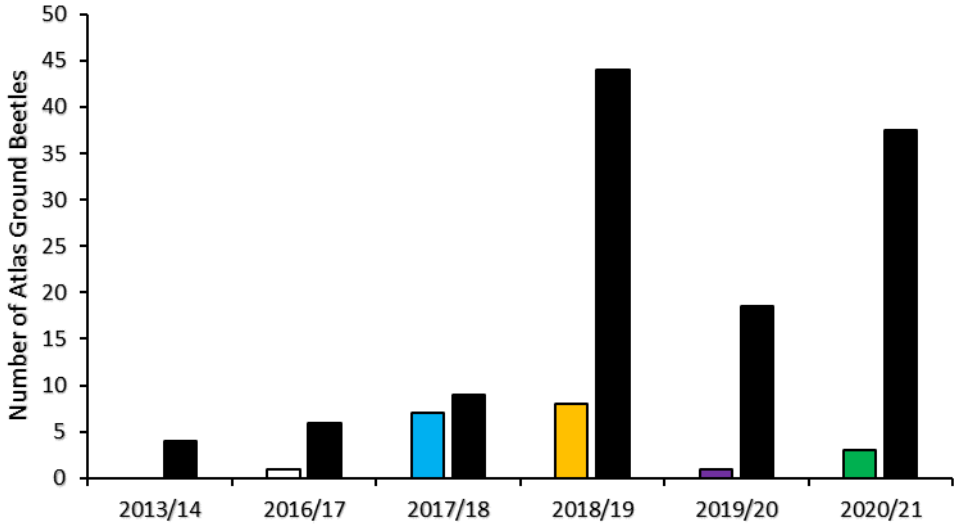


Figure 3.5. Atlas Rainforest Ground Beetle total maximum abundance at impact monitoring sites during pre-construction (2013/14 and 2016/17, white bars), construction year 1 (2017/18, blue bar), construction year 2 (2018/19, orange bar), construction year 3 (2019/20, purple bar) and operation year 1 (2020/21, green bar) 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 was no evidence of a decline in beetle abundance in this population during the first three years of highway construction in comparison with pre-construction abundance (**Figure 3.5**). Atlas Rainforest Ground Beetle apparent abundance was substantially reduced at both impact and control sites during the Year 3 monitoring, but this was likely due to the prevailing extremely dry conditions following substantially below average rainfall. The apparent loss of a small cluster of 3-4 burrows at a location between impact sites T1 and T5 prior to the first year of operation may be linked to a change in tree canopy cover resulting from weed control for native rainforest rehabilitation.

3.4. RICHMOND BIRDWING

Richmond Birdwing larvae were found at five different impact sites (total of 28 larvae) and were particularly abundant in planted host vines near site C2 in Victoria Park Nature Reserve (total of 63 larvae, 5 pupae; **Photo 3.1**), with larvae found during all five surveys through the 2020/21 season (**Table 3.1**). Adult butterflies were observed at control site C2 (**Photo 3.1**) and impact site T2. The locations of these observations are shown in **Figure 3.4**.

Photo 3.1. Richmond Birdwing pupa at site C2.

Photo 3.2. Richmond Birdwing butterfly at site C2.

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). 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.

3.5. HABITAT CONDITION

Detailed data from the habitat condition assessments are presented in **Appendix 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 has been substantially modified since the previous surveys in 2019 as a result of herbicide treatments to kill invasive trees in the vicinity of this location 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 (**Photo 3.3**). 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 (**Photo 3.4**). While this has resulted in a short-term negative impact on Southern Pink Underwing Moth host plants at this site where the highest larvae densities have previously been found, there will be longer term benefits resulting from the forest restoration activities; good recruitment of native rainforest tree saplings was evident throughout the areas of canopy and subcanopy tree weed control. Furthermore, overall habitat condition has been improved through the reduction in weed tree cover (**Appendix B**), which will facilitate the growth of a native rainforest tree canopy over time.

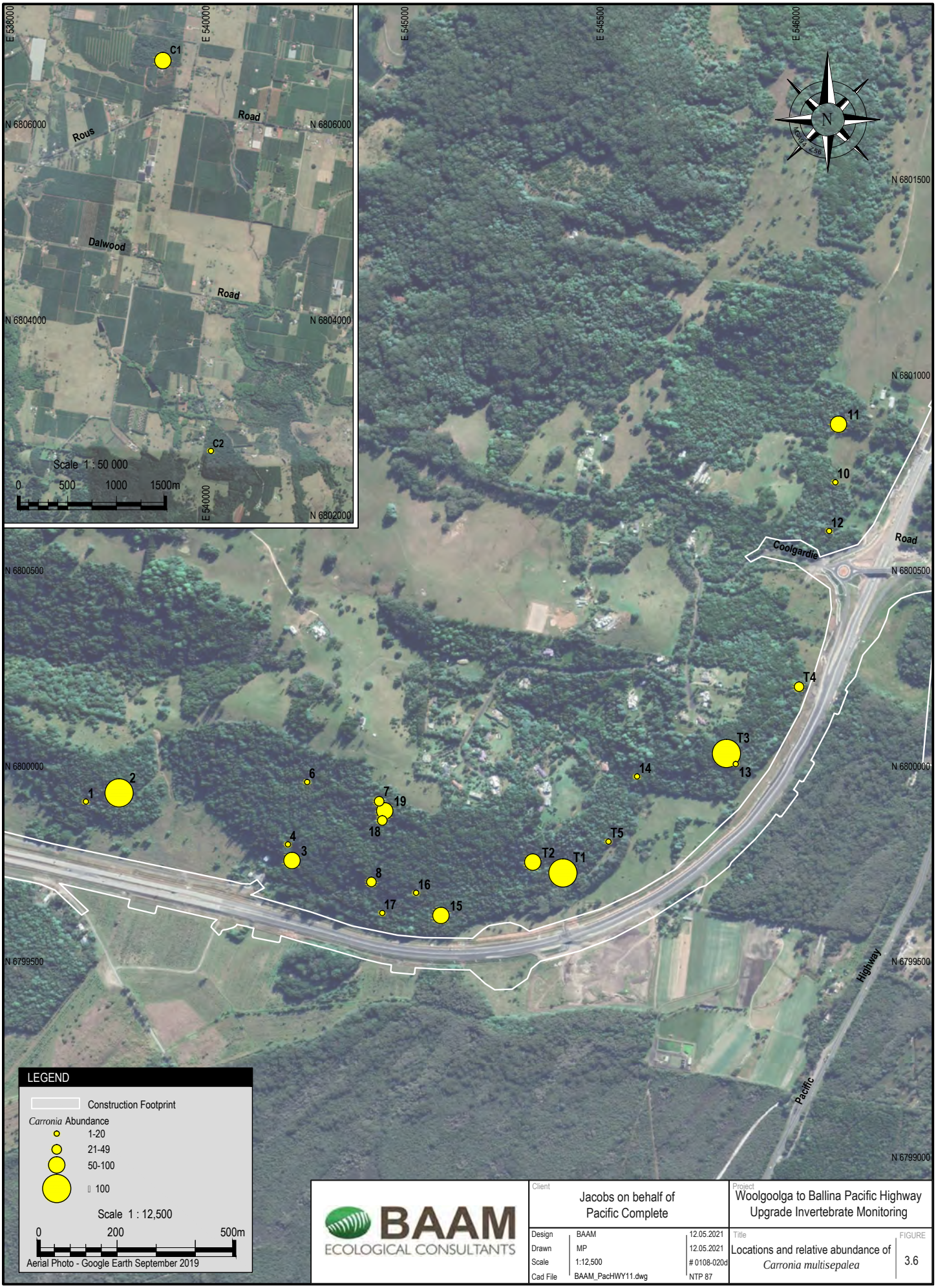
Photo 3.3. Reduced canopy cover at site T1 following herbicide treatment of invasive canopy trees for rainforest rehabilitation.

Photo 3.4. Mile-a-minute vine (*Ipomoea cairica*) growing over carronia shrubs at site T1.

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 2019 (**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 summer rainfall. Plants at most locations showed signs of recent or old herbivory consistent with larval feeding activity. Much of this herbivory likely results from an abundance of fruit-piercing moth larvae that were found feeding on carronia plants at most survey sites.



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Title: Locations and relative abundance of *Carronia multisepalea*

FIGURE 3.6

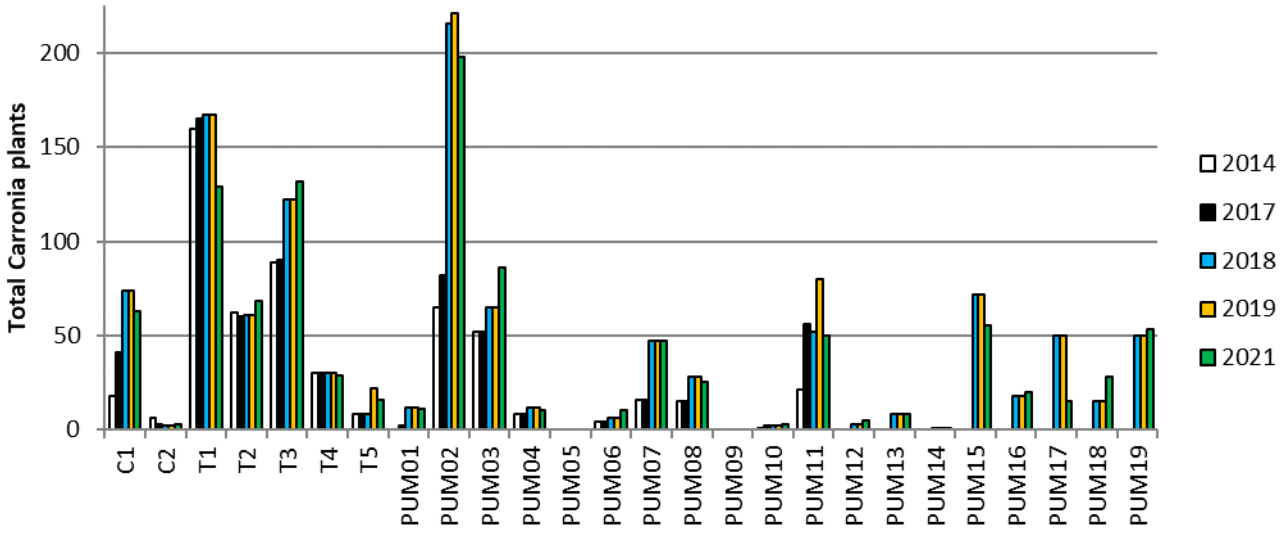

Figure 3.7. Comparison of *Carronia multisepalea* counts between surveys during pre-construction (2014 and 2017), construction year 1 (2018), construction year 2 (2019) and operation year 1 (2021).

All Southern Pink Underwing Moth larvae from the 2020/21 season were recorded at sites where larvae have previously been recorded. Consequently, there has been no change to the extent of known habitat for the species since 2018/19. **Table 3.5** 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 since the previous habitat condition assessment in December 2018 (BAAM 2019). The habitat mapping and condition scores for Southern Pink Underwing Moth are presented in **Figure 3.2**.

Table 3.5. Extent of known or potential habitat for Southern Pink Underwing Moth 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	0	3.9+	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	45.6	14.7	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)

3.5.2. Atlas Rainforest Ground Beetle

Habitat condition for Atlas Rainforest Ground Beetle has remained stable since the 2017 preconstruction survey and the 2018, year 1 construction 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 3.6** below. Also included in **Table 3.6** is an assessment of whether corrective actions are triggered by the monitoring results of the 2020/21 season.

The construction phase and early operation phase monitoring conducted to date has not identified an exceedance of any trigger for corrective action; consequently, no corrective actions are triggered (**Table 3.6**). Since no indirect impacts of the Project on any threatened invertebrate species have been detected, adaptive management of the mitigation measures set out in the TIMP is not required. The revised monitoring approach for Southern Pink Underwing Moth implemented through the 2018/19 to 2020/21 seasons has increased the effectiveness of monitoring intra-seasonal variation in breeding activity and larval abundance in this species. The revised monitoring approach has also increased the effectiveness of searching for Atlas Rainforest Ground Beetle burrows during the day.

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 2020/21 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 first year of the post-construction survey period. 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 minor impact of vine weeds at site T1. No evidence of reduced survival of retained host plants. 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 quantity or habitat condition. No corrective actions triggered.

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.

BoM (2021). 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 photomonitoring 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				
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				
	2017				
	2018				

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

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

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**
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				
	2018				
	2019				

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

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) on 16-17 March 2021, 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				Evidence of eating	Count of Carronia			Leaf type	Count of fleshy fruit trees
					2nd	3rd	4th	5th		Se	Shr	Vine		
T1	-28.929457	153.465693					2		Yes	2	121	6	Mixed	71
T2	-28.929211	153.464903						1	Yes		55	13	Mixed	71
T3	-28.926688	153.469976							Yes		118	14	Mixed	54
T4	-28.925143	153.471871							No		25	4	Broad	54
T5	-28.92873	153.466887							Yes		8	8	Narrow	71
PUM01	-28.927856	153.453179							No		10	1	Narrow	69
PUM02	-28.927654	153.454049							Yes		138	60	Narrow	69
PUM03	-28.929196	153.458586				3			Yes		48	38	Narrow	46
PUM04	-28.928825	153.458482							Yes	1	9		Narrow	47
PUM05	-28.9282	153.458							NA				NA	39
PUM06	-28.927382	153.458982							No		6	4	Narrow	71
PUM07	-28.927823	153.460869							Yes		42	5	Narrow	71
PUM08	-28.929688	153.460674							Yes	2	20	3	Narrow	71
PUM09	-28.9276	153.467							NA				NA	
PUM10	-28.920415	153.472801							No		3		Narrow	13
PUM11	-28.91908	153.472878							Yes		38	12	Broad	50
PUM12	-28.921539	153.472647							No			5	Narrow	
PUM13	-28.926927	153.470222							Yes		8		Narrow	
PUM14	-28.927228	153.467632							No		1		Narrow	
PUM15	-28.930453	153.462502							Yes	21	30	5	Narrow	
PUM16	-28.929934	153.46185							Yes	5	14	1	Narrow	
PUM17	-28.930402	153.460959							Yes		8	7	Narrow	
PUM18	-28.928264	153.46095							Yes		26	2	Narrow	
PUM19	-28.928045	153.461016							Yes		48	5	Narrow	
C1	-28.866728	153.405019			2		1		Yes	1	48	14	Narrow	47
C2	-28.902754	153.410189							No		1	2	Narrow	50

Table B.2. Summary of habitat assessment data (within 50m x 20 plots) from Southern Pink Underwing Moth habitat assessment sites close to the highway footprint (T1 to T5) and control sites at Davis Scrub Nature Reserve (C1) and Victoria Park Nature Reserve (C2) on 16-17 March 2021.

	Percentage cover												
Site name	Native canopy	Exotic canopy	Native subcanopy	Exotic subcanopy	Native shrub	Exotic shrub	Native grass	Native forbs	Exotic forbs	Litter	Bare ground	Rock	Logs (m)
T1	44	0	11	14	12	4	4	4	6	75	0	15	20
T2	91	9	20	0	15	0	1	5	0	70	2	25	10
T3	9	91	20	34	11	0	0	3	1	22	0	75	15
T4	47	60	24	8	2	17	1	5	15	67	4	21	30
T5	98	0	43	0	13	0	4	1	2	76	0	13	24
C1	100	0	88	0	29	0	0	5	0	88	6	0	68
C2	100	0	80	0	55	0	0	6	0	90	0	4	40

Table B.3. Summary of data from Atlas Rainforest Beetle 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) on 16-17 March 2021, 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	% cover logs	% cover rocks	% cover overhangs
T1	-28.9294	153.466	2	2	1	15	5
T2	-28.9292	153.465	0	0	5	25	5
T3	-28.9265	153.47	0	0	1	75	5
T4	-28.9253	153.472	0	0	1	21	1
T5	-28.9286	153.467	1	1	1	13	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	10
ARB5	-28.9279	153.459	0	0	5	30	10
ARB6	-28.9277	153.467	0	0	1	40	10
ARB7	-28.9242	153.47	0	0	5	30	5
ARB8	-28.9205	153.473	0	0	10	5	0
C1	-28.8665	153.405	41	57	10	0	5
C2	-28.9028	153.41	0	0	10	4	5