Woolgoolga to Ballina Pacific Highway upgrade

Threatened Rainforest Communities and Rainforest Plants Monitoring Program Annual Report 2021

Operation Phase Report

NSW GOVERNMENT

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Woolgoolga to Ballina Pacific Highway Upgrade, Sections 10 & 11, Threatened Rainforest Communities and Rainforest Plants, Annual Monitoring Report # 5 (2021)

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Executive Summary

As part of the rainforest management plan for the Woolgoolga to Ballina (W2B) Pacific Highway upgrade (Roads and Maritime 2015), a monitoring program was implemented to record potential impacts to threatened rainforest communities and threatened rainforest plants during the construction and operation phases of Sections 10 and 11. Permanent plots were established to monitor changes in the composition and structure of rainforest communities. The rainforest plots consisted of Impact and Control pairs and were located in four types of rainforest. Impact plots were positioned immediately adjacent the highway at the edge of clearing and Control plots away from the highway inside the forest. Threatened rainforest species were also monitored for changes in growth and condition. Threatened plants close to the highway and further inside the rainforest were found during surveys and tagged for monitoring. A total of 14 Impact and Control rainforest community plots and 210 threatened rainforest plants were included in the monitoring program.

EMM and Ecos Environmental recorded baseline data for the monitoring program in February 2014 before construction of Sections 10 and 11 began (see EMM 2014 for results). During construction, Ecos Environmental carried out monitoring in 2017, 2018 and 2019 (see Ecos 2017, 2018 and 2019 for results). In September 2020, Sections 10 and 11 opened to traffic and in November 2020 Ecos Environmental undertook the first year of operation phase monitoring (see Ecos 2020 for results). This was followed by the second year of operation phase monitoring in October-November 2021, the results of which are described in this report.

PCA ordination of the plot data revealed that the rate of vegetation change (from February 2014 to Spring 2020) at the Impact sites was not consistently greater compared to the Control sites, suggesting no/minimal edge effects from vegetation clearing. There has been increases in the abundance of exotic species at some of the Impact sites since 2014, however this has also occurred at Control sites, suggesting edge effects were not necessarily the cause.

Since monitoring of the threatened rainforest plants began in 2014, there has been six plant mortalities - one White Laceflower, four Smooth Davidsonia, and one Green-leaved Rose Walnut. These plants died or declined in 2019, which was one of the driest years on record, and so it is likely that moisture stress was the cause.

Some of the threatened rainforest plants went backwards in the 2019 drought but resumed growing in 2020 and continued in 2021. Surprisingly most plants continued to grow through 2019 despite the extreme conditions.

Ongoing operational phase monitoring of the threatened rainforest communities and threatened rainforest plants will help determine if there are any longer-term impacts of the highway upgrade.

1 Introduction

1.1 Overview

Transport for New South Wales (TfNSW) aims to minimise impacts on threatened rainforest communities and threatened rainforest plant species during construction and operation of Sections 10 and 11 of the Woolgoolga to Ballina (W2B) Pacific Highway upgrade. To achieve this aim, a management plan was prepared specifically for threatened rainforest communities and species, which included methods for monitoring the potential impacts of highway construction and operation, resulting in changes in species composition and condition. For details see *Woolgoolga to Ballina Threatened Rainforest Communities and Rainforest Plants Management Plan* (TFNSW 2015). TFNSW prepared this management plan based on data collected in preconstruction surveys and baseline monitoring by EMM and Ecos Environmental (see EMM 2014 for details).

The objective of the monitoring program was to determine the effectiveness of mitigation measures in avoiding direct and indirect impacts and maintaining the condition of threatened rainforest communities and species during highway construction and operation (TFNSW 2015).

The schedule for the monitoring program includes three years of construction phase monitoring and three years of operation phase monitoring. The results of the construction phase monitoring are described in three annual monitoring reports (Ecos 2017, 2018 and 2019). In September 2020, Sections 10 and 11 of the W2B upgrade opened to traffic and in November 2020, Ecos Environmental undertook the first year of operation phase monitoring (see Ecos 2020 for results). This was followed by the second year of operation phase monitoring in spring 2021, the results of which are described in this report. The contents of this annual monitoring report are set out as follows:

- Section 2: methods, data analysis and results of the threatened rainforest communities component of the monitoring program
- Section 3: methods, data analysis and results of the threatened rainforest plants component of the monitoring program, and
- Section 4: conclusion and recommendations.

1.2 Performance Criteria

The management plan (TfNSW 2015) requires that mitigation measures implemented to protect threatened rainforest communities and species during highway construction of operation be assessed for effectiveness against performance criteria, using the results of monitoring.

This monitoring report is concerned with management of in situ vegetation and threatened plant species – ie those naturally occurring and remaining in situ in the road reserve after the finish of clearing. Relevant performance criteria are those relating to management of in situ threatened rainforest communities and in situ threatened rainforest plant species during the operational phase of ecological monitoring (lasting for three years).

Objectives of rainforest management during the operational period are given in Section 8.2 of the management plan (TfNSW 2015). Similarly, the objectives of rainforest monitoring are given in Sections 9.2 and 9.3 of the management plan. Although performance criteria may not be specifically stated in some cases, stated objectives or management goals can be considered as equivalent to performance criteria, and are provided in relevant sections of the plan. Specific performance criteria for threatened rainforest communities and species during the operational monitoring period lasting for three years, include:

- Zero mortality of retained *in situ* threatened plant populations has occurred during construction and for three consecutive monitoring periods post-construction and 80 per cent survival of tree, shrub and herbaceous perennials after three years
- At least 90 per cent of the plants planted as part of the revegetated areas have survived after the first year and 80 per cent after three consecutive monitoring events; and
- Less than five per cent weed cover at retained *in situ* threatened flora sites (after three years).

See also Sections 9.2 and 9.3 which describe the objectives of monitoring and is reproduced below:

9.2 In situ threatened rainforest plants

Retained in situ threatened flora species/populations within the project area would be monitored during and post-construction until the mitigation measures have been proven successful for three consecutive monitoring periods. Post construction monitoring of in-situ rainforest plant and rainforest communities will be undertaken annually. A particular focus would be to identify any changes in health and condition which require management actions for remediation.

9.2.1 Monitoring goals

All retained in-situ threatened rainforest plants have survived during construction and for three consecutive monitoring periods post-construction and 80 per cent survived after three years, especially for trees, shrubs and large vines.

Species may differ in resilience, longevity and sensitivity to disturbance. Plant health may seasonally fluctuate in its natural environment depending on the species (e.g. shade loving species would need more attention to buffering disturbances, particularly in the understorey). These factors would need to be consideredl.

9.3 Rainforest communities

Monitoring sites of the Lowland and Littoral rainforest communities in Sections 10 and 11 of the project have been established by EMM (2014) and focus on patches within 50 metres of the project where access is achievable. The monitoring includes an assessment of habitat condition within remnant patches. Control sites have also

been selected to monitor natural variation within the habitat condition which are not attributable to the impacts associated with the project.

9.3.1 Monitoring goals

Monitoring would provide reliable information such that sound conclusions can be drawn in relation to the management of rainforest communities. The overall monitoring objectives include:

- Evaluating the success of mitigation measures, including protection of in situ rainforest communities
- Evaluating any impacts to rainforest communities as a result of the project (e.g. edge effects, weed incursion, changes in microclimate); and
- Evaluating the success of weed control.

Performance Criteria (including management objectives and goals) provided in the management plan (TfNSW) for assessing the effectiveness of mitigation measures in protecting threatened rainforest species and rainforest communities during highway operation are summarised in the table below:-

Rainforest Species
Objective/Performance Criteria (see MP Table 8.3, Section 8.4)
80% survival of threatened species after three years
80% of plants planted in revegetated areas (translocation sites) have survived after three years
<5% weed cover at in situ threatened flora sites
Rainforest Communities
Objective/Performance Criteria (see MP Section 9.3)
• Evaluating any impacts to rainforest communities as a result of the project (e.g. **edge effects**, weed incursion, **changes in microclimate**)
• Evaluating the success of weed control.
• Evaluating the success of mitigation measures, **including protection of rainforest communities adjacent to the clearing extents** and in situ threatened rainforest plant populations
Rainforest - General
The objective of the monitoring program was to determine the effectiveness of mitigation measures in avoiding direct and indirect impacts and **maintaining the condition of threatened rainforest communities** and species during highway construction and operation (TFNSW 2015).

This monitoring report does not address mitigation measures and objectives aimed at revegetation, which is also identified as a mitigation measure in the rainforest management plan (TfNSW 2015). For example:

- Revegetation with native species reflective of the local area and pre-disturbed vegetation communities where possible will occur post construction. Revegetation design of areas adjacent to *in situ* threatened plant populations will ensure the plantings will not impact on the species (e.g. will not compete for light or moisture) and are consistent with their habitat requirements. Further details of areas for revegetation and native species to be used, will be provided in the Urban Design and Landscape Plan (UDLP) for each section of the project.

Revegetation and habitat restoration were carried out by Ecos Environmental at the two rainforest translocation sites (Lumleys Lane and Coolgardie Rd). Results are described in the relevant annual translocation monitoring reports and again address general objectives and goals rather than specific performance criteria. Other revegetation work was carried out adjoining the Coolgardie Road interchange by another contractor.

2 Threatened Rainforest Communities

2.1 Methods

2.1.1 Identification of rainforest types

Two threatened rainforest communities occur within and adjacent to sections 10 and 11 of the W2B Pacific Highway upgrade:

- Lowland Rainforest of the NSW North Coast and Sydney Basin Bioregion - an Endangered Ecological Community (EEC) listed under the NSW *Biodiversity Conservation Act 2016* (BC Act). This community is equivalent with the Commonwealth *Environment Protection and Biodiversity Conservation Act 199*9 (EPBC Act) listed Lowland Rainforest of Subtropical Australia, which has the status of critically endangered ecological community (CEEC); and

- Littoral Rainforest in the South East Corner, Sydney Basin and NSW North Coast Bioregions (herein referred to as Littoral Rainforest) - listed under the TSC Act as an EEC, equivalent with the EPBC Act listed Littoral Rainforest and Coastal Vine Thickets of Eastern Australia, which is listed as a CEEC.

In addition to the two listed threatened rainforest types, the preconstruction survey carried out in 2014 (EMM 2014) identified four rainforest types as present in the study, as follows:

- Littoral rainforest
- Swamp rainforest
- Rainforest on alluvium
- Hillside rainforest regrowth.

The first community is equivalent to the EEC *Littoral Rainforest* and the other three are equivalent to, or sub-foTfNSW of, the EEC *Lowland Rainforest*. This initial classification of rainforest types by EMM was subsequently confirmed by cluster analysis of plot data, as described in Ecos (2017).

2.1.2 Data collection at Control and Impact sites

A total of 14 Control and Impact monitoring sites were positioned in the four different rainforest types within and adjacent to Sections 10 and 11 of the highway upgrade (Figure 1). Each Impact site was paired with a Control site in the same rainforest type, as indicated in Table 1. Control sites were located at a minimum of 20 m from the clearing boundary and within 100 m of the project boundary, as specified in the management plan (TFNSW 2015). Impact sites were located as close as possible to the clearing boundary. The Impact sites are potentially subject to negative edge effects such as elevated light intensity, higher temperatures, lower moisture availability, stronger wind, weed invasion and lower

seedling survival due to branch fall. Control sites are expected to be unaffected by highway construction and operation.

Each monitoring plot was 20 m x 20 m and divided into four 20 m x 5 m sub-plots, labelled *a*, *b*, *c* and *d*. The long edge of each sub-plot was aligned parallel with the clearing boundary (Figure 2). Sub-plot *a* was always closest to the clearing boundary and subplot *d* was placed furthest from the boundary.

GPS coordinates and photographs were taken at the corners of each plot. 1.2 m hardwood stakes were used to mark the corners of each plot, while smaller 60 cm stakes were used to mark the ends of each sub-plot.

Within each of the four sub-plots, the following data were recorded:

- All species and their abundance in five fixed vertical height strata or layers: 0-1 m, 1-5 m, 5-10 mm, 10-20 m, and 20+ m
- The general health of plants
- Any disturbances or weed invasion
- General landscape features (slope, aspect, soil, etc).

Species abundance was recorded as crown-cover, which can be defined as the percentage of the plot area (or sub-plot in the case of this monitoring program) covered by the vertical projection onto the ground of the perimeter or outline of plant crowns. The area within the crown perimeter contributes to crown cover regardless of spaces between leaves. As a guide, in this monitoring study a plant crown covering 1 m x 5 m of the sub-plot was equal to a crown cover of 5%, a plant crown covering 2 m x 5 m of the sub-plot was equal to a crown cover of 10%, etc. Species crown cover was recorded for each height stratum.

Distance from forest edge/clearing

The distance from each Impact plot to the forest edge was recorded to assess which Impact plots are most likely to be susceptible to edge effects.

Monitoring Schedule

The second annual operational phase monitoring of the rainforest communities was carried out in October-November (Spring) 2021 (Table 2).

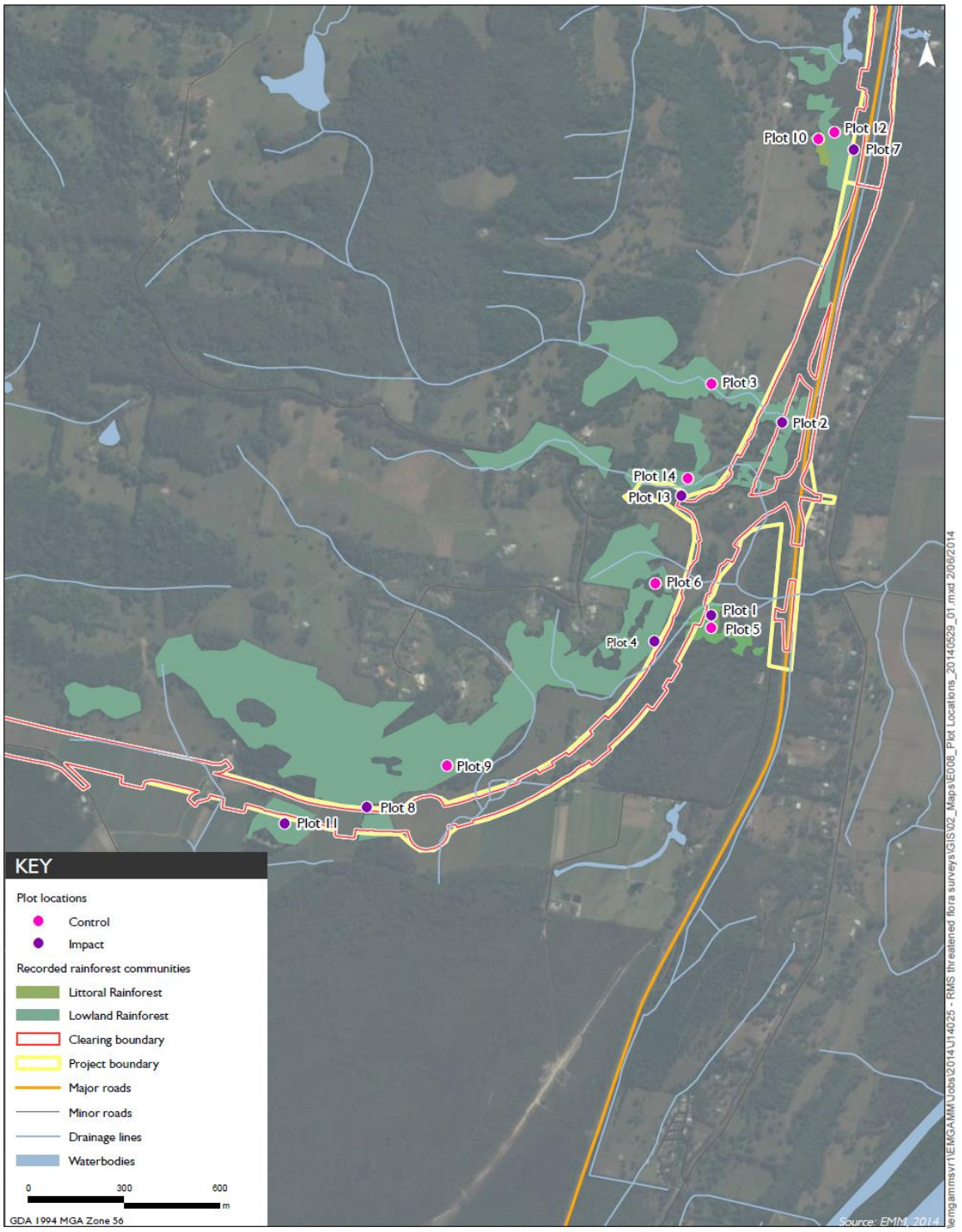


Figure 1. Monitoring plots in relation to W2B Pacific Highway upgrade project boundary and threatened rainforest communities. Map is sourced from EMM (2014).

Table 1. Details and habitat description of paired Impact and Control monitoring plots.

Paired sites	Impact/ Control	Rainforest type/subtype	Habitat/Location
1	Impact	Littoral rainforest	Flat, Pleistocene sand bench, off Kays Rd
5	Control		~20m east
2	Impact	Lowland Rainforest on creek alluvium	Both plots on Randell's Creek
3	Control	Disturbed, mostly open canopy	~300m upstream
4	Impact	Rainforest regrowth on rocky hillside	Regrowth, weedy, lower slope
6	Control		~300m north
7	Impact	Swamp rainforest – Bangalow Palm	Flat floodplain swale, flood-prone, peaty soil
12	Control		~100m apart very similar
8	Impact	Rainforest regrowth on rocky hillside	Regrowth, weedy, lower to mid slope
9	Control		~300m north
11	Impact	Littoral rainforest/Lowland Rainforest	Flat Pleistocene sand merging with bedrock hillslope
10	Control		~2.5km north; not merging with bedrock
13	Impact	Rainforest regrowth on hillside	Lower slope, north of Coolgardie Rd.
14	Control		~50m north

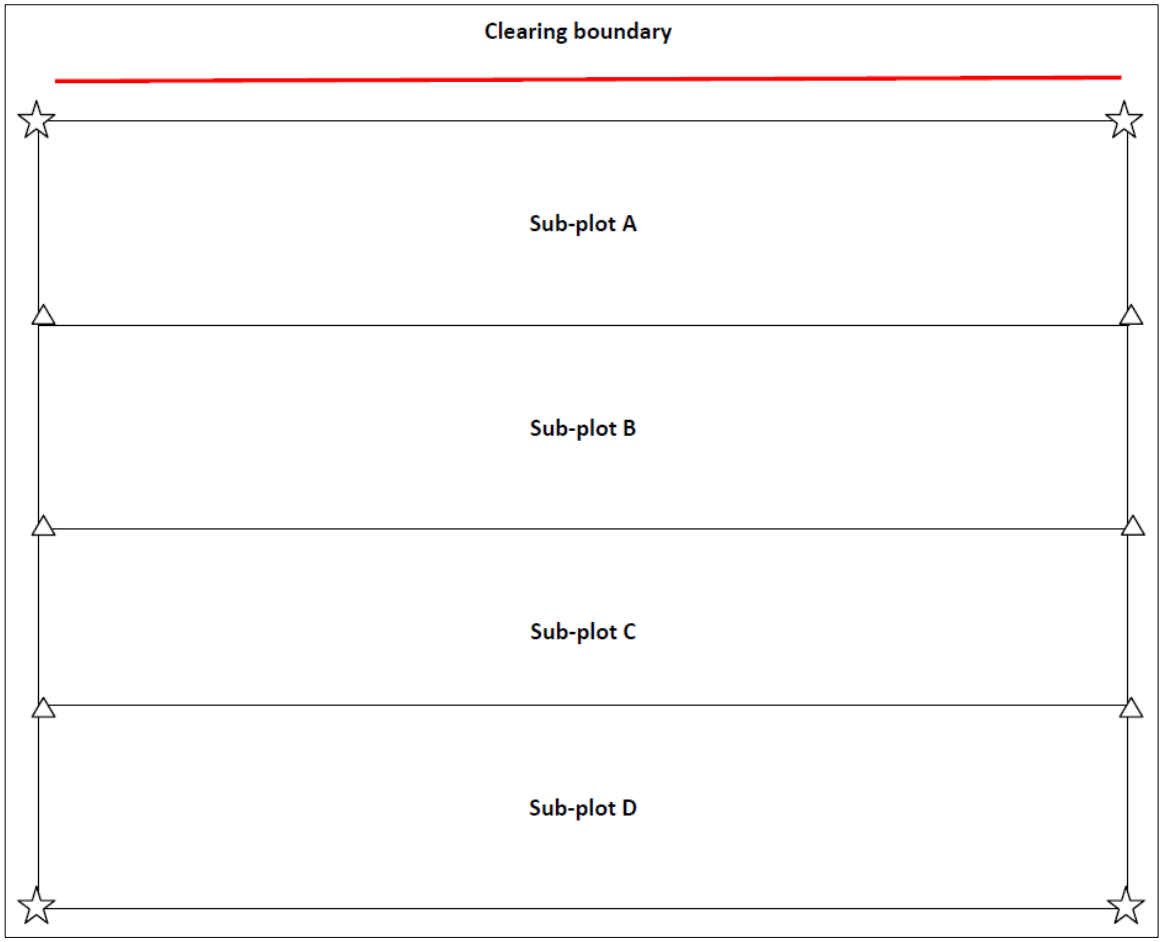


Figure 2. Plot layout for threatened rainforest communities monitoring plots. Plots were 20 m x 20 m and divided into four 20 m x 5 m sub-plots. Diagram is sourced from EMM (2014).

Table 2. Schedule for W2B Threatened Rainforest Plants and Rainforest Communities monitoring program. Table sourced TFNSW (2015).

Monitoring	Year	Phase	Section
1st quarter - Rainforest Plant Monitoring	1	Construction	S10-11
2nd quarter - Rainforest Plant Monitoring	1	Construction	S10-11
3rd quarter -Rainforest Plant Monitoring	1	Construction	S10-11
4th quarter - Rainforest Plant Monitoring	1	Construction	S10-11
Autumn - Rainforest Community Monitoring	1	Construction	S10-11
Spring - Rainforest Community Monitoring	1	Construction	S10-11
1st half - Rainforest Plant Monitoring	2	Construction	S10-11
2nd half - Rainforest Plant Monitoring	2	Construction	S10-11
Autumn - Rainforest Community Monitoring	2	Construction	S10-11
Spring - Rainforest Community Monitoring	2	Construction	S10-11
Annual monitoring - Rainforest Plants	3	Construction	S10-11
Autumn - Rainforest Community Monitoring	3	Construction	S10-11
Spring - Rainforest Community Monitoring	3	Construction	S10-11
Annual monitoring - Rainforest Plants	4	Operation	S10-11
Annual monitoring - Rainforest Communities	4	Operation	S10-11
Annual monitoring - Rainforest Plants (Provisional)	5	Operation	S10-11
Annual Monitoring - Rainforest Communities (Provisional)	5	Operation	S10-11
Annual monitoring - Rainforest Plants (Provisional)	6	Operation	S10-11
Spring - Rainforest Community Monitoring (Provisional)	6	Operation	S10-11

2.2 Data Analysis

2.2.1 Ordination and point sequences

The perceived threat of the highway upgrade to the adjacent threatened rainforest communities is that it will cause edge effects resulting in a decrease in habitat condition (through weed invasion and death of plants due to exposure to harsher abiotic factors). Based on this assumption we can make predictions about how the vegetation at the monitoring sites will change following construction and operation of the highway, such as:

> After construction begins, the rate of vegetation change at the Impact sites will be greater than at the Control sites.

To test these predictions, a data analysis method from Chapter 7 of *Data Analysis in Vegetation Ecology* (Wildi 2017) for detecting and investigating temporal trends in vegetation was followed.

An excel spreadsheet containing data for sub-plot *a* of each site from the baseline monitoring (2014) and the 2021 operation phase monitoring was imported into a data matrix object in the statistical software *R* (R Core Team 2018). Principal Component Analysis (PCA) was performed separately on each pair of Control and Impact sites (e.g., Plot 2 and Plot 3, Plot 1 and Plot 5, etc) using the *pcaser* function in the *dave* package (Wildi 2017). Like all ordination methods, PCA enables complex multivariate datasets to be arranged in two-dimensional space where the closer samples (represented by points) are to each other, the more similar (in teTfNSW of the variables measured) they are. Only subplot *a* and baseline versus 2021 data were analysed to make it clearer to see trends in ordination space. Note, that the rate of vegetation change at the impact sites is expected to be greatest at sub-plot *a* as it is closest to construction.

2.2.2 Abundance of exotic species

The abundance of exotic species was used as an indicator of rainforest condition. An increase in the abundance of exotic species was interpreted as a decline in vegetation condition. The abundance of exotic species per plot was derived by summing the crown cover of each sub-plot and then averaging across the four sub-plots.

It is noted that following recommendations in the last monitoring report, a Rainforest Weed Management Plan was prepared by Jacobs and implemented in 2021. According to information supplied by Pacific Complete, Bushland Restoration Services (BRS) carried out weed control work in relation to the Weed Plan in Feb/March 2021. This was followed by further work by GMC Environmental Consulting in August 2021. Further exotic species removal in the area relevant to the Weed Plan was carried out by Ecos Environmental surrounding the Coolgardie Rd translocation area in 2021. A copy of the Rainforest Weed Management Plan (Jacobs 2020) and a work completion report are appended to this report.

2.2.3 Native tree recruitment

Native tree recruitment was used as an indicator of overall rainforest condition and recovery (following historical disturbances). Recruitment was calculated by counting the number of sub-plots each tree species was recorded in the 0-1 m stratum.

2.3 Results

2.3.1 Overall changes in rainforest community plots (2014 vs 2021)

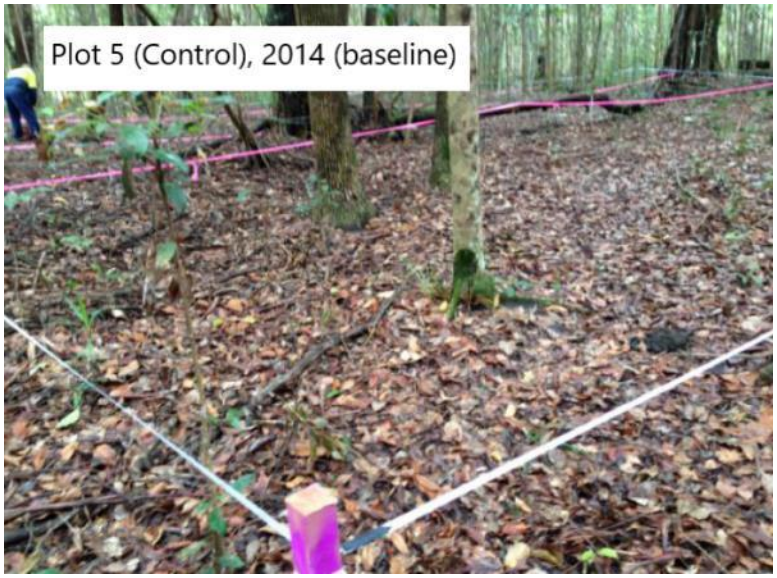
Table 3. Changes in composition and structure of rainforest communities. The spring 2021 monitoring data (second year of operation phase monitoring) was compared with 2014 (baseline) to determine overall floristic changes.

Monitoring sites	Vegetation changes (2014 vs. 2021)
 	• Small increase in weed abundance, esp. Ochna. • Tree fall in subplot *a* resulting in canopy gap. • Large increase of *Litsea australis* in 0-1 m stratum, species appears to be recruiting via root-suckering. • Large decrease in vine species *Cissus hypoglauca* and Smilax following 2019 drought. • Medium decrease in native grass spp. following 2019 drought. • Steady recruitment of native tree species – Three-veined Laurel, Tuckeroo, Guioa, Foambark.

- Medium increase in weed (Devil's Fig and Broad-leaved Paspalum) abundance, mostly next to clearing edge.
- Large increases in vines *Cissus hypoglauca* and Native Wisteria.
- Several annual weed species died out.
- High growth of native tree species in mid strata.

- Large increase in Lantana in sub-plot *a.*
- Increase in Broad-leaved Paspalum across subplots.
- Increase in vine *Flagellaria indica.*
- Increase in *Carronia multisepalea*, host vine for endangered Pink Underwing Moth.
- Increase in *Pararistolochia praevenosa*, host vine for endangered Richmond Birdwing Butterfly.
- High growth of native tree species in mid strata.
- Steady recruitment of native tree species – Three-veined Laurel, Pepperberry, Steelwood.

- Large increase in Large-leaved Privet in the 1-5 m stratum, mostly in sub-plot a.
- Increase in scrambler *Calamus muelleri*.
- Decrease in vines Smilax and Cockspur.
- Tree fall in subplot *b* resulting in canopy gap.
- Medium infestation of *Ochna serrulata* that has increase throughout monitoring program.
- Canopy dominated by Large-leaved Privet and Camphor Laurel but steady recruitment of native tree species – Rough-leaved Elm, Tuckeroo, Pepperberry.



- Increase in *Flindersia bennettiana* recruitment.
- Increase in *Litsea australis*, esp. in 0-1 m and 1-5 m strata.
- Most species relatively unchanged.
- Newly recorded species *Cryptocarya triplinervis* and *Diospyros pentamera*.
- New recorded in plot since baseline monitoring includes *Celtis paniculata, Parsonsia straminea, Pyrrosia rupestris, Platycerium bifurcatum.*
- Small infestation of *Ochna serrulata*, only slightly increased.
- Groundcover minimal since monitoring began and has remained unchanged.

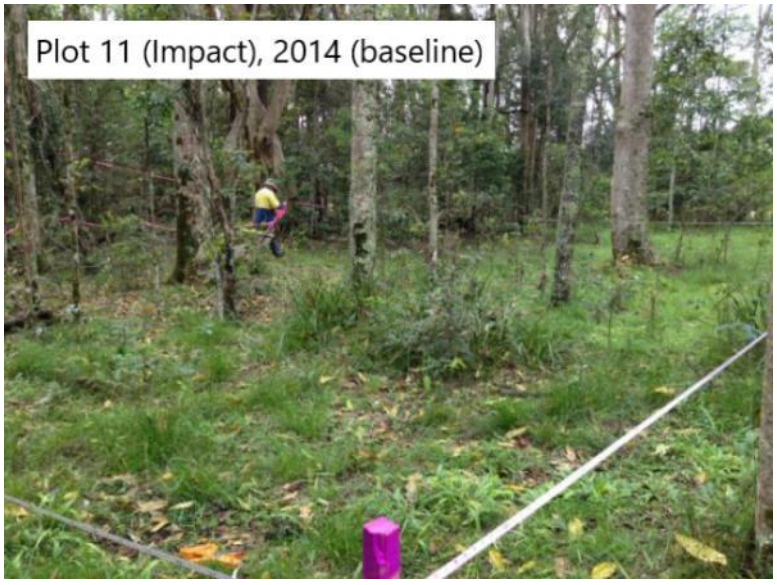
- Large increase in *Ochna serrulata,* mostly in subplots *a* and *b*.
- Medium increase *Gahnia aspera*.
- Large patch of Native Wisteria that has remained stable.
- Medium levels of native tree recruitment, mostly in bottom end of plot – Guioa, Jagera, Tuckeroo.
- Canopy and mid strata relatively unchanged.

- Increase in Small-leaf Privet in subplot *a.*
- Coastal Morning Glory (weed) invaded sub-plot *a* from clearing edge and has slightly increased.
- Most noticeable changes in subplot *a*, e.g., increase in *Trophis scandens*, *Cordyline stricta* and *Hypolepis muelleri.*
- Tree fall in sub-plot *a* resulting in small canopy gap.
- Native tree recruitment mostly Pink Doughwood and Bangalow Palm (species also dominant in canopy).

- Weed abundance (Lantana, Broad-leaved Paspalum, Large-leaved Privet) high in sub-plot *a* at edge of clearing, but weed invasion into forest has been minimal.
- Canopy and mid strata relatively unchanged.
- Canopy dominated by Large-leaved Privet and Camphor Laurel but steady recruitment of native tree species – Rough-leaved Elm, Tuckeroo, Pepperberry.

- Large-leaved Privet was dominant species in canopy.
- Bush regeneration work undertaken in 2020, Large-leaved Privet trees poisoned resulting in canopy gaps and increased sunlight.
- Large-leaved Privet seedling germination thick since trees poisoned.
- Increase in scrambler *Calamus muellerii*, mostly in sub-plots *b, c,* and *d*.
- Vine mass thick in most of plot.
- Minimal native tree recruitment since monitoring program began.
- Coastal Morning Glory recently invaded plot and beginning to increase.

- Floristics of plot have remained relatively unchanged since monitoring program began.
- Plot dominated by *Litsea australis* which is recruiting via root-suckering.
- Minimal weeds throughout monitoring program.
- Minimal recruitment of native tree species.



- Medium growth in mid strata of native tree species since monitoring program began.
- Small increases in weed species Climbing Asparagus, Lantana, Ochna.
- Bush regeneration work undertaken, treatment of understorey weeds.
- Floristics in groundcover and canopy relatively unchanged.

- Floristics of plot have remained mostly unchanged since monitoring program began.
- Weeds minimal/absent.
- Small increase in ferns *Blechnum cartilagineum* and *Hypolepis muelleri*.
- Small increase in sedge *Carex maculata*.
- Native tree recruitment low.

- Large increase in weed abundance since monitoring program began, species including Small-leaved Privet, Broad-leaved Paspalum, Climbing Asparagus, Madeira Vine, Coastal Morning Glory, Ochna.
- Weed abundance higher in NE corner of plot at edge of clearing.
- Decrease in native grass spp.
- High growth of species in mid strata.
- Native tree recruitment includes Sweet Pittosporum, Red Kamala, Guioa.

- Steady growth of species in mid strata.
- Increase in vine mass, esp. *Calamus muelleri*.
- Steady recruitment of native tree species – Three-veined Laurel, *Baloghia inophylla*, Guoia.
- Decrease in native grass spp.
- Increase in weed abundance in NE corner of plot where there is a canopy gap, species include Climbing Asparagus, Lantana, Broad-leaved Paspalum.

2.3.2 Ordination and point sequences

The PCA graphs showed the rate of vegetation change at sub-plot *a* for each pair of Control and Impact sites (Figure 3 and 4). In each PCA graph the length of the line connecting the two points in the time series indicates the rate of change, i.e., the longer the line, the greater the rate of change. If the highway upgrade negatively affected the adjacent rainforest communities through edge effects, we would expect the rate of change at the Impact sites to be greater than at the Control sites. This was the case for some areas, for example, Plot 2 and Plot 3. Sub-plot 2a (Impact) has changed more than sub-plot 3a (Control) (Figure 3). However, for other areas, the Control site has changed more than the Impact site, for example, Plot 8 and Plot 9 (Figure 4). As the rate of vegetation change is not consistently greater at the Impact sites compared to the Control sites, it is difficult to draw conclusions through multivariate analysis about the impact of the highway upgrade on the neighbouring rainforest communities.

The PCA graphs for the other paired sites are included in Appendix 1.

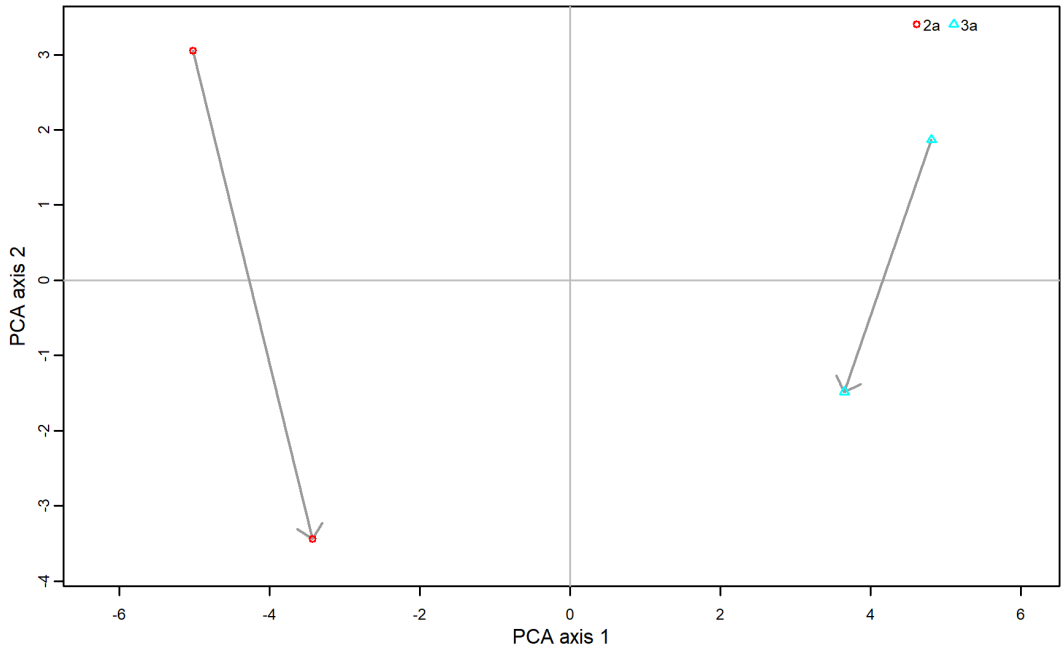


Figure 3. PCA ordination graph of a time series of sub-plot 2a (Impact) and sub-plot 3a (Control). The arrow points from the beginning state (i.e., autumn 2014) to the end state (i.e., spring 2021). Note that the rate of vegetation change is greater at the Impact site.

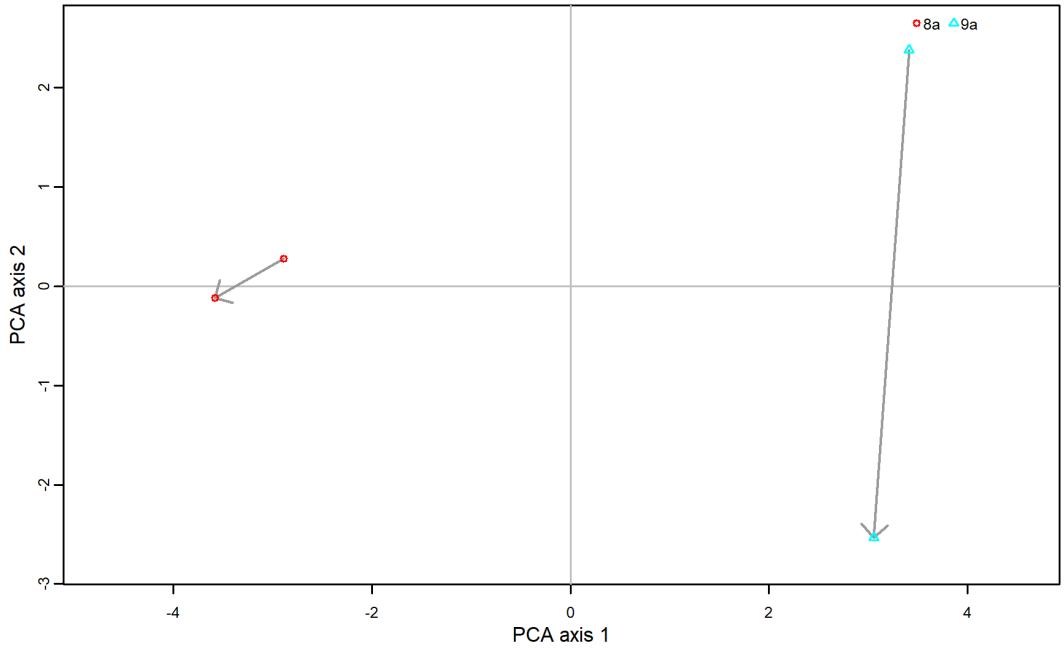


Figure 4. PCA ordination graph of a time series of sub-plot 8a (Impact) and sub-plot 9a (Control). The arrow points from the beginning state (i.e., autumn 2014) to the end state (i.e., spring 2021). Note that the rate of vegetation change is greater at the Control site.

One possible explanation for the absence of a temporal trend is that not enough time has elapsed for one to emerge. So far, the rainforest plots have been monitored for eight years (2014-2020), which is a small time-scale in the context of ecological succession.

A factor worth considering, however, is that some of the Impact plots were not situated directly beside the forest edge (edge of clearing) and therefore, are not expected to be subject to strong edge effects (Table 4). For some Impact plots the forest edge has become closer due to clearing for the highway upgrade, while the distance to the forest edge has not changed for others as there was a cleared edge already, at the start of construction.

Table 4. Variable distance of Impact plots from edge of clearing or construction and whether clearing was effective or ineffective. Effective clearing is where clearing of forest took place next to the plot and ineffective clearing is where clearing (of the construction footprint) next to the plot did not result in removal of forest, only pasture.

Impact plot	Approx. distance of plot to edge of clearing/ construction	Effective/ineffective clearing
1 (LRF Kays Ln)	15 m	Effective
2 (STRF Randall's Ck)	0 m	Effective
4 (RF rocky)	10 m	Ineffective
7 (Swamp RF)	0 m	Effective
8 (RF rocky)	10 m	Ineffective
11 (LRF Lumleys)	10 m	Effective
13 (Coolgardie Rd)	5 m	Ineffective

Previous monitoring studies of the impact of clearing on threatened rainforest flora found that weed incursion into threatened species habitat rarely extends more than 10 m inside newly created forest edges (Ecos Environmental 2006). Four of the seven impact monitoring plots for this study are 10 m or more from the edge of clearing and therefore, based on Ecos Environmental (2006), would be unlikely to register a significant increase in weediness due to reduced distance to the forest edge.

It should be noted that positioning of the Impact plots at the immediate edge of clearing was difficult as they were installed in 2014 when only early models of the road design and construction footprint were available. Ideally, such plots should be installed directly after clearing, to record the true edge effect.

Ordination methods are useful for simplifying complex datasets and detecting overall tends in plant communities. A limitation of this approach, however, is that common or abundant species in plant communities can mask small but important changes occurring among less frequent species. Therefore, it is important to also investigate trends that may be occurring at the species level or among certain components of the flora (e.g., exotic species, specific growth foTfNSW or strata within the plant community) as described below.

2.3.3 Abundance of exotic species

A total of 33 exotic species were recorded in spring 2021 across the 14 monitoring plots. Like in previous monitoring events, most were common garden escapees or herbaceous annuals that do not pose a serious threat to the integrity of rainforest communities. Eleven species were recorded that are considered serious weeds in rainforest communities, these were Madeira Vine, Climbing Asparagus Fern, Camphor Laurel, Coastal Morning Glory, Large-leaved Privet, Ochna, Broad-leaved Paspalum, Devil's Fig, Winter Senna and Crofton

Weed. Of these eleven weed species, Camphor Laurel, Large-leaved Privet, Broad-leaved Paspalum, Climbing Asparagus Fern and Ochna were most common among the monitoring plots.

Exotic abundance averaged across the seven Impact plots has increased from 32% crown cover in February 2014 to 55% crown cover in Spring 2021 (Table 5). Impact plots 2, 4 and 13 had the largest increases in exotic abundance since February 2014 (11%->42%, 61%->113%, and 38%->90%, respectively). The other Impact plots either had small increases in exotic abundance or remained relatively unchanged.

The increase in exotic abundance in the Impact plots could be indicative of detrimental edge effects (i.e., an increase in light availability favouring weed species), however, there has also been an increase in exotic abundance in the Control plots. Exotic abundance averaged across the seven Impact plots has increased from 17% crown cover in February 2014 to 29% crown cover in Spring 2021. In all of the Control plots there has been an increase in exotic abundance throughout the monitoring program. Control plots 3, 5 and 6 had the largest increases in exotic abundance since February 2014 (4%->24%, 12%->25%, and 28%->67%, respectively).

Weeds establish in rainforest where there is increased light availability, which can either be at the edge of the rainforest or underneath canopy gaps as a result of tree fall. In the rainforests of north-eastern Queensland, Pohlman (2006) found that weeds were confined exclusively to the forest edge or where there were large canopy gaps. Once some rainforest weeds are established however, they can continue to grow in low light conditions. This is true for the weed species Climbing Asparagus, Madeira Vine and Ochna (Darren Bailey pers. comm.). The finding in this monitoring study that there has been an increase in weed abundance at both the Impact and Control plots suggests that weed abundance has increased not because of construction-related edge effects but because weeds were established at the plots prior to the monitoring study commencing, and have continued to grow regardless of increased light availability from clearing.

Another factor that may explain the increase in weed abundance is the removal of cattle grazing. The monitoring sites have a history of cattle grazing and it is generally recognised that removal of cattle from forest where they formerly grazed is followed by an increase in weediness. Weeds can become established in a forest as a result of cattle foraging but as long as cattle continue to graze the forest the weeds are controlled. Removing cattle to restore natural conditions can have the opposite effect by encouraging weed growth and necessitate expensive weed control programs.

The monitoring sites that are positioned on the rocky slopes of the Blackwall Range (Plots 4, 8, 9 and 13) have a canopy dominated by Broad-leaved Privet and to a lesser extent Camphor Laurel. These exotic species are often the first trees to establish in cleared areas that previously had rainforest and a range of birds feed on these species fruit. Although Broad-leaved Privet and Camphor Laurel are aggressive competitors, they may serve as an initial nursery layer that enables native species dispersed by birds to establish. Indeed, Plots 4, 8, and 13 all had native trees, shrubs, ferns and herbs establishing in the lower canopy strata, and native vines were already abundant in the higher strata.

Some of the current weed infestations at the monitoring sites are more likely to cause a reduction in rainforest condition and a loss of biodiversity in the future. This is the case for infestations at sites 6, 7, and 13. At site 6 (Control) there is a patch of Ochna that has increased substantially since the site was first visited in 2014.The patch is likely to continue to expand as the understorey is sparse and open (minimal competition) and Ochna can tolerate low light-availability underneath rainforest canopies. Ochna is difficult and time-consuming to treat as it has a high tolerance to herbicide, meaning substantial time and resources are required to control large infestations.

At site 7 (Impact), Coastal Morning Glory has invaded the forest from the edge of clearing. Currently, there is only a small patch in the monitoring plot but it should be controlled before it spreads further into the forest, as this weed is extremely hard to eradicate from an area once it has established. At site 13 (Impact) the situation is similar. The invasive vines Coastal Morning Glory and Madeira Vine have invaded into the forest from the edge of clearing and should be controlled immediately to prevent further spread.

2.3.4 Native tree recruitment

In Spring 2021, the ten native tree species with the highest frequency of active recruitment (i.e. present in 0-1 m stratum) were Three-veined Laurel (*Cryptocarya triplinervis*), Tuckeroo (*Cupaniopsis anacardioides*), Guoia (*Guioa semiglauca*), Rough-leaved Elm (*Aphananthe philippinensis*), Foambark Tree (*Jagera pseudorhus*), Bollywodd (*Litsea australis*), Bangalow Palm (*Archontophoenix cunninghamiana*), Pepperberry Tree (*Cryptocarya obovata*), Red Kamala (*Mallotus phillippensis*), Steelwood (*Sarcopteryx stipata*) (Table 6). Generally, these were also the ten most actively recruiting species in Spring 2017 and in 2014 (baseline monitoring) but in a different order. The exotic trees *C. cinnamomum* and *L. lucidum*, in comparison, were as frequent in the 0-1 m stratum as some of the top ten most actively recruiting native tree species.

Of the 141 native tree species recorded in the monitoring program, 74 species were present in the 0-1 m height stratum indicating active recruitment and 40 species were absent from this stratum indicating little or no recruitment. Of the species with no active recruitment were several that would have once been common in the rainforest communities before European settlement, including Australian Teak (*Flindersia australis*), White Booyong (*Argyrodendron trifoliatum*), Rose Satinash (*Syzygium crebrinerve*), White Beach (*Gmelina leichhardtiana*) and Rosewood (*Dysoxlum fraserianum*), which persist in the study area as a few stunted, remnant trees. Many other species such as the large figs *Ficus macrophylla, F. watkinsiana, F. virens* and *F. superba* almost certainly present in the original rainforest, were also absent and no evidence of recolonization was seen.

2.3.5 Importance of exotic trees and native vines in rainforest regrowth

Exotic trees dominate the canopy of subtropical rainforest regrowth between Lumleys Lane and Coolgardie Rd (and elsewhere on the Blackwall Range) and appear to have been pivotal in facilitating rainforest regeneration, because of their ability to colonise cleared open sites. Some native species can do this such as Cheese Tree and Brush Kurrajong, but they are relatively scarce locally and the two exotic trees Camphor Laurel (*Cinnamomum camphora*) and Large-leaved Privet (*Ligustrum lucidum*) dominate regrowth. The monitoring method showed that these species are facilitating colonisation by native rainforest species, the majority of which are mainly present as seedlings, saplings and young trees under the exotic species dominated canopy. Also recorded was a general absence or scarcity of seedlings and young plants of the two exotics, indicating they do not recruit well in a forest, but require relatively open conditions to do this (perhaps formed by elephants and rhinoceros in the countries they originally came from).

The exotic trees are playing a key role in restoring rainforest ecosystem functions, by creating a suitable microclimate for native species to regenerate and by building up biomass and organic matter in the soil. Without this, the rainforest ecosystem would not have enough nutrient cycling between soil and vegetation to grow into a tall rainforest.

Vines are also common in the rainforest regrowth and form a main component of the forest canopy, enhancing the protected microclimate below and also adding substantial amounts of biomass to the ecosystem. There is a common perception that vines hold back the development of rainforest, which is a misconception. Ecologically, vines are essential for development and maintenance of rainforest. The most southerly occurrences of subtropical rainforest in eastern Australia which are in East Gippsland consist of gully vine thickets with a few vines and one or two tree species, demonstrating the important colonising role played by vines in maintenance of this ecosystem. The large vines seen in rainforest do not grow up and strangle the forest canopy, but start in canopy gaps or rainforest edges and are carried up by growing trees.

There was no evidence the exotic canopy trees and native vines were suppressing native species, more the contrary.

The importance of exotic trees and vines in rainforest regrowth is pointed out because landowners with good intentions, but mis-understanding the ecological role of these species, are engaging bush regenerators to poison and cut them out of rainforest regrowth. This approach for rainforest restoration should be discouraged, or at least implemented scientifically with control and treatment plot or areas, to compare their effect on the rainforest as it continues to regenerate.

Ecos Environmental recommends that bush regenerators focus on removing weed species from the understory of rainforest regrowth such as Asparagus Fern, Small-leaved Privet and Ochna, but leave exotic trees and native vines in the forest canopy. This approach should be specified in any future Biodiversity Stewardship Agreement sponsored by Transport for NSW and communicated to Ballina Shire Council.

Table 5. The abundance of exotic species of each pair of Control and Impact plots, compared across monitoring events. Abundance is percentage crown cover. Values can be higher than 100% because species abundance values were summed for the five strata. Averages rounded to the nearest integer.

		February 2014	**Autumn 2017**	**Spring 2017**	**Spring 2018**	**Spring 2019**	**Spring 2020**	**Spring 2021**
1	Impact	2	4	14	12	11	18	15
5	Control	12	10	18	25	22	25	26
2	Impact	11	36	18	35	30	42	50
3	Control	4	7	7	18	15	24	34
4	Impact	61	81	102	106	95	113	121
6	Control	28	41	37	57	52	67	90
7	Impact	2	1	1	2	1	4	4
12	Control	1	1	<0.5	1	1	1	1
8	Impact	103	92	127	114	117	108	108
9	Control	68	42	63	73	72	71	71
11	Impact	4	12	19	12	10	9	9
10	Control	4	2	2	4	5	5	4
13	Impact	38	54	37	92	81	90	95
14	Control	5	2	6	9	6	10	16
Overall Impact		32	40	45	53	49	55	57
Overall Control		17	15	22	27	25	29	35

Table 6. The 10 most frequent native tree species in 0-1 m height stratum, recorded in Spring 2017 and Spring 2018. Percentages rounded to the nearest one.

Baseline 2014		**Spring 2017**		**Spring 2021**	
Native tree species	**Percentage of subplots (n = 56)**	**Native tree species**	**Percentage of subplots (n = 56)**	**Native tree species**	**Percentage of subplots (n = 56)**
Cryptocarya triplinervis	26	*Cryptocarya triplinervis*	48	*Cryptocarya triplinervis*	37
Cupaniopsis anacardioides	24	*Archontophoenix cunninghamiana*	43	*Cupaniopsis anacardioides*	36
Aphananthe philippinensis	23	*Cryptocarya obovata*	40	*Guioa semiglauca*	32
Archontophoenix cunninghamiana	22	*Cupaniopsis anacardioides*	40	*Aphananthe philippinensis*	24
Cryptocarya obovata	22	*Aphananthe philippinensis*	32	*Jagera pseudorhus*	23
Guioa semiglauca	20	*Jagera pseudorhus*	32	*Litsea australis*	19
Litsea australis	20	*Guioa semiglauca*	28	*Archontophoenix cunninghamiana*	18
Jagera pseudorhus	19	*Litsea australis*	27	*Cryptocarya obovata*	18
Sarcopteryx stipata	17	*Sarcopteryx stipata*	25	*Mallotus phillippensis*	18
Flindersia schottiana	12	*Flindersia schottiana*	23	*Sarcopteryx stipata*	18
Exotic tree species					
**Cinnamomum camphora*	13	**Cinnamomum camphora*	20	**Cinnamomum camphora*	30
**Ligustrum lucidum*	10	**Ligustrum lucidum*	18	**Ligustrum lucidum*	9

3 Threatened Rainforest Plant Monitoring

3.1 Species included in monitoring program

The threatened rainforest plants being monitored are located on Sections 10 and 11 of the highway upgrade. Section 10 extends from the Richmond River north to Coolgardie Rd and Section 11 from Coolgardie Rd north to the Ballina bypass tie-in. Individuals closest to the forest edge as well as a selection of plants further back inside the forest were included in the monitoring program.

The following eight threatened rainforest plant species are located adjacent to Sections 10 and 11 of the W2B Pacific Highway upgrade and are being monitored as part of the *Woolgoolga to Ballina Threatened Rainforest Communities and Rainforest Plants Management Plan* (TFNSW 2015):

- Rough-shelled Bush Nut (*Macadamia tetraphylla*) (vulnerable under the Biodiversity Conservation Act, 2016 (BC Act) & Environment Protection and Biodiversity Conservation Act (EPBC Act)
- Green-leaved Rose Walnut (*Endiandra muelleri* subsp. *bracteata*) (endangered under the BC Act)
- White Lace Flower (*Archidendron hendersonii*) (vulnerable under the BC Act)
- Rusty Rose Walnut (*Endiandra hayesii*) (vulnerable under the BC Act & EPBC Act)
- Stinking Cryptocarya (*Cryptocarya foetida*) vulnerable under the BC Act & EPBC Act)
- Southern Ochrosia (*Ochrosia moorei*) (endangered under the BC Act & EPBC Act)
- Red Lilly Pilly (*Syzygium hodgkinsoniae*) (vulnerable under the BC Act & EPBC Act)
- Smooth Davidsonia (*Davidsonia johnsonii*) (endangered under the BC Act & EPBC Act).

Streblus brunonianus and *Acronychia littoralis* were included in the initial monitoring program (EMM 2014) but have since been removed. *Streblus brunonianus* was taken out as it is no longer listed as a threatened species and *Acronychia littoralis* was removed due to misidentification. For further details see Ecos (2017).

3.2 Data collection and analysis

A total of 210 plants were tagged and recorded in the baseline monitoring and pre-construction survey in February 2014 (Table 6). The tagged plants were positioned close to the highway construction footprint and further back inside the forest.

The following plant attributes were recorded: plant condition on a scale of 0-5 (Table 7), height and girth, presence of flowers or fruit, any insect/grazing damage, evidence of disease, and signs of recruitment.

Plant height was recorded with a tape measure for plants up to about 3.5 m high and visually estimated for taller plants.

Plant height was averaged across individuals of the same species and compared across 2017, 2019 and 2021. The 2017 monitoring data was included instead of the 2018 data in order to compare plants across a longer timeframe. Heights that were visually estimated (i.e., individuals higher than 3.5 m) were excluded from averaging. Averages were not calculated for Rusty Rose Walnut and Southern Ochrosia because there is only one plant being monitored for each species.

The tagged plants were monitored quarterly in year 1 (2017), biannually in year 2 (2018) and annually in years 3 to 5 (2019 - 2021) (Table 2).

Table 7. Condition scores applied to threatened rainforest plant species.

Score	Condition
0	Dead
1	Leafless, possibly still alive and may reshoot
2	Small (<0.7- 1m), seedling or sapling, reasonably healthy; or taller plant that has dieback but still has some leaves
3	Sapling or small tree, healthy, evidence of recent new growth, not reproductively mature; or tree showing evidence of minor dieback
4	Reproductively mature, healthy but relatively small for the species
5	Reproductively mature, healthy, good size

3.4 Results

3.4.1 Summary

At spring 2021 (eight years since the monitoring program began), six of the tagged threatened plants appeared dead – two White Laceflower, three Smooth Davidsonia, and one Green-leaved Rose Walnut (Table 8). In 2019, five Smooth Davidsonia appeared dead but in 2020 one reshot and another one in 2021. Survival for Stinking Cryptocarya, Rough-shelled Bush Nut, Rusty Rose Walnut, Southern Ochrosia and Red Lilly Pilly was 100% in 2021.

Figure 5 shows the growth of plants below 3.5 m high (see Section 3.2 for why heights above 3.5 m were excluded) for each species in 2017, 2019, 2020 and 2021. Note, Rusty Rose Walnut and Southern Ochrosia were not included in the graph because there is only one plant being monitored for these species.

The 2019 drought was one of the driest years on record (Figure 6). It was not surprising that some individuals went backwards in 2019 or did not grow. This was true for plants of the species White Laceflower, Rough-shelled Bush Nut, Smooth Davidsonia and Green-

leaved Rose Walnut (Figure 7). The year 2020 had above average rainfall as did 2021 and most of the drought-affected plants resumed growing, which can be seen in Figure 7.

It was surprising that most of the individuals continued to grow in 2019, despite it being one of the driest years on record (see Figure 5). Most of the plants that went backwards resumed growing in 2020. Our data suggest that subtropical rainforest species are better adapted to drought than one might expect.

Table 8. The number of plants being monitored for each threatened species and their survival for the years 2017, 2019, 2020 and 2021.

Species	No. of plants monitored	Survival (%) 2017	Survival (%) 2019	Survival (%) 2020	Survival (%) 2021
Archidendron hendersonii	36	100	94	94	97
Cryptocarya foetida	12	100	100	100	100
Davidsonia johnsonii	26	100	81	85	88
Endiandra hayesii	1	100	100	100	100
Endiandra muelleri subsp. bracteata	56	100	100	98	98
Macadamia tetraphylla	74	100	100	100	100
Ochrosia moorei	1	100	100	100	100
Syzigium hodgkinsoniae	4	100	100	100	100

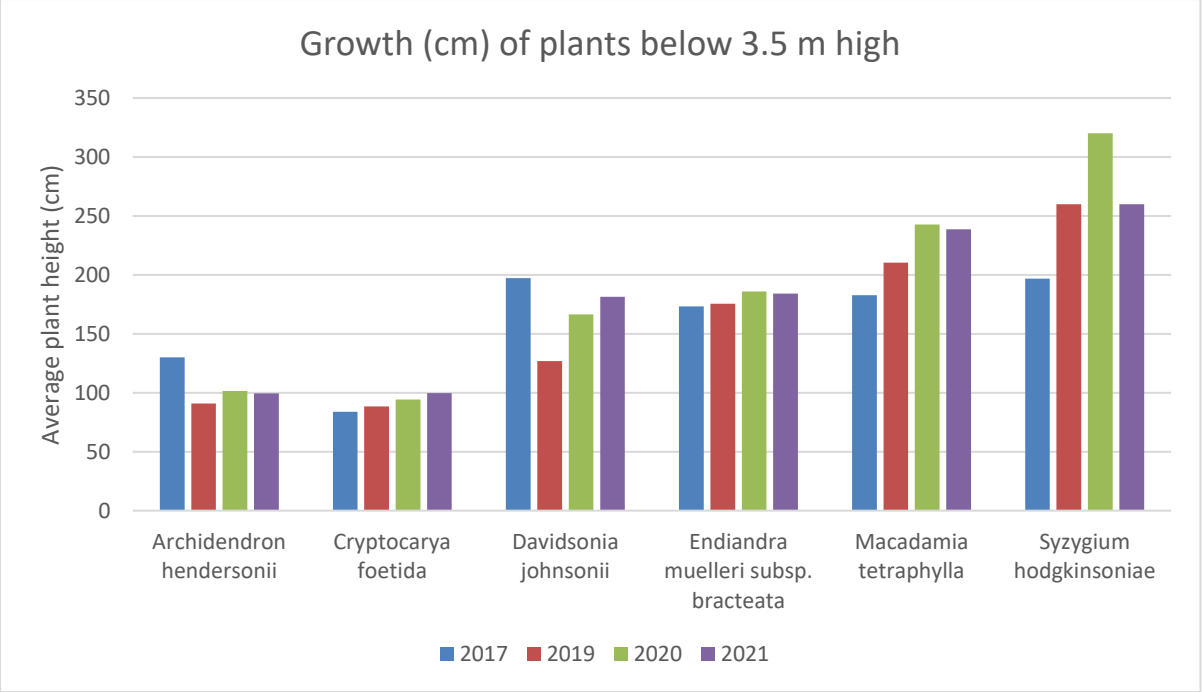


Figure 5. Average plant height (cm) of threatened species in 2017, 2019, 2020 and 2021 for plants under 3.5 m high. Note, Rusty Rose Walnut and Southern Ochrosia were not included because there is only one plant being monitored for these species.

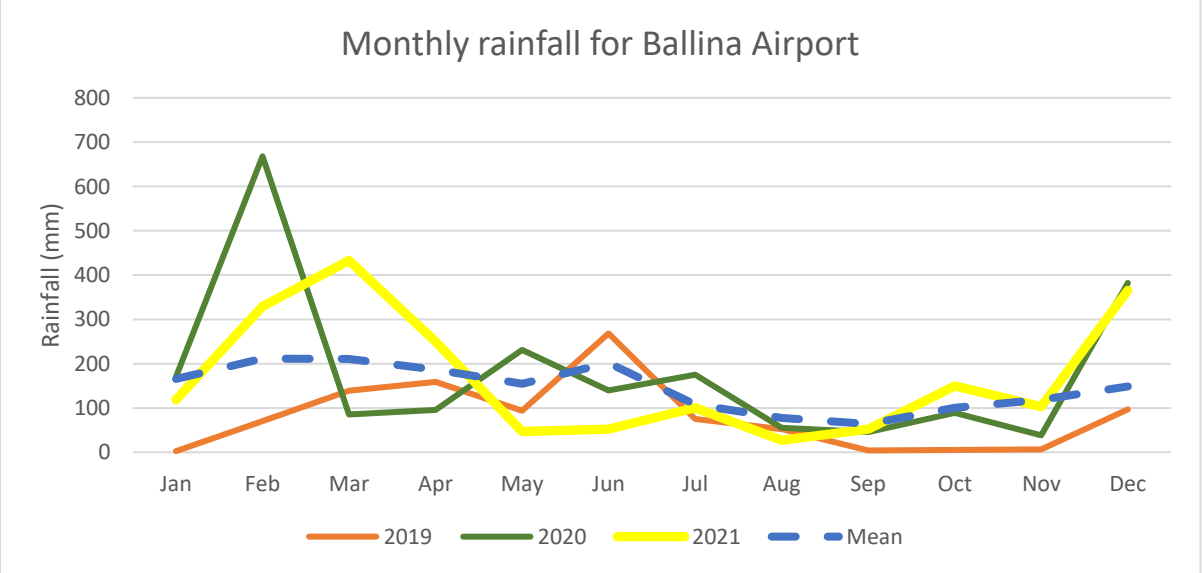


Figure 6. Monthly rainfall for Ballina Airport AWS, in 2017, 2019, 2020 and 2021, and mean montly rainfall for 21 years (1992-2021). Data sourced from http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=139&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=058198

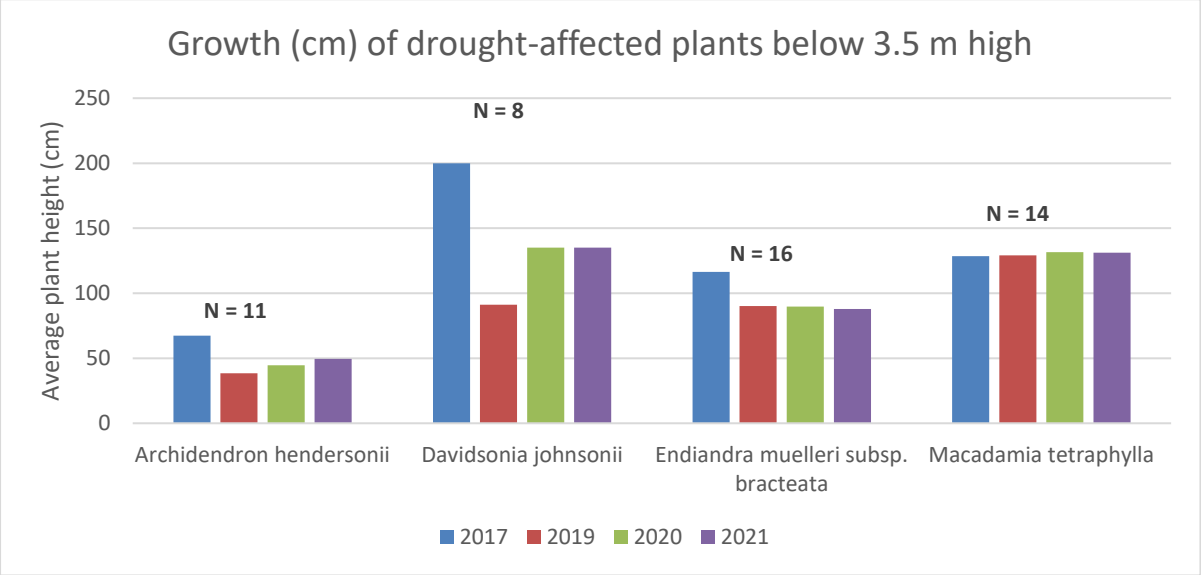


Figure 7. Average plant height (cm) of threatened species in 2017, 2019, 2020 and 2021 for drought-affected plants under 3.5 m high. *N*, sample size.

3.4.2 Condition of Threatened Species 2020

Rough-shelled Bush Nut (*Macadamia tetraphylla*)

Survival/condition: 100% survival; some plants have insect damage (e.g., Plate 1, Appendix 2) but they have still survived and grown (i.e., increased in height).

Growth: minimal for some plants throughout the monitoring program; these are growing under dense canopy and receiving little sunlight. Plants under 3. 5 m high on average grew from 183 cm in 2017 to 239 cm in 2021 (Figure 5).

Reproduction: 12 of the 74 plants being monitored were reproductive in 2021 (i.e., flowers and/or fruit present) (e.g., Plate 2, Appendix 2).

Green-leaved Rose Walnut (*Endiandra muelleri* subsp. *bracteata*)

Survival/condition: survival was 98% at spring 2021 (1 plant mortality). The single plant died during the 2019 drought most likely due to moisture stress.

Growth: some went backwards during the 2019 drought but most consistently grew throughout the monitoring program. For plants under 3.5 m high, average height was 173 cm in 2017 and 184 cm in 2021.

Reproduction: one plant was observed flowering in 2021 (Plate 3, Appendix 2).

White Lace Flower (*Archidendron hendersonii*)

Survival/condition: 97% survival; 2 plants appeared dead in 2019 and 2020 but one reshot in 2021.

Growth: most plants went backwards in 2019 but reshot and grew in 2020; for plants under 3.5 m high, average height was 130 cm in 2017 and 100 cm in 2021.

Reproduction: one plant was observed flowering in 2021 (Plate 4, Appendix 2).

Rusty Rose Walnut (*Endiandra hayesii*)

Survival/condition: only one plant of this species is being monitored; this plant was healthy in 2021.

Growth: the single plant grew from 4.6 m in 2017 to 7 m in 2021.

Reproduction: no flowers or fruit were recorded in 2021, as in previous years.

Stinking Cryptocarya (*Cryptocarya foetida*)

Survival/condition: survival was 100% in 2021 and plants were in healthy condition (Plate 5, Appendix 2).

Growth: most plants continued to grow through the 2019 drought. For plants under 3.5 m high, average height was 84 cm in 2017 and 100 cm in 2021.

Reproduction: no flowers or fruit were recorded, as in previous years.

Southern Ochrosia (*Ochrosia moorei*)

Survival/condition: only one plant of this species is being monitored and this plant was in healthy condition in 2021 (Plate 6, Appendix 2).

Growth: the single plant was 3 m in 2017 and grew to 6 m by 2021.

Reproduction: no flowers or fruit were recorded, as in previous years.

Red Lilly Pilly (*Syzygium hodgkinsoniae*)

Survival/condition: survival was 100% in 2020 and plants were in healthy condition.

Growth: all plants continued to grow through the 2019 drought but went backwards after 2020; for plants under 3.5 m high, average height was 320 cm in 2020 and 260 cm in 2021.

Reproduction: no flowers or fruit were recorded in 2020.

Smooth Davidsonia (*Davidsonia johnsonii*)

Survival/condition: survival was 88% in 2021 (three mortalities). Five plants appeared dead in 2019 but on of these reshot in 2020 and another one in 2021; plants were growing in a clump with other tagged Smooth Davidsonia and it is likely that they are different stems of the same genetic individual as the species reproduces vegetatively via root-suckering (it is the species only known form of reproduction).

Growth: some plants went backwards in the 2019 drought but some continued to grow through 2020 and 2021. For plants under 3.5 m, average height was 197 cm in 2017 and 182 cm in 2021.

Reproduction: one plant was observed flowering in 2021 (Plate 7, Appendix 2).

4 Conclusion and recommendations

4.1 Threatened rainforest communities

The monitoring program has been running for eight years (since 2014) and has provided an in-depth understanding of the threatened rainforest communities adjacent Sections 10 and 11 of W2B and detected any changes to vegetation integrity that may be due to construction-related edge effects.

The main findings of the monitoring program at spring 2021 (second year of operation) for the threatened rainforest communities were:

- PCA ordination of the monitoring data revealed that the rate of vegetation change (from February 2014 to Spring 2021) at the Impact sites was not consistently greater compared to the Control sites, suggesting no/minimal edge effects from construction.
- There were increases in the abundance of exotic species at some of the Impact sites but this has also occurred at Control sites, suggesting edge effects were not necessarily the cause.
- There were changes in the composition and structure of the rainforest at the monitoring sites but these changes are most likely due to natural ecosystem processes rather than induced edge effects.
- Species composition, vegetation structure and recruitment dynamics suggest that the rainforest communities are healthy and resilient, and have partly recovered from historical disturbances, except for key canopy species that would have been common pre-disturbance but are now scarce/absent.

Ongoing monitoring of the threatened rainforest communities for indirect impacts may gauge longer-term effects as operation of the highway upgrade continues.

4.2 Threatened rainforest plant species

The monitoring study has helped determine whether construction of Sections 10 and 11 of W2B has had any indirect impacts on the nearby threatened rainforest plants and added to our understanding of each species growth and reproduction. The main findings of the monitoring program at spring 2021 were:

- Survival was 100% for Red Lilly Pilly, 100% for Southern Ochrosia, 100% for Stinking Cryptocarya, 100% for Rough-shelled Bush Nut, 100% for Rusty Rose Walnut, 98% for Green-leaved Rose Walnut (1 mortality), 97% for White Lace Flower (1 mortality), and 88% for Smooth Davidsonia (3 mortalities).
- Individuals of Smooth Davidsonia and White Lace Flower appeared dead in 2019 but reshot and resumed growing in 2020 and continued in 2021.
- Individuals of Green-leaved Rose Walnut, White Lace Flower and Smooth Davidsonia went backwards in the 2019 drought but resumed growing in 2020 and continued in 2021.

- The threatened species were not observed fruiting or flowering most years; the exception was Rough-shelled Bush Nut with several individuals having abundant flowers and fruit each year and seedlings observed below mature trees.

4.3 Performance Criteria and Recommendations

Of the Performance Criteria identified in the management plan (TfNSW) and outlined in Section 1.2 above, most were considered to have been achieved and no corrective actions were required (see Table 8). The only exception was increasing abundance of exotic species at some sites.

Table 8: Performance Criteria, Monitoring Results and Corrective Actions

Rainforest Species	**Monitoring Result**	**Corrective Action**	**TfNSW response**
Objective/Performance Criteria (see MP Table 8.3, Section 8.4)			
80% survival of threatened species after three years	On track to achieve after 3 years – one more year to go	Not required	
80% of plants planted in revegetated areas (translocation sites) have survived after three years	On track to achieve after 3 years for nearly all species – one more year to go. See translocation report.	Not required	
Rainforest Communities			
Objective/Performance Criteria (see MP Section 9.3)			
Evaluating any impacts to rainforest communities as a result of the project (e.g. **edge effects**, weed incursion, **changes in microclimate**)	No significant adverse impact detected	Not required	
Evaluating the success of weed control.		Carry out weed control in and around Sites 7 and 13 (impact sites and inside project boundary) to remove the high	Adopted

		threat weeds Ochna, Coastal Morning Glory and Madeira Vine, to help control their spread and reduce further infestation. Remove understory weeds, not exotic canopy dominants or native vines – see discussion in report.	
Evaluating the success of mitigation measures, **including protection of rainforest communities adjacent to the clearing extents** and in situ threatened rainforest plant populations	No significant adverse impact detected	Not required	
Rainforest - General			
The objective of the monitoring program was to determine the effectiveness of mitigation measures in avoiding direct and indirect impacts and **maintaining the condition of threatened rainforest communities** and species during highway construction and operation (TFNSW 2015).	Overall, threatened rainforest communities and species were maintained in good condition over two years (operational phase), except for the proliferations of several sub-canopy exotic weed species, that threaten the long-term condition and quality of rainforest habitat within and adjacent the project boundary. Corrective action described above.		

5 References

EMM (2014) 'Rainforest Communities and Threatened Rainforest Plants Preconstruction Targeted Surveys and Baseline Monitoring Report'.

Ecos Environmental (2017) 'Woolgoolga to Ballina Pacific Highway Upgrade Sections 10 & 11 Threatened Rainforest Communities and Rainforest Plants Annual Monitoring Report # 1'. Report prepared for Jacobs.

Ecos Environmental (2018) 'Woolgoolga to Ballina Pacific Highway Upgrade Sections 10 & 11 Threatened Rainforest Communities and Rainforest Plants Annual Monitoring Report # 2'. Report prepared for Jacobs.

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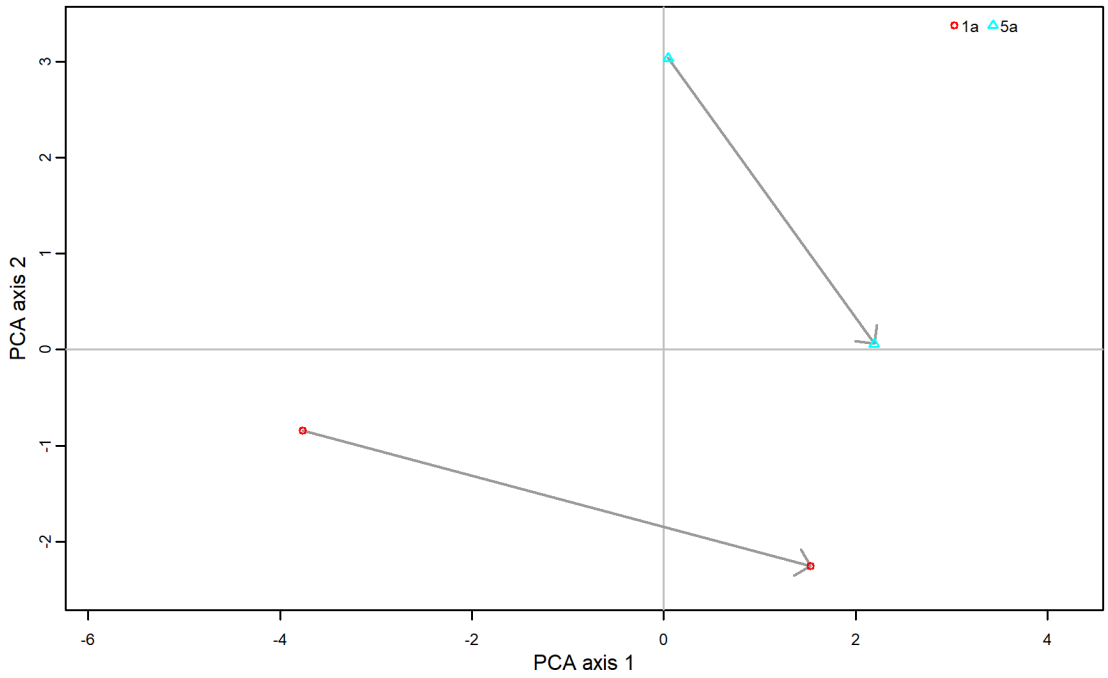
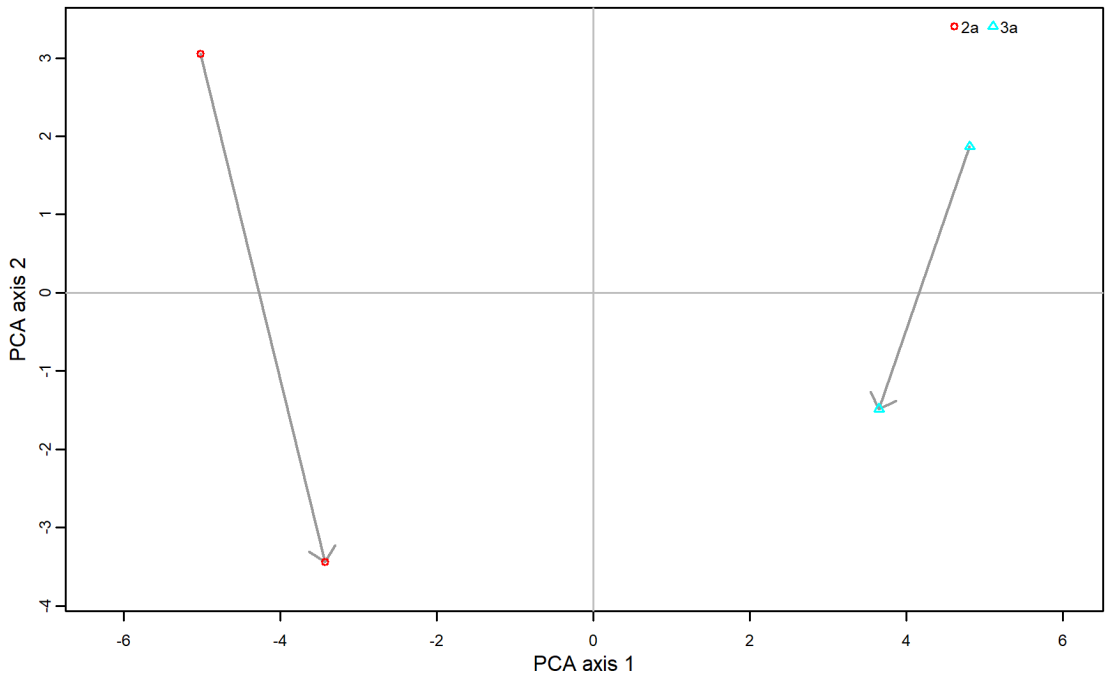
Appendix 1.

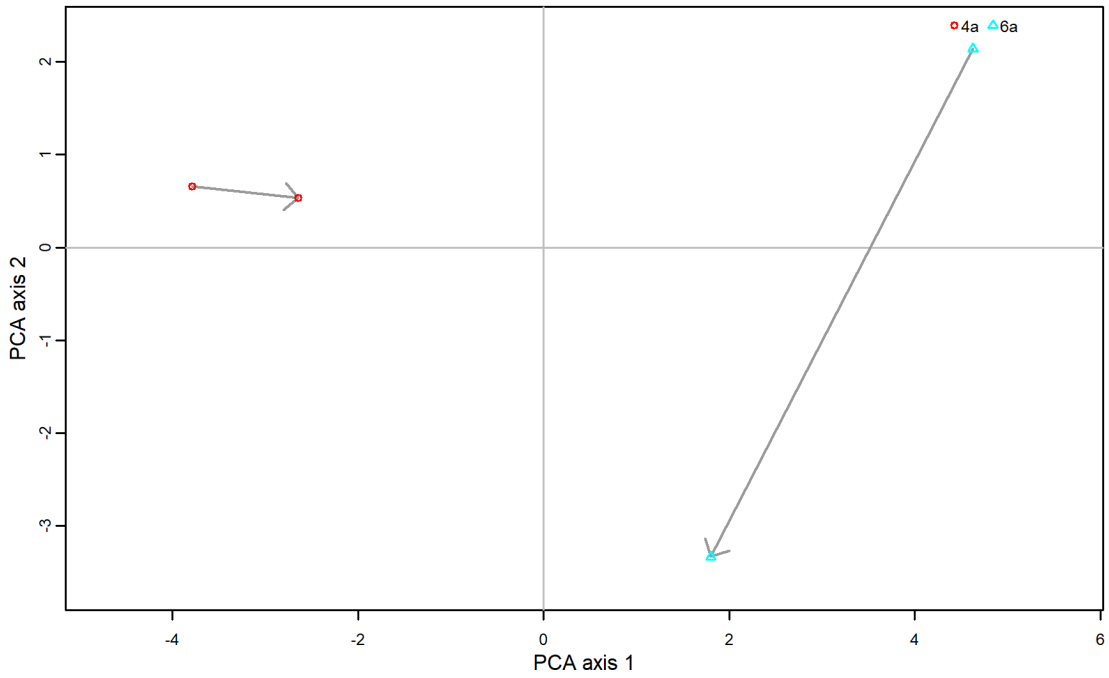
Ordination outputs – comparison of floristics in Impact and Control plots.



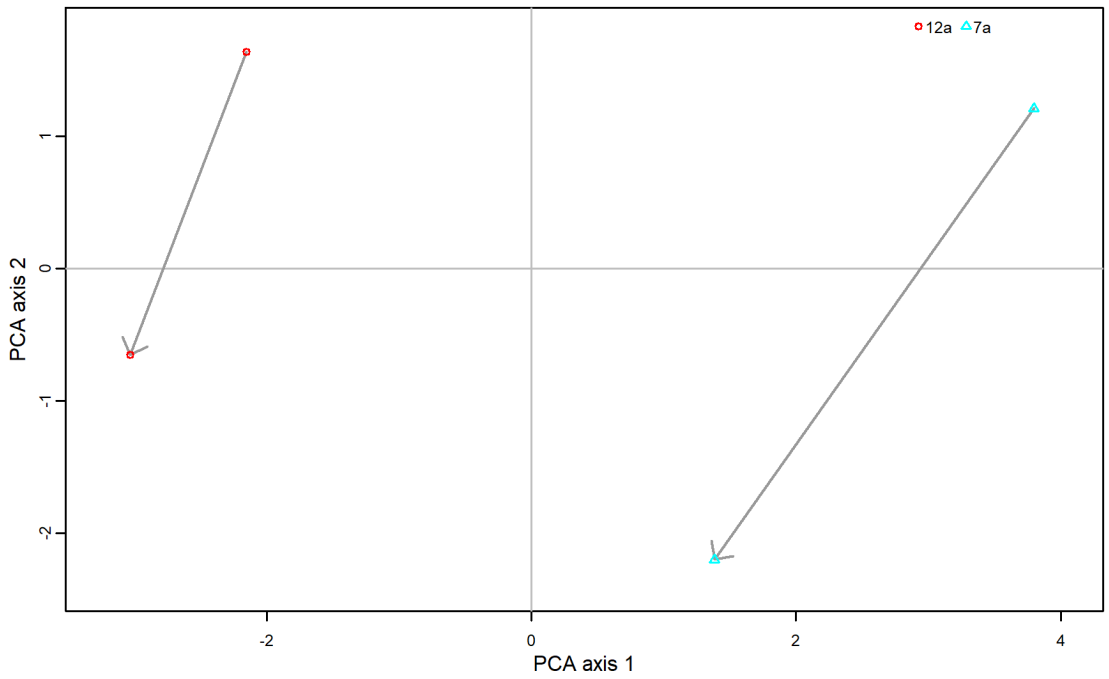
Sites 1a and 5a – Site 1 red = impact; Site 5 blue = control



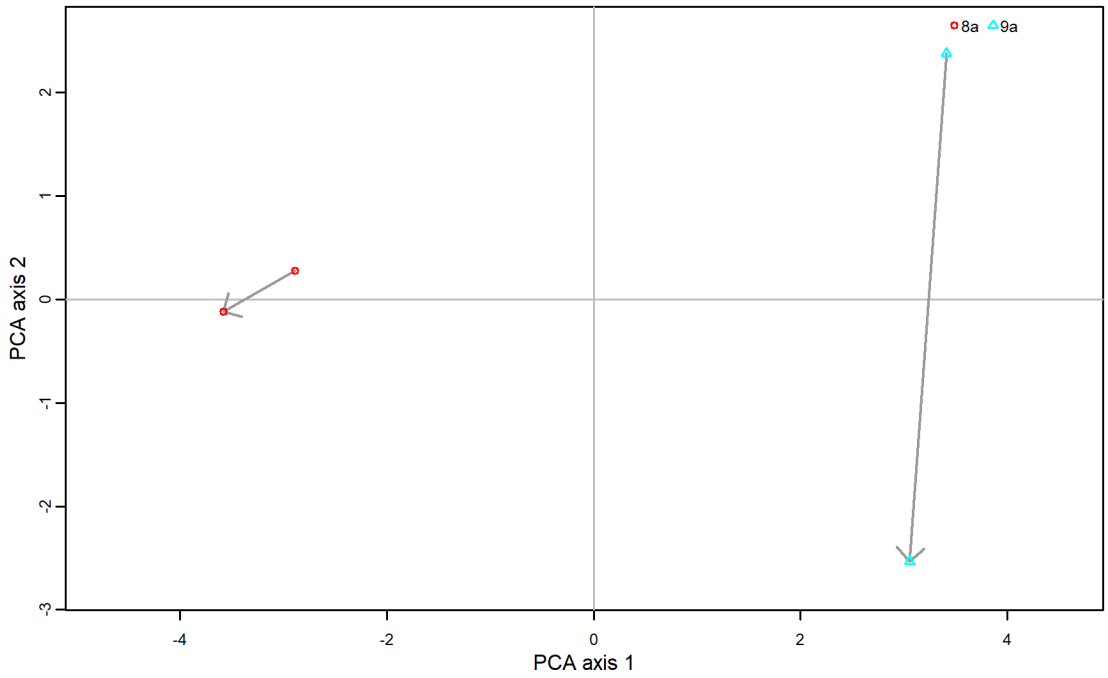
Sites 2a and 3a – Site 2 red = impact; Site 3 blue = control



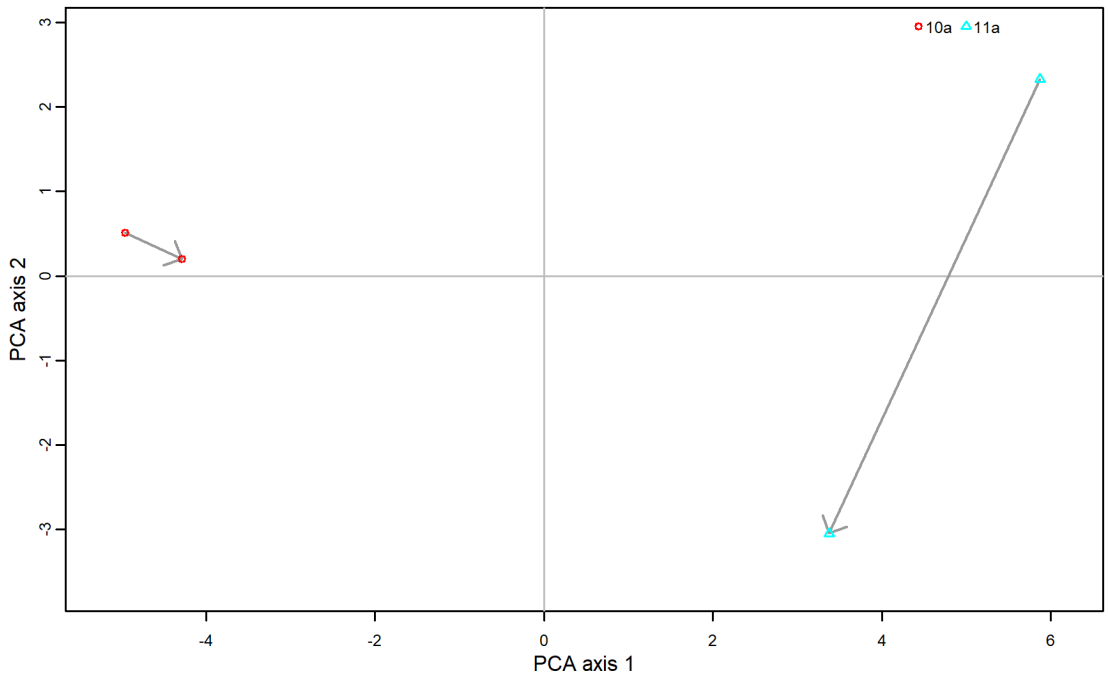
Sites 4a and 6a – Site 4 red = impact; Site 6 blue = control



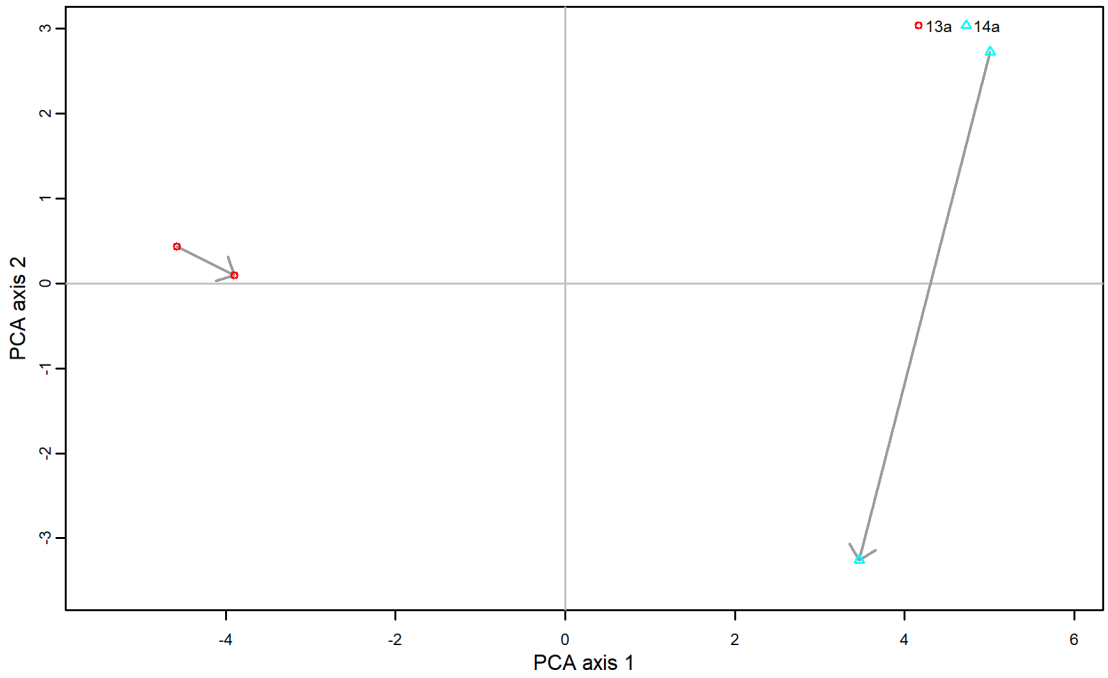
Sites 12a and 7a – Site 12 red = impact; Site 7 blue = control



Sites 8a and 9a – Site 8 red = impact; Site 9 blue = control



Sites 10a and 11a – Site 10 red = impact; Site 11 blue = control



Sites 13a and 14a – Site 13 red = impact; Site 14 blue = control

Appendix 2.

Photos of threatened rainforest plants – spring 2021

Plate 1. *Macadamia tetraphylla* juvenile with leaf damage.

Plate 2. *Macadamia tetraphylla* fruit developing. Monitoring ID 176.

Plate 3. *Endiandra muelleri* subsp. *Bracteata* flowers developing. Monitoring ID 84.

Plate 4. *Archidendron hendersonii* flowers developing. Monitoring ID 169.

Plate 5. *Cryptocarya foetida*. Monitoring ID 130.

Plate 6. *Ochrosia moorei*.

Plate 7. Davidsonia johnsonii flowering. Monitoring ID 184.

Appendix 3.

Key mature-phase rainforest canopy species, missing from rainforest due to past clearing, for supplementing remnant rainforest within and around the Blackwall Range (Ballina Shire, NSW)

From 2014 until 2021, the rainforest within and around the Blackwall Range (Ballina Shire, NSW) was monitored for changes in species composition, vegetation structure and recruitment success, as part of the Woolgoolga to Ballina (W2B) Pacific Highway upgrade.

One important finding of the monitoring program was that key mature phase canopy species that would have been dominant in the original rainforest (pre-European disturbance) in the area are scare or absent, most likely due to historical clearing and logging combined with poor recruitment success. The following is a list of these key mature phase canopy species that are scare/missing.

To help the rainforest in this area recover to its natural state, restoration activities should include measures to supplement the rainforest with these species. This could be achieved through direct seeding in rainforest canopy gaps or revegetation of cleared land.

For more information on seed collection, propagation and planting of subtropical rainforest species consult *Subtropical Rainforest Restoration* (Big Scrub Landcare 2019) and *Australian Rainforest Seeds* (Chapman et al. 2020).

Table 1: Species recommended for enrichment plantings in regrowth subtropical rainforest between Lumleys Lane to Coolgardie Rd. These species although typical of subtropical rainforest in the local area, are rare or absent from regrowth rainforest, which appears to have been totally cleared in the past.

Common Name	**Botanical Name**
White Booyong	*Argyrodendron trifoliatum*
Flame Tree	*Brachychiton acerifolium*
Blackbean	*Castanospermum austral*
Olivers Sassafras	*Cinnamomum oliveri*
Churnwood	*Citronella moorei*
Morton Bay Fig	*Ficus macrophylla*
Small-leaved Fig	*Ficus obliqua*
Strangler Fig	*Ficus watkinsiana*

Small-leaved Tamarind	*Diploglottis campbellii*
Yellow Tulipwood	*Drypetes deplanthei*
Rosewood	*Dysoxylum fraserianum*
White Quandong	*Elaeocarpus kirtonii*
Australian Teak	*Flindersia australis*
Cudgerie Tree	*Flindersia schottiana*
White Beech	*Gmelina leichhardtiana*
Silky Oak	*Grevillea robusta*
Alectryon tomentosus	*Hairy Alectryon*
Satinwood	*Harpullia pendula*
Ixora	*Ixora beckleri*
Red Carabeen	*Karabina benthamii*
Brachychiton discolor	*Lacebark*
Crows Ash	*Pentaceras austral*
Pseudoweinmania lachnocarpa	*Rose Marara*
Maidens Blush	*Sloanea australis*
Yellow Carabeen	*Sloanea woollsii*
Sour Cherry	*Syzygium corynanthum*
Coolamon Tree	*Syzygium moorei*
Red Cedar	*Toona ciliata*