Woolgoolga to Ballina Pacific Highway upgrade

Invertebrate Monitoring Program Annual Report 2019

Year 2 Construction Phase Report

NSW GOVERNMENT

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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 2019, Year 2 Construction Phase Report

Project Author/s: Dr Penn Lloyd and Mr Rob Price

Project Summary: This report presents the results of the second construction 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 construction footprint and at two control sites in Victoria Park Nature Reserve and Davis Scrub Nature Reserve monthly from November 2018 to March 2019 for comparison with baseline pre-construction monitoring results.

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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 Pacific Complete (the "Client") for the sole purpose of documenting the results of the second construction 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.

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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 second construction phase survey and monitoring for two threatened invertebrate species for the Woolgoolga to Ballina Pacific Highway Upgrade Project. 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 construction 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. 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.
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 2018 to March 2019 (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.

A habitat assessment survey, conducted over two days 12-13 December 2019, 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 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 in rainforest habitats close to the highway construction footprint.

Results and Discussion

Extensive breeding activity by Southern Pink Underwing Moth was found on the first survey on 27 November 2018 when 41 larvae of various ages were found. Consequently, the habitat condition

assessment survey that included survey for larvae over a larger network of annual monitoring sites was brought forward to the December survey two weeks later. This survey found 14 larvae of older age classes. No larvae were found during the January survey, but three young larvae were found during the February survey and 18 larvae of various ages were found a month later during the March survey.

Atlas Rainforest Ground Beetle was detected on all nocturnal surveys. The greatest numbers of Atlas Rainforest Ground Beetles confirmed at burrow entrances along monitoring transects were as follows: T1 (2 beetles, 3 burrows), T5 (3 beetles, 3 burrows), between T1 and T5 (3 beetles, 7 burrows) and C1 in Davis Scrub NR (33 beetles in 40 burrows checked, with up to 55 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 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 on host plant foliage during each of the five monthly surveys, and a pair of butterflies were observed engaged in egg-laying behaviour in December.

Measures of habitat condition for both the moth and beetle were found to have remained stable since the March 2018 first construction survey, with no evidence of any habitat degradation or damage since the baseline surveys. The extent of known habitat for the species close to the construction footprint has increased from 43.9 ha to 45.6 ha following confirmation of use of one additional habitat area by the species for breeding in.

Conclusions

The timing of breeding and the relative abundance of Southern Pink Underwing Moth larvae during each breeding event are variable, but the environmental factors responsible for inter-annual and intra-seasonal variation in breeding activity remain poorly understood. The abundance of Southern Pink Underwing Moth larvae across the network of impact monitoring sites during the two construction-year survey periods was equivalent to or greater than larval abundance during the pre-construction surveys. This result demonstrates that the construction works on the highway upgrade to date have had no indirect impact on the breeding success of Southern Pink Underwing Moth in retained rainforest habitats close to the highway construction footprint.

A low-density population of Atlas Rainforest Ground Beetle continues to persist in retained rainforest habitats close the highway construction footprint and there is no evidence of a decline in beetle abundance in this population during the highway construction period, indicating that construction works on the highway upgrade to date have had no indirect impact on Atlas Rainforest Ground Beetle in retained rainforest habitats close to the highway construction footprint.

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. The revised monitoring approach for Southern Pink Underwing Moth implemented through the 2018/19 season 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.

INVERTEBRATE MONITORING PROGRAM ANNUAL REPORT 2019
YEAR 2 CONSTRUCTION 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 TSC 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 second year of the construction phase. 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 will build a partly raised, multi-lane highway, with interchanges, lighting and temporary construction infrastructure located at appropriate points. This development requires clearing of vegetation and earthwork along a linear corridor through the study area; however, the position of the road corridor has been 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.

1.4. 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 TSC Act) and its host plant *Carronia multisepalea* (not threatened)
- Atlas Rainforest Ground Beetle *Nurus atlas* (listed as endangered under the TSC 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.

1.5. 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.

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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

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 NSW Roads and Maritime Services prior to the start of the second year 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 2018 to March 2019 (six monitoring events in total), and a single habitat assessment survey in December 2019. Surveys were performed by Dr Penn Lloyd and Rob Price on 27 November and 12-13 December 2018 and by Dr Penn Lloyd and Shelley Trevaskis on 22 January, 5 February and 5 March 2019. 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 once each month from November 2018 to March 2019 (five survey events). Four of these surveys (November, January to March) were 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 construction footprint. The locations of the monthly monitoring sites are shown in **Figure 2.1**.

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Drawn	Bentline | MP	13.05.2019
Scale	1:12,500	# 0108-020b
Cad File	BAAM_PacHWY09.dwg	NTP 87
Title	Locations of Monthly Monitoring Sites	FIGURE 2.1

The first survey in late November detected larvae at many of the monitoring sites; therefore, the survey for Southern Pink Underwing Moth breeding activity and larval abundance across the larger network of 26 monitoring sites including all habitat assessment sites was conducted two weeks later in early December. 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.

2.2. MONITORING ATLAS RAINFOREST GROUND BEETLE ABUNDANCE

Monitoring of Atlas Rainforest Ground Beetle abundance was conducted once each month from November 2018 to March 2019 (five survey events) 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. In conjunction with the habitat assessment survey in December, burrows consistent with Atlas Rainforest Ground Beetle were also searched for at all habitat assessment sites. 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 12-13 December 2019, 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.

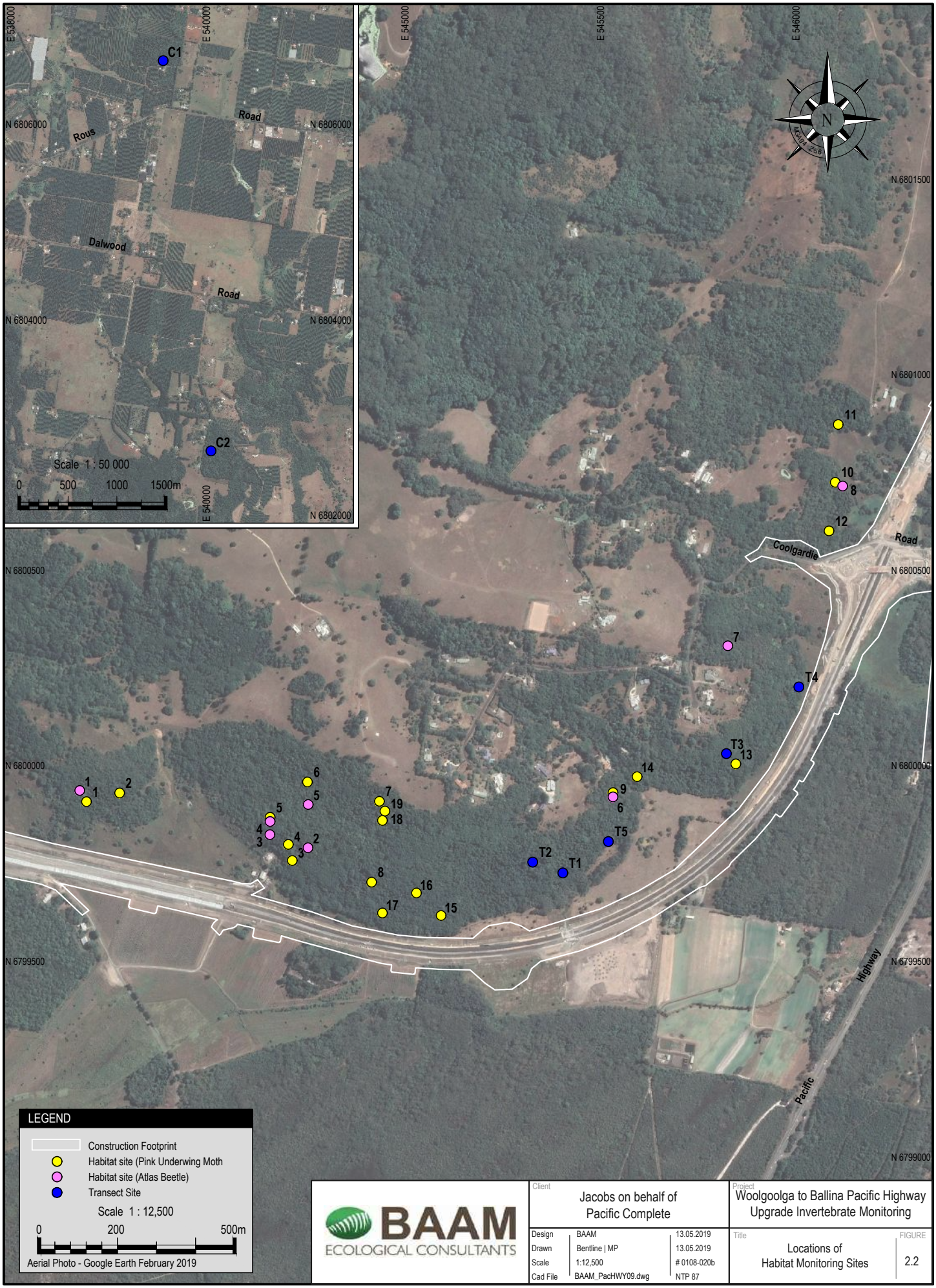
2.3.1. Southern Pink Underwing Moth

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.



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Scale	1:12,500	# 0108-020b
Cad File	BAAM_PacHWY09.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 present study amended 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 total number and form of host plants in the patch were recorded, the coordinates of the patch were recorded via hand-held GPS and 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 prior to and during the monitoring surveys was generally substantially below average, but substantially above average in the spring months of September and October (**Figure 3.1**).

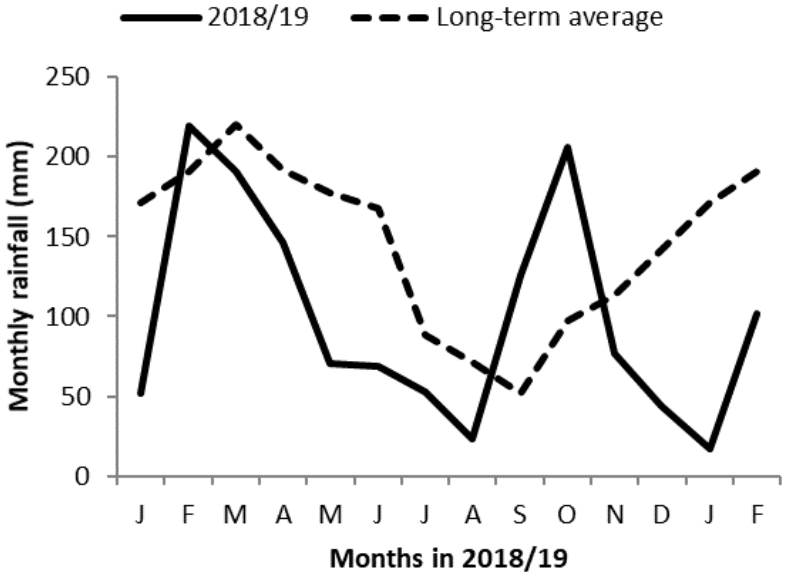


Figure 3.1. Monthly rainfall between January 2018 and February 2019 at Meerschaum Vale weather station compared to the long-term average (BoM 2019).

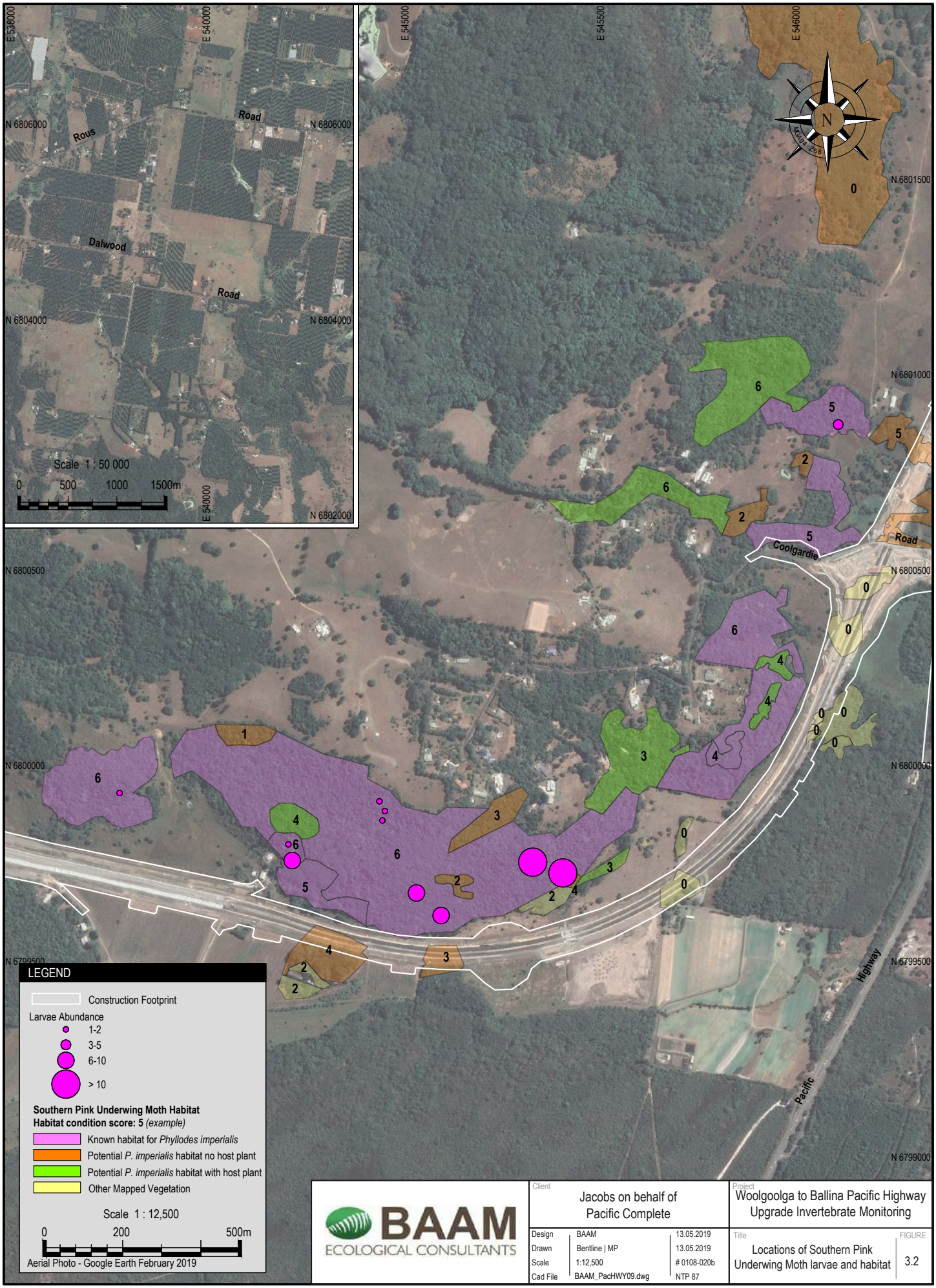
3.2. SOUTHERN PINK UNDERWING MOTH ABUNDANCE

A summary of the monthly monitoring results is provided in **Table 3.1**. Evidence of extensive breeding activity was found on the first survey on 27 November 2018 when 41 larvae of various ages (instars 2 to 5) were found at T1, T2, and six of the other 10 monthly monitoring sites (**Table 3.2, Figure 3.2**). Due to this finding, the habitat condition assessment survey that included survey for larvae over a larger network of annual monitoring sites was brought forward to the December survey two weeks later. This survey found 14 larvae of older age classes (instars 4 and 5) at T1, T2 and five of the other 17 annual monitoring sites with host plants present, including at one site not included in the monthly monitoring. No larvae were found during the January survey but three 2nd instar larvae were found at site S3 during the February survey and 18 larvae of various ages (instars 2 to 4) were found a month later during the March survey at T2 and two of the other monthly monitoring sites.

Table 3.1. Summary of the results of nocturnal monitoring for Southern Pink Underwing Moth and Atlas Rainforest Ground Beetle during the 2018/19 season.

Date	Rainfall	General Notes	Atlas Rainforest Ground Beetle	Southern Pink Underwing Moth
27 November 2018	Substantially above average rainfall in September and October. A total of 97mm on 18th November but mostly dry since then.	Warm and dry during the day (27°C maximum); warm and dry during the evening (23-24°C); moderate wind throughout the day and evening (mostly 22-32 km/h).	Burrows consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (2 burrows), T5 (2 burrows), between T1 and T5 (6 burrows in a tight cluster) and C1 (10 burrows in a tight cluster). Beetle activity at burrow entrances was low during the evening survey (4 beetles observed), most likely due to the prevailing dry conditions. The total count of 20 burrows, located at the same sites as observed in previous seasons, is the largest since monitoring began.	A total of 41 larvae of various ages (instars 2 to 5) were found on Carronia foliage during the day at T1 (17 larvae), T2 (12 larvae), and 12 larvae scattered across six of the other 10 monthly monitoring sites: PUM3 (2 larvae), PUM7 (2 larvae), PUM15 (5 larvae), PUM18 (1 larva) and PUM19 (2 larvae). Carronia plants showed abundant fresh growth following the above-average spring rainfall. No larvae of fruit-piercing moth species were found. Three Richmond Birdwing larvae were found at one site (T5).
12-13 December 2018	No rainfall since the survey of November 2018, resulting in prevailing dry conditions.	Warm and dry during the day (26-29°C maximum); warm and dry during the evening survey of the 13th (24°C); moderate winds on the 12th, strong winds on the 13th (up to 39 km/h).	Burrows consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (4 burrows), T5 (3 burrows), between T1 and T5 (7 burrows in a tight cluster), C1 (22 burrows scattered along the transect) and C2 (2 burrows). Additional burrows outside of the monitoring transects were found scattered along the southern edge of Davis Scrub NR (between the Rous Rd Cemetery and C1) and near the Victoria Park NR picnic site (near C2: 7 burrows), resulting in a survey total of over 45 burrows. There was virtually no beetle activity at burrow entrances during the evening survey, most likely due to the dry, windy conditions.	A total of 14 larvae of older age classes (instars 4 and 5) were found on Carronia leaves during the day at T1 (7 larvae), T2 (1 larvae), and 6 larvae scattered across five of the other 17 annual monitoring sites with host plants present: PUM2 (1 larva), PUM3 (1 larva), PUM4 (1 larva), PUM11 (1 larva) and PUM15 (2 larvae). A total of 12 Richmond Birdwing larvae and two adult butterflies were found at six monitoring sites, including six larvae feeding on a planted vines in rainforest adjacent to the Victoria Park NR picnic area (near C2).

Date	Rainfall	General Notes	Atlas Rainforest Ground Beetle	Southern Pink Underwing Moth
22 January 2019	Substantially below average in December and January, with 44mm in December and no rain in January prior to the survey, resulting in prevailing dry conditions.	Warm and dry during the day (30°C maximum); warm and dry during the evening (25-26°C); moderate winds (20-30 km/h).	Burrows potentially consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (3 burrows), T5 (3 burrows), between T1 and T5 (7 burrows in a tight cluster) and C1 (51 burrows in 50mx20m transect). There was limited beetle activity at burrow entrances during the evening survey, with one beetle detected at T1, one at T5, none at the cluster between T1 and T5 and 4 beetles detected among 20 burrows examined at C1, but noting that many of these latter burrows were determined to be either too small for Atlas Rainforest Beetle or occupied by other invertebrates.	No larvae of Southern Pink Underwing Moth were found, which indicates that larval development from earlier breeding has been completed. No larvae of fruit-piercing moth species were found. Two small Richmond Birdwing larvae were found at T5.
5 February 2019	Substantially below average in December and January, with 44mm in December, 16mm in January and 1mm in February prior to the survey, resulting in prevailing dry conditions.	Warm and dry during the day (29-31°C); warm and humid during the evening (25-27°C) with a light shower at the start of the nocturnal survey; gentle winds (13-26 km/h).	Burrows potentially consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (3 burrows), T5 (3 burrows), between T1 and T5 (6 burrows in a tight cluster) and C1 (50 burrows in 50mx20m transect). The light shower of rain at the start of the nocturnal survey stimulated excellent beetle activity. Atlas Rainforest Beetles were observed in 2 burrows at T1, 3 burrows at T5, 3 burrows between T1 and T5, in 33 of 40 burrows checked along the C1 transect at Davis Scrub NR, and in 8 burrows near the Victoria Park NR picnic area (near C2).	Three 2nd instar larvae of Southern Pink Underwing Moth were found on the same Carronia shrub at one of the monthly monitoring sites (PUM3); no larvae were detected at any of the other monthly monitoring sites. No larvae of fruit-piercing moth species were found. A single small Richmond Birdwing larva was found at T5.
5 March 2019		Warm and humid during the day; mild and humid during the evening; moderate breeze.	Burrows consistent with Atlas Rainforest Ground Beetle were found during the day at T1 (3 burrows), T5 (2 burrows), between T1 and T5 (5 burrows in a tight cluster) and C1 (55 burrows in 50mx20m transect). Atlas Rainforest Beetles were observed in 2 burrows at T1, 2 burrows at T5, 3 burrows between T1 and T5, in 22 of 35 burrows checked along the C1 transect at Davis Scrub NR.	A total of 18 larvae of various ages (instars 2 to 4) were found on Carronia foliage during the day at T2 (6 larvae), and two of the monthly monitoring sites: PUM11 (2 larvae), and PUM16 (10 larvae). These data confirm a moderate level of late-season breeding by Southern Pink Underwing Moth. No larvae of fruit-piercing moth species were found. A single small Richmond Birdwing larva was found at PUM11.



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Client	Jacobs on behalf of Pacific Complete	
Project	Woolgoolga to Ballina Pacific Highway Upgrade Invertebrate Monitoring	
Design	BAAM	13.05.2019
Drawn	Bentline | MP	13.05.2019
Scale	1:12,500	# 0108-020b
Cad File	BAAM_PacHWY09.dwg	NTP 87
Title	Locations of Southern Pink Underwing Moth larvae and habitat	FIGURE 3.2

Table 3.2. Summary of the total number of Southern Pink Underwing Moth larvae found during each survey event that larvae were recorded on.

Type of site	Site	1st	2nd	3rd	4th	5th	Total
27 November 2018							
Impact	T1		4	6	6	1	17
Impact	T2		1	6	4	1	12
Impact	PUM03				2		2
Impact	PUM07		2				2
Impact	PUM15		4	1			5
Impact	PUM18				1		1
Impact	PUM19		2				2
	Total	***0***	***13***	***13***	***13***	***2***	***41***
12-13 December 2018							
Impact	T1				5	2	7
Impact	T2				1		1
Impact	PUM02					1	1
Impact	PUM03					1	1
Impact	PUM04					1	1
Impact	PUM11					1	1
Impact	PUM15				2		2
	Total	***0***	***0***	***0***	***8***	***6***	***14***
5 February 2019							
Impact	PUM03		3				3
5 March 2019							
Impact	T2			3	3		6
Impact	PUM11				2		2
Impact	PUM16		9	1			10
	Total	***0***	***9***	***4***	***5***	***0***	***18***

No adult 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 current and earlier surveys (see **Table 3.3** for a summary) confirms 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.

Survey	Summary of larvae found
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 (this study).	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.

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.

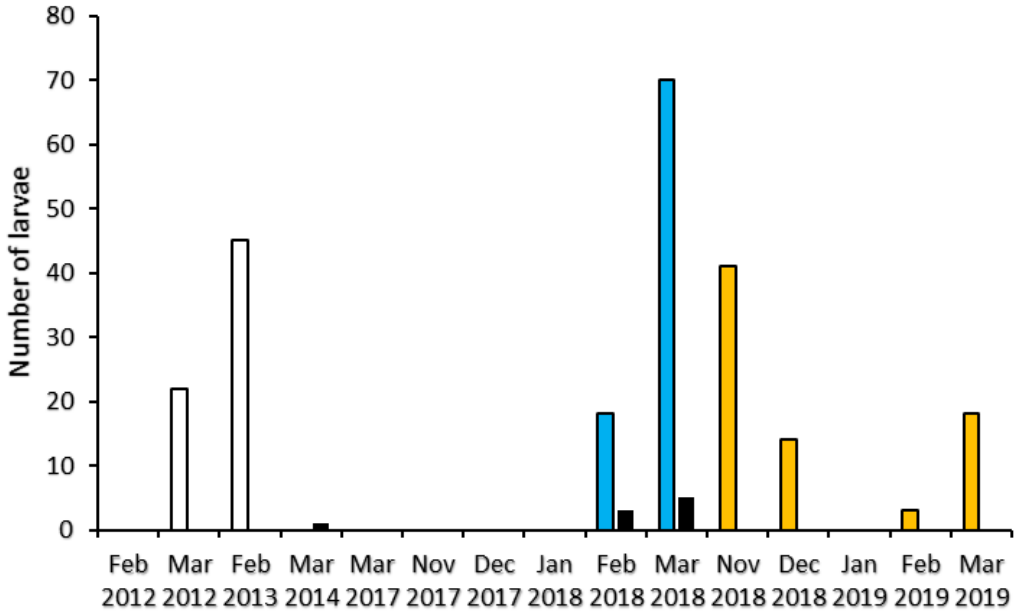

Figure 3.3. Southern Pink Underwing Moth total larval abundance at impact monitoring sites during pre-construction (February 2012 to March 2017, white bars), construction year 1 (November 2017 to March 2018, blue bars) and construction year 2 (November 2018 to March 2019, orange bars) surveys. Black 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 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 construction works on the highway upgrade to date have had no indirect impact on the breeding success of Southern Pink Underwing Moth in retained rainforest habitats close to the highway construction footprint.

3.3. ATLAS RAINFOREST GROUND BEETLE ABUNDANCE

Atlas Rainforest Ground Beetle (**Photo 3.1**) was detected on all nocturnal surveys (**Table 3.1, Figure 3.4**); the activity of this species was minimal on dry, windy evenings, but much greater after recent rainfall. During the course of the season, the greatest numbers of Atlas Rainforest Ground Beetles confirmed at burrow entrances along monitoring transects were as follows: T1 (2 beetles, 3 burrows), T5 (3 beetles, 3 burrows), between T1 and T5 (3 beetles, 7 burrows) and C1 in Davis Scrub NR (33 beetles in 40 burrows checked, with up to 55 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 consistent with Atlas Rainforest Ground Beetle were found at any of the other monitoring sites, which is consistent with the results of previous surveys. However, numerous additional burrows were found scattered along the southern edge of Davis Scrub NR (between the Rous Rd Cemetery and C1) and a cluster of burrows near the Victoria Park NR picnic site (near C2), in which up to eight beetles were confirmed.

Photo 3.1. Atlas Rainforest Ground Beetle outside its burrow under a root.

Photo 3.2. Richmond Birdwing larva.

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 increase in the total number of beetles at Davis Scrub Nature Reserve control site C1 is largely due to the changed Southern Pink Underwing Moth survey protocol that allows more time for searching for beetle burrows during the day. While no burrows were located at control site C2 at Victoria Park Nature Reserve, up to eight beetles in burrows were located nearby but outside the C2 monitoring site.

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Project	Woolgoolga to Ballina Pacific Highway Upgrade Invertebrate Monitoring	
Design	BAAM	13.05.2019
Drawn	Bentline | MP	13.05.2019
Scale	1:12,500	# 0108-020b
Cad File	BAAM_PacHWY09.dwg	NTP 87
Title	Locations of Atlas Rainforest Ground Beetle and Richmond Birdwing observations	FIGURE 3.4

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
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.
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.
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.
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.
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 (this study).	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.

These results confirm that a low-density population of Atlas Rainforest Ground Beetle continues to persist in retained rainforest habitats close the highway construction footprint. Furthermore, there is no evidence of a decline in beetle abundance in this population during the highway construction period in comparison with pre-construction abundance (**Figure 3.5**), indicating that construction works on the highway upgrade to date have had no indirect impact on Atlas Rainforest Ground Beetle in retained rainforest habitats close to the highway construction footprint.

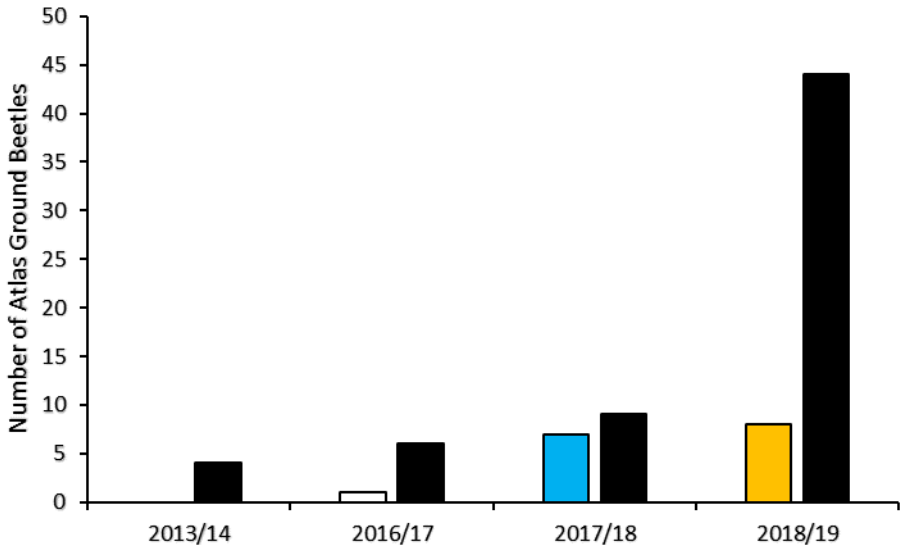


Figure 3.5. Atlas Rainforest Ground Beetle total maximum abundance at impact monitoring sites during pre-construction (2013/14 and 2016/17, white bars), construction year 1 (2017/18, blue bar) and construction year 2 (2018/19, orange bar) surveys. Black bars show maximum beetle abundance at control sites.

3.4. RICHMOND BIRDWING

Richmond Birdwing larvae were found on host plant foliage during each of the five monthly surveys (**Photo 3.2**), and a pair of butterflies were observed engaged in egg-laying behaviour in December (**Table 3.1**). The locations of these observations and total number of individuals observed at each location during the season are shown in **Figure 3.4**. Casual observation of host plant vines suggests they are healthy, with no evidence of a decline in abundance.

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). 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 remained stable since the March 2018 first construction survey, with no evidence of any habitat degradation or damage since the baseline surveys.

3.5.1. Southern Pink Underwing Moth

Patches of the host plant *Carronia multisepalea* were re-located 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 or had increased since the preconstruction surveys (**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. A few plants at most locations showed signs of recent or old herbivory consistent with larval feeding activity.

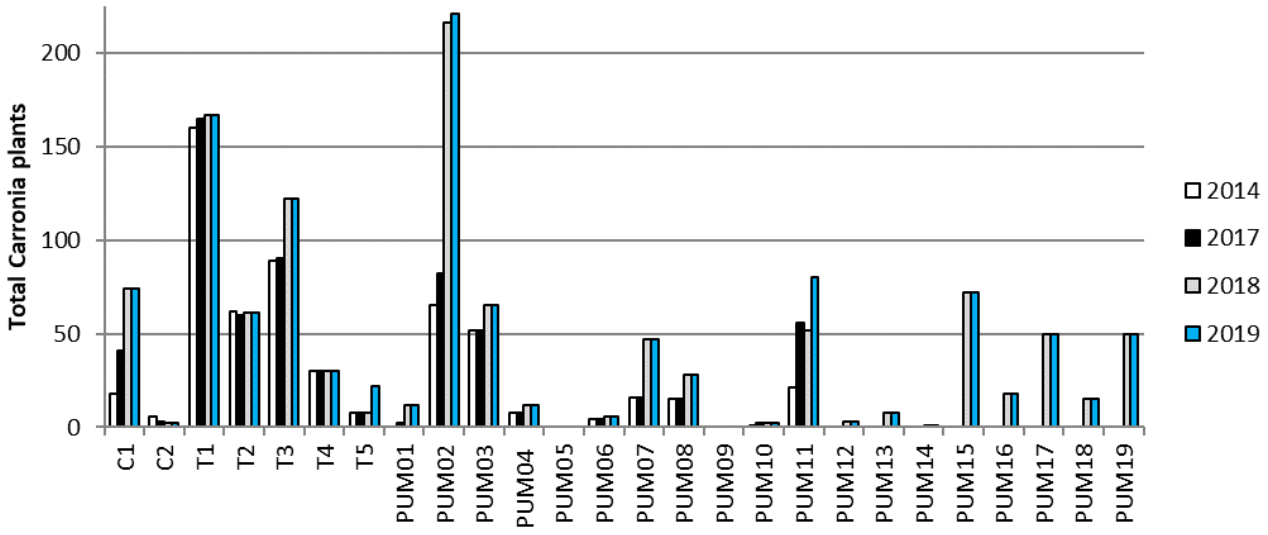
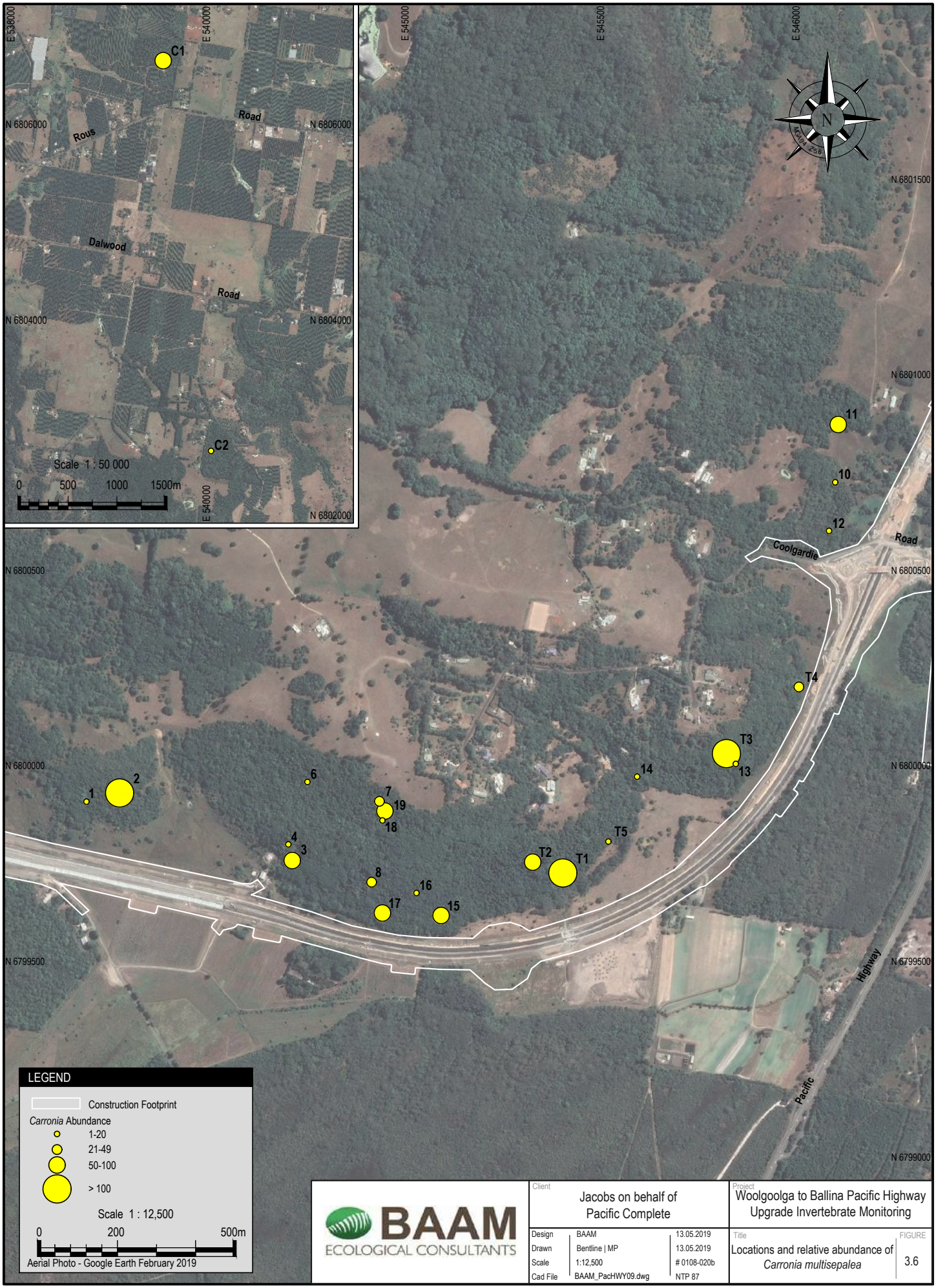


Figure 3.7. Comparison of *Carronia multisepalea* counts between surveys during pre-construction (2014 and 2017), construction year 1 (2018) and construction year 2 (2019).



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Client	Jacobs on behalf of Pacific Complete	
Project	Woolgoolga to Ballina Pacific Highway Upgrade Invertebrate Monitoring	
Design	BAAM	13.05.2019
Drawn	Bentline | MP	13.05.2019
Scale	1:12,500	# 0108-020b
Cad File	BAAM_PacHWY09.dwg	NTP 87
Title	Locations and relative abundance of *Carronia multisepalea*	FIGURE 3.6

Most Southern Pink Underwing Moth larvae from the 2018/19 season were recorded at sites where larvae have previously been recorded. However, larvae were also detected from one habitat polygon with host plants where the species has not previously been found. Consequently, the extent of known habitat for the species increased from 43.9ha to 45.6 ha following confirmation of use of the habitat areas by the species for breeding in. **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 March 2017 (BAAM 2017). 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)

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 2018/19 season.

The construction 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 season 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 2018/19 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 in numbers of either Southern Pink Underwing Moth or Atlas Rainforest Ground Beetle. 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 or 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 condition. No corrective actions triggered.

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APPENDIX A

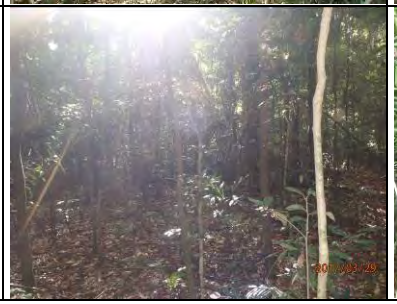
Descriptions and photo-monitoring results for impact and control site transects

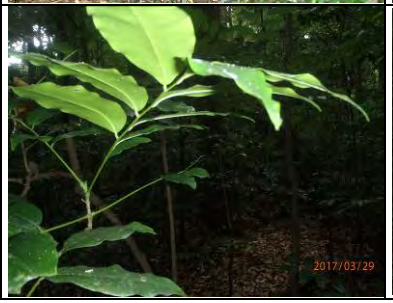
Transect name, target species and position		**Comparative photographs**			
		North	**East**	**South**	**West**
T1. Confirmed location for Southern Pink Underwing Moth and Atlas Rainforest Ground Beetle. Start: 28.9296°S 153.4652°E. End: 28.9294°S 153.4657°E.	2014				
	2017				
	2018				
	2019				

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

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

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

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

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 construction footprint (T1 to T5 and PUM01 to PUM11) and control sites at Davis Scrub Nature Reserve (C1) and Victoria Park Nature Reserve (C2) on 12-13 December 2018, 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	0	0	4	6	11	3	Yes	48	100	9	Mixed	71
T2	-28.929211	153.464903	0	0	1	9	8	1	Yes	10	40	11	Mixed	71
T3	-28.926688	153.469976	0	0					No	10	100	12	Mixed	54
T4	-28.925143	153.471871	0	0					No	0	27	3	Broad	54
T5	-28.92873	153.466887	0	0					Yes	7	6	9	Narrow	71
PUM01	-28.927856	153.453179	0	0					No	0	11	1	Narrow	69
PUM02	-28.927654	153.454049	0	0				1	Yes	3	156	62	Narrow	69
PUM03	-28.929196	153.458586	0	0	3		2	1	Yes	10	50	5	Narrow	46
PUM04	-28.928825	153.458482	0	0				1	Yes	4	8	0	Narrow	47
PUM05	-28.9282	153.458	0	0					NA	0	0	0	NA	39
PUM06	-28.927382	153.458982	0	0					No	0	2	4	Narrow	71
PUM07	-28.927823	153.460869	0	0	2				Yes	13	33	1	Narrow	71
PUM08	-28.929688	153.460674	0	0					Yes	15	10	3	Narrow	71
PUM09	-28.9276	153.467	0	0					NA	0	0	0	NA	
PUM10	-28.920415	153.472801	0	0					No	0	2	0	Narrow	13
PUM11	-28.91908	153.472878	0	0			2	1	Yes	0	68	12	Broad	50
C1	-28.866728	153.405019	0	0					Yes	46	20	8	Narrow	47
C2	-28.902754	153.410189	0	0					No	0	1	1	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 construction footprint (T1 to T5) and control sites at Davis Scrub Nature Reserve (C1) and Victoria Park Nature Reserve (C2) on 12-13 December 2018.

	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	38	66	30	0	1	0	2	3	0	64	0	31	22.5
T2	92	48	26	0	10	0	3	4	0	64	1	28	15
T3	24	62	72	6	24	0	0	22	0	41	2	35	31
T4	58	22	62	0	12	4	0	9	15	47	2	27	35
T5	52	20	86	0	13	0	5	12	2	59	1	13	21
C1	100	0	90	0	37	0	0	22	0	74	4	0	65
C2	84	0	88	0	62	0	0	14	0	79	3	4	59

Table B.3. Summary of data from Atlas Rainforest Beetle habitat assessment sites close to the highway construction footprint (T1 to T5 and PUM01 to PUM11) and control sites at Davis Scrub Nature Reserve (C1) and Victoria Park Nature Reserve (C2) on 12-13 December 2018, 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	4	1	31	3
T2	-28.9292	153.465	0	0	3	28	3
T3	-28.9265	153.47	0	0	1	35	5
T4	-28.9253	153.472	0	0	1	27	1
T5	-28.9286	153.467	3	3	2	13	0
ARB1	-28.9276	153.453	0	0	5	30	2
ARB2	-28.9289	153.459	0	0	1	45	1
ARB3	-28.9286	153.458	0	0	7	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	44	55	10	0	5
C2	-28.9028	153.41	0	0	10	4	5