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Dendrobium Areas 3A and 3B:
Terrestrial Ecology Monitoring Program
Annual Report 2021

Prepared for South32 Illawarra Metallurgical Coal | 28 April 2022

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Document control

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Version	Authors	Review	Status	Date
D1	Sian Griffiths and Luke Stone	Sian Griffiths	Draft	06/04/2022

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Executive summary

In 2003 South32 Illawarra Metallurgical Coal (IMC) commissioned Biosis Pty Ltd (Biosis) to undertake terrestrial ecology monitoring for the Dendrobium Coal Mine in accordance with the *Flora and Fauna Environmental Management Program (Subsidence)* (Biosis, 2003) required by the Dendrobium Colliery Planning Approval, originally issued in 2001, and as modified in 2008 and 2010. As of 2020, Niche Environment and Heritage (Niche) have continued the Dendrobium Ecological Monitoring Program (the Program) replicating, as far as possible, the methods as previously implemented.

The 2021 iteration of the monitoring program has adopted a number of recommendations from the previous report (Niche 2021), which represents a continuation of refinement in the monitoring approach with a number of existing assessment methodologies augmented by additional analyses.

The Program is undertaken within the Metropolitan Special Area and Southern Coalfield of New South Wales and includes two mining domains (Dendrobium Area 3A and Dendrobium Area 3B) and associated Control sites.

Ecological values and indicators which are currently being monitored include:

- Coastal Upland Swamps in the Sydney Basin Bioregion (Upland Swamps) listed as Endangered under the NSW *Biodiversity Conservation Act 2016* (BC Act) and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)
  - swamp extent
  - species composition
  - total species richness (TSR).
- Amphibians - with a focus on *Litoria littlejohni* (Littlejohn's Tree Frog), which is listed as Endangered under the EPBC Act and Vulnerable under the BC Act, and is known to breed within first and second (and occasionally third) order waterways within two Dendrobium Areas (3A and 3B)
  - population attributes (number of individual frogs within different life-stages)
  - habitat such as breeding pool characteristics.

Monitoring is undertaken each spring and autumn (Upland Swamps) and winter (Amphibians) with Upland Swamps and creeks being added to the Program according to longwall progression. As of 2021, there are seven Control swamps and eight Control creeks in the wider Catchment area, with nine Impact swamps, 11 Impact creeks (plus two pre-impact creeks) across two Dendrobium Areas (3A and 3B).

Within the Upland Swamp survey all species present were recorded in each quadrat, for TSR and species composition analysis. Mapping of swamp extent (including sub-communities) uses LiDAR imagery for ecosystem functionality analysis. Additionally, photo monitoring is taken at fixed point, direction and angle at all flora monitoring locations to assist in interpreting any on-ground changes.

Within the amphibian surveys, a targeted nocturnal survey for Littlejohn’s Tree Frog Adults, Tadpoles and Eggmass counts across both Control and Impact creeks is conducted and since 2020 an additional assessment of habitat (breeding pool) condition (water capacity and water level on night of survey) has been reported to assist in determining suitable breeding habitat for Littlejohn’s Tree Frog in relation to the Trigger Action Response Plan (TARPs).

Upland Swamps

In 2020, visual trends of drying (or areas of die-back) were observed at Impact swamps that have been directly mined beneath during field survey, and in the UAV imagery (Niche 2021). The drying of the Impact Upland Swamps over time since impact may be exacerbated by the effect of the most recent drought, though the correlation between impact of mining and drying of the Impact Upland Swamps was evidenced by the statistically significant difference between Control and Impact Upland Swamps over this drought period. The trends in floristic data and LiDAR analysis in 2021 represent in general a continuation of the trends observed in recent years at the impact swamp. Although additional breakpoint analysis in 2021 is suggestive of changing swamp conditions pre-mining and some limited observations of regeneration in previous areas of drying have been observed.

Cumulative impacts have been observed at a number of Impact Upland Swamps, which show stronger trends of statistically significant decline in TSR over time and statistically significant changes to composition, with ‘wetter’ species becoming less common post impact, suggesting a loss of species that prefer moist soils. Some swamps show a loss of species over time, with limited recruitment of new species.

For Area 3A, TARPS were triggered in the two Impact Upland Swamps with no changes relative to 2020. For Area 3B, TARPS were triggered for five Upland Swamps. The increase in TARP triggers in Area 3B in 2021 is due to a continuation of trends observed across consecutive years, but largely a result of re-assessment of the complete LiDAR dataset that was not possible in 2020.

Threatened frogs – Littlejohn’s Tree Frog (Littlejohn’s Tree Frog)

The Control creeks in general have a higher quality of breeding habitat for Littlejohn’s Tree Frog and were presumably chosen at the beginning of the Program due to the known population of breeding adult records of Littlejohn’s Tree Frog and habitats. The 2021 analysis has identified that where pre-mining frog detection data is available, detection was statistically significantly lower at impact transects than the controls, indicating this disparity in control and impact transect pre-dates mining effects. However, it is also notable that environmental conditions (water levels and absence of flocculant) were also more favourable at the Control transects. Additional analysis in 2021 has identified a statistically significant relationship between flocculant and the detection of the Adult and Eggmass lifecycle stages and that flocculant is more likely to occur at post-mining transects.

For Area 3A, three tributaries (SC10C, SC10(10) and WC17) had triggered a TARP and for Area 3B five tributaries: WC15, DC(1), DC13, WC21 and LA2 had triggered a TARP. These tributaries are consistent with that of 2020, with LA2 being the only additional tributary to trigger a TARP level in 2021.

Management actions and offsetting

The TARP system is to trigger corrective actions (which can include reporting, additional monitoring and assessment, mitigation or offsetting), once specified impacts were detected. A number of previously described management actions (e.g. grouting) are subject to ongoing research and trialling to demonstrated the expected level of effectiveness.

Offset areas have been established and research funding committed to the *Swamp Remediation Research Program* (SRRP). Similarly, after consultation with stakeholders, IMC and WaterNSW agreed to improve monitoring equipment. The most recent consent conditions for Dendrobium Mine state that Biodiversity Offsets for Upland Swamp have been met as part of the *Strategic Biodiversity Offset*.

Therefore, the TARP triggers are used as a guide to assess the health of the Upland Swamps and watercourses over time rather than initiating management actions. Impacts to Upland Swamps and watercourses have been deemed to have been offset via protection of lands elsewhere (e.g. Maddens Plains and Cataract River).

Recommendations

A number of recommendations to improve the monitoring program have been detailed in Section 4.4. The monitoring program will continue to achieve the following key objectives:

- Ongoing monitoring of Upland Swamps and amphibians within Dendrobium Areas 3A and 3B.
- Determine if mining results in changes to the Upland Swamps or Littlejohn's Tree Frog populations of the Dendrobium mining area through comparison of baseline and control data with that collected through ongoing monitoring.

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Glossary and list of abbreviations

Term or abbreviation	Definition
AEMR	Annual Environmental Management Report
ANOVA	Analysis of Variance
BC Act	NSW *Biodiversity Conservation Act 2016*
BCD	Biodiversity Conservation Division of DPE
BGR-NIR	Blue Green Red – Near Infrared
BHPBIC	BHP Billiton Illawarra Coal (now South32 Illawarra Metallurgical Coal)
BSO EA	Bulli Seam Operations Environmental Assessment
CHM	Canopy height model
CMA	Corrective Management Action
CPUE	Catch per unit effort
DA3A	Dendrobium Area 3A
DA3B	Dendrobium Area 3B
DAWE	Commonwealth Department of Agriculture, Water and the Environment
DEE	Commonwealth Department of Environment and Energy (now DAWE)
DEM	Digital Elevation Model
DoPE	Department of Planning and Environment (now DPE)
DPE	NSW Department of Planning and Environment
DPIE	Department of Planning, Industry and Environment (formerly OEH/ DoPE, now DPE)
DSM	Digital Surface Model
EEC	Endangered Ecological Community
e.g.	exempli gratia, meaning “for example.
EP&A Act	NSW *Environmental Planning and Assessment Act 1979*
EPBC Act	Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*
GEE	Generalised Estimating Equations
GLM	Generalised Linear Model
ha	Hectares
i.e.	id est, meaning "that is’’
IMC	South32 Illawarra Metallurgical Coal
IQR	Interquartile range
LAS	Laser
Littlejohn’s Tree Frog	Littlejohn’s Tree Frog
m	Meters
mRL	Meters of reduced level (piezometer unit of measure)
NDVI	Normalised difference vegetation index
NPWS	National Parks and Wildlife Service
OEH	NSW Office of Environment and Heritage (now DPE)
RMZ	Risk Management Zone
Study Area	Dendrobium Area 3A and 3B

Term or abbreviation	Definition
T&I	Trade and Investment
TARP	Trigger Action Response Plan
The Program	Dendrobium Ecological Monitoring Program
TSR	Total Species Richness
UAV Imagery	Unmanned Aerial Vehicles Imagery
USBT	Upland Swamp: Banksia Thicket
USTTT	Upland Swamp: Tea-tree Thicket
USSHC	Upland Swamp: Sedgeland-heath Complex
USFEW	Upland Swamp: Fringing Eucalypt Woodland

1. Introduction

1.1 Background

In 2003 South32 Illawarra Metallurgical Coal (IMC) commissioned Biosis Pty Ltd (Biosis) to undertake terrestrial ecology monitoring for the Dendrobium Coal Mine in accordance with the *Flora and Fauna Environmental Management Program (Subsidence)* (Biosis, 2003) required by the Dendrobium Colliery Planning Approval, originally issued in 2001, and as subsequently modified.

The Approval included the requirement for a Before, After, Control, Impact (BACI) monitoring program, designed to identify ecological change within Dendrobium Areas 3A and 3B (hereafter referred to as the Study Area) as a result of mine subsidence by comparisons between control and impact areas before and after longwall mining (the Dendrobium Ecological Monitoring Program, hereafter referred to as the Program). Changes were measured against specific thresholds outlined in the trigger action response plans (TARPs) (Annex 7) (IMC 2020a, IMC 2020b, IMC 2020c). Monitoring was required to commence at least two years prior to the start of mining in each affected area to gather baseline data at each site and continue once mining commenced. Monitoring is expected to continue throughout the duration of mining activities and for a period after the completion of mining.

In 2020, Niche Environment and Heritage (Niche) continued the Program replicating, as far as possible, the methods as previously implemented. The 2020 monitoring report (Niche 2021) identified a number of potential improvements to the monitoring methods, which have been adopted for the 2021 iteration of the monitoring program and are detailed within this report.

The Program is undertaken within the Metropolitan Special Area, part of the Southern Coalfield region of New South Wales (Figure 1). The area monitored includes two mining domains (Dendrobium Area 3A and Dendrobium Area 3B) and associated control sites.

Ecological values and indicators which are currently being monitored include:

- Coastal Upland Swamps in the Sydney Basin Bioregion (Upland Swamps) listed as Endangered under the NSW *Biodiversity Conservation Act 2016* (BC Act) and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)
    - Swamp extent
    - species composition
    - total species richness (TSR).
- Amphibians, with a focus on *Litoria littlejohni* (Littlejohn's Tree Frog) which is listed as Vulnerable under the BC Act and Endangered under the EPBC Act, and is known to breed within first, second and third order watercourses within Dendrobium Area 3A and Area 3B
    - Population attributes (number of individual frogs within different life-stages) and
    - habitat such as breeding pool characteristics.

Prior to the commencement of mining within Dendrobium Areas 3A and 3B, monitoring of Upland Swamp vegetation and amphibians commenced in spring 2003 within two swamps. Monitoring has continued each spring and autumn with Upland Swamps and creeks being added to the Program according to longwall progression.

At the time of 2021 monitoring, there were seven monitored Control swamps and eight Control creeks in the wider catchment area and nine Impact swamps and 11 Impact creeks (plus two pre-impact creeks) across Dendrobium Areas 3A and 3B.

1.2 Aim

The primary aim of the Program remains the same as previous years:

[...]to determine whether subsidence effects associated with longwall mining result in impacts to terrestrial ecological values located above the longwalls (Biosis 2020).

To assist in achieving the above aim, the TARP thresholds determined for Dendrobium Areas 3A and 3B (Section 1.5, Annex 7) are used to determine the significance of any direct or indirect impacts potentially caused by mining activity. The current report includes monitoring data collected during 2021 and provides analysis of data collected to date for the Program (2003-2021) where relevant to the identified aim.

Identification of opportunities to improve the Program are discussed in Section 4.4.

1.3 Monitoring design and definition of treatments

The monitoring design is structured around the BACI concept: Before, After, Control and Impact. Predicted impact areas are compared with control areas and measurements taken both before and after an impact event (longwall mining) occurs. Where measurable impacts occur, comparisons of before and after data should reveal changes at an impact site after mining. Control sites remain unimpacted before and after mining, where the mining plan evolves and has the potential to impact a previous Control Upland Swamp, this will be updated to reflect the on-ground works (e.g. the data that was previously listed as Control is now listed as pre-mining Impact data (Before) and is no longer included in the analysis as a Control). Where both Control and Impact sites change in a similar manner, observed changes may be due to other wider-ranging factors such as above or below average rainfall.

Impacted areas are those within the 400 metre risk management zone (RMZ) which are sensitive to valley closure, uplifts, strains, and fracturing. This is in accordance with recommendations made by the Department of Planning (2008).

The Impact sites are referred to as pre-impact (Before) prior to mining activity, until the closest point of secondary extraction is located within the RMZ of the site. This allows for baseline (Before) data to be collected at each potential impact site. Once the point of secondary extraction is located within a RMZ the site is then referred to as post-impact but not yet mined beneath, this allows for the potential of observing any indirect impacts resulting from mining within the RMZ. Given that any observed impacts to natural features become most evident after the natural feature is mined beneath, the date the site has been mined beneath has also been considered in the assessment and analysis of trends over time. At this point the sites are referred to as post-impact and mined beneath.

Selected Upland Swamps and creeks located within each of the mining domains are generally monitored for a minimum of two years prior to mining to gather baseline data (two swamps - Swamp 23 and Swamp 14 - were only monitored one year prior but include both autumn and spring seasons). The Upland Swamps and creeks being monitored are defined as either Control or Impact sites.

There are some Upland Swamps and creeks that will remain in the RMZ, as they are not planned to be mined beneath.

Control sites are situated outside the RMZ (greater than 400 meters from mining activity). The data from Control sites is gathered to compare with Impact sites to determine whether there are any observable impacts as a result of mining or wider landscape scale changes in the Metropolitan Catchment (due to effects of drought, fire etc).

1.4 Survey sites and monitoring periods

Monitoring of Upland Swamps and creeks within Dendrobium Areas 3A and Area 3B continued in 2021 as detailed below. A summary of timing for all Impact sites and corresponding Control sites has been provided below in Table 1 and Table 2.

1.4.1 Dendrobium Area 3A

Dendrobium Area 3A includes Longwalls 6, 7 and 8. Mining of Area 3A commenced in 2010 and concluded with Longwall 8 in December 2012. Mining is proposed to re-commence at Longwall 19 following the completion of Dendrobium Area 3B. Longwall 19 is situated south of Longwall 8. The Dendrobium Area 3A Impact Upland Swamps monitored as a part of the Program include Swamp 15A(2) and Swamp 15B (Figure 2, Table 1 and Table 9). Both swamps are also included in the LiDAR monitoring.

Monitoring along five Littlejohn's Tree Frog transects was undertaken within two creek systems within Dendrobium Area 3A. Four transects were along Sandy Creek tributaries: SC10 (two sections, SC10(1) and SC10(2)), SC10C, 6CDL; and one along a tributary of Wongawilli Creek: WC17 (Figure 5, Table 2).

1.4.2 Dendrobium Area 3B

Dendrobium Area 3B includes Longwalls 9 through to 18. Mining of Area 3B commenced with Longwall 9 in February 2013 and has continued through to Longwall 17 which commenced in December 2020 and was completed in October 2021. Longwall 18 is currently being extracted.

Seven Upland Swamps are currently monitored as a part of the Program in 2021 (Swamp 1A, Swamp 1B, Swamp 5, Swamp 11, Swamp 13, Swamp 14 and Swamp 23), (Figure 3, Table 1 and Table 9). All swamps in Area 3B have now been mined beneath and are therefore Impact sites for the 2021 iteration of the Program. All Area 3B impact swamps are included in the LiDAR analysis.

Monitoring along six Littlejohn's Tree Frog transects was undertaken within three creek systems located within Dendrobium Area 3B. Two transects were along Donald Castles Creek tributaries: DC(1), DC13, two along Wongawilli Creek tributaries: WC15, WC21, and two from Lake Avon tributaries: LA4A and LA2, the last of which was mined beneath by Longwall 16 in 2020 (Figure 5, Table 2). The above creeks in Dendrobium Area 3B have now been mined beneath and therefore are Impact sites since the 2020 iteration of the program. Pre-mining sites along Native Dog Creek and one of its tributaries are also monitored, NDC and ND2 (see section 2.4 for further discussion). Future mining will have these two Native Dog Pre-mining creeks (and one Native Dog Control creek) becoming Impact creeks due to the proximity of the Longwall progressions, as Longwall 18 will have commenced.

1.4.3 Control sites

A number of Control sites have been established for comparison with Impact sites that have or will be mined beneath. Control sites for vegetation monitoring include seven Upland Swamps; Swamp 15A(1), Swamp 22, Swamp 33, Swamp 86 (previously named FT6X Swamp), Swamp 85 (monitored for LiDAR analysis only), Swamp 87 (previously named FT15E Swamp) and Swamp 88 (previously named Gallahers Creek Swamp). These sites were established to ensure an even mix of Impact and Control sites in the BACI experimental design (Figure 4, Table 1). Five control swamps are utilised in the LiDAR monitoring, including Swamp 85 which is not included in the vegetation monitoring.

Monitoring of Control sites for Littlejohn's Tree Frog was undertaken along eight transects in four creeks: four Sandy Creek tributaries: SC7 (two sections SC7(1) and SC7(2)), SC7A, SC8, two Wongawilli Creek tributaries: WC10, WC11, one Donald Castles Creek tributary DC8, and one tributary of Native Dog Creek ND1 (Figure 5, Table 2).

Table 1: Mining progress and status of swamps

Mine Area	Treatment (current)	Swamp name	Nearest longwall	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Outside	Control	**Swamp 22**																				
Outside	Control	**Swamp 33**																				
Outside	Control	**Swamp 85***																				
Outside	Control	**Swamp 86**																				
3A	Control	**Swamp 15A(1)**																				
Outside	Control	**Swamp 87**																				
Outside	Control	**Swamp 88**																				
3A	Impact	**Swamp15A(2)**	8																			
3A	Impact	**Swamp15B**	8																			
3B	Impact	**Swamp 11**	13, 14																			
3B	Impact	**Swamp 13**	14, 15																			
3B	Impact	**Swamp 14**	15, 16, 17																			
3B	Impact	**Swamp 1A**	9, 10																			
3B	Impact	**Swamp 1B**	9																			
3B	Impact	**Swamp 5**	9, 10, 11																			
3B	Impact	**Swamp 23**	15																			

*Green cell = Control Site, Blue cell = Impact Site, pre-mining, Orange cell = Impact site Post-mining although not yet mined beneath (Risk management zone, RMZ), Red cell = Impact site post-mining and directly mined beneath. Swamps highlighted in bold also include LiDAR monitoring. *LiDAR monitoring only.*

Table 2: Mining progress and status of creeks

Mine Area	Treatment (currently)	Creek Name	Nearest Longwall	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
3A	Control	SC7(1)																	
3A	Control	SC7(2)																	
3A	Control	SC7A																	
3A	Control	SC8																	
3B	Control	ND1																	
Outside	Control	DC8																	
Outside	Control	WC10																	
Outside	Control	WC11																	
3A	Impact	6CDL	7																
3A	Impact	SC10(1)	8																
3A	Impact	SC10(2)	8																
3A	Impact	SC10C	8																
3A	Impact	WC17	7, 8																
3B	Impact	WC15	14, 15																
3B	Impact	DC(1)	9																
3B	Impact	LA4A	13																
3B	Impact	LA2	16, 17																
3B	Impact	DC13	9																
3B	Impact	WC21	9, 10, 11																
3B	Pre-mining	ND2																	
3B	Pre-mining	NDC																	

Green cell = Control Site, Grey cell = no monitoring, Blue cell = Impact Site (pre-mining), Orange cell = Impact Site (post mining although not yet mined beneath – i.e. Risk Management Zone only), Red cell = Impact Site (post mining and directly mined beneath). Note: Some creeks are within the RMZ of the LW but are not planned to be directly mined beneath due to the length of the survey transects and nature of the creek.

1.5 Trigger Action Response Plans (TARPs)

The approvals for Dendrobium Area 3A and Area 3B have set TARPs at specified levels which act as indicators of potential impacts from mining. Once a TARP is detected (or triggered) further investigation is required to determine whether the change is mining related and what management and/or corrective actions, if any, are required.

The purpose of the Program is to detect changes (if any) and investigate the mechanism of change using the data collected. The triggering of a TARP does not always indicate that immediate management actions are required. The approved TARP Level triggers (IMC 2020b; IMC 2020c; Annex 7) are used to determine required management actions or other responses for any particular Upland Swamp or creek being monitored. Dendrobium Area 3A was approved in 2012 and has a separate set of TARPs to Dendrobium Area 3B which was approved in 2013 and 2015 (and updated for each subsequent longwall in the domain) (Annex 7). Therefore, Niche have considered these TARP Level triggers separately. The relevant TARPs are detailed below.

1.5.1 Changes to TARP objectives

The TARP system (see Table 4 and Table 6) is to trigger corrective actions (which can include reporting, additional monitoring and assessment, mitigation or offsetting), once specified impacts were detected. A number of previously described management actions (e.g. grouting) are subject to ongoing research and trialling to demonstrated the expected level of effectiveness.

Offset areas have been established and research funding committed to the *Swamp Remediation Research Program* (SRRP) (IMC 2016a). Similarly, after consultation with stakeholders, IMC and WaterNSW agreed to improve monitoring equipment (IMC 2019). The most recent conditions for Dendrobium Mine state that Biodiversity Offsets for Upland Swamp have been met as part of the *Strategic Biodiversity Offset* (IMC 2016b).

TARP level 3 in Area 3A Upland Swamps relate to on-ground management actions such as grouting. As no grouting has been implemented in Area 3A to date, the monitoring and TARPs relate to an assessment of the health of the Upland Swamps and watercourses over time rather than initiating management actions. Impacts to swamps and watercourses have been deemed to have been offset via protection of lands elsewhere (e.g. Maddens Plains and Cataract River).

Niche have attempted to be consistent with the wording of the most up to date TARPs (Area 3B), hence the Upland Swamp Interpretation column in Table 4 that mentions species richness and species diversity with composition in brackets. Niche have noted that the purpose for the word “diversity” was likely to assess composition (as this is in line with the data available from the Program, i.e. diversity/abundance data is not collected as part of the monitoring methods, only composition data) and we have addressed it accordingly throughout the document. Niche notes composition is referenced in the “Potential Impacts” column to the TARPs, this indicator is not explained within the “Performance Triggers” (Swamp vegetation changes of IMC 2015a; Annex 7). As such, Niche have added composition (in brackets) to the Upland Swamp trigger levels in Table 6 to clarify where this is relevant.

1.5.2 Dendrobium Area 3A

For Dendrobium Area 3A, the terrestrial TARPs are combined for threatened flora and fauna as landscape impacts. The relevant Dendrobium Area 3A creeks and Upland Swamps to be considered are listed in Table 3. Dendrobium Area 3A TARPs are comparatively non-specific being limited to assessment of Upland Swamps and threatened fauna, namely threatened frogs. The TARP does not include any specific associated habitats or parameters for determining trigger levels/impacts. Niche have included habitat and other measurements within the interpretation of trigger levels for both Upland Swamps and threatened frogs (Table 4). For example, assessment of habitat quality has been included within TARP interpretations as it is a key element of frog health, may respond more quickly to impacts and is usually more amenable to consistent/reliable measurement compared with direct measurements of frog populations.

Table 3: Impact sites being monitored under Dendrobium Area 3A TARPs

Upland Swamps Impact sites	Threatened frog transect Impact sites
Swamp 15A(2), Swamp 15B	6CDL, SC10(1), SC10(2), SC10C, WC17

Table 4: Dendrobium Area 3A TARPs and Niche interpretations for analysis

Trigger Levels	Trigger level - landscape impacts (IMC 2020a)	Upland Swamp interpretation	Threatened Frog interpretation
Level 1	Vegetation impacted by mining (by rockfalls, soil slippage, gas emissions) that is likely to naturally regenerate within the monitoring period.	No statistically significant difference between Before After Control Impact sites within previous year monitoring (2020-2021) but some observable adverse changes at Impact site (before and after mining) through photo point monitoring or UAV imagery. The same pattern is not detected at control sites.	Observed and measured adverse changes in habitat at site through pool water levels, stream appearance (e.g. iron flocculant, debris build up) or number of breeding pools available from the previous year *without* the same pattern at control sites.
Level 2	Vegetation impacted by mining (by rockfalls, soil slippage, gas emissions) that is unlikely to naturally regenerate within the monitoring period; or statistically significant difference of species richness and species diversity between Before After Control Impact sites as a result of mining.	Statistically significant difference for species richness and species diversity (composition) between Before After Control Impact sites as a result of mining within the previous year (2020-2021).	As per above Level 1 observational changes and the frog population changes (Tadpole, Eggmass or Adults) between Before After Control Impact Sites as a result of mining within the previous year (2020-2021).
Level 3	Vegetation impacted by mining that is not responding to Corrective Management Actions (CMAs).	Vegetation not responding to corrective management actions from the TARP Level 2 triggers and further declining impacts from the previous year.	Populations not responding to corrective management actions from the TARP Level 2 triggers and further declining impacts from previous years or for several years.

Note: TARP interpretations based on discussions with Gary Brassington of IMC on 16 April 2021.

1.5.3 Dendrobium Area 3B

The creeks and Upland Swamps to be assessed within Dendrobium Area 3B are detailed in Table 5. For Dendrobium Area 3B, the terrestrial TARPs considered are limited to the assessment of flora, ecosystem functionality (IMC 2015a) and fauna (IMC 2015b) (Table 6).

Table 5: Impact sites being monitored under Dendrobium Area 3B TARPs

Upland Swamps Impact sites	Threatened Frog transect Impact sites
Swamp 11, Swamp 13, Swamp 14, Swamp 1A, Swamp 1B, Swamp 5, Swamp 23	WC15, DC(1), LA4A, LA2, DC13, WC21

To maintain consistency with previous analysis and interpretation of the fauna and aquatic TARPs, Niche will continue to define the *reduction of aquatic habitat* for Littlejohn's Tree Frog, as a reduction in aquatic habitat (potential breeding habitat) by the number of dry pools along the transect. Additional metrics have been included since 2020 to assist in a more detailed examination of potential changes in key breeding habitats (pools).

The approved definition of ecosystem functionality from the SIMMCP (Section 3.9; IMC 2020b) stated *"ecosystem function of swamps is measured via the following attribute: the size of the groundwater dependent communities contributing to the swamps. Specifically, any changes in the proportion of Banksia Thicket, Tea-tree Thicket and Sedgeland-heath Complex within the monitored swamps. Any change in area of a groundwater dependent community within a swamp will be compared to its pre-mining area and any change in area of that groundwater dependent community within reference swamps*" (IMC 2020b).

Table 6: Area 3B TARPs and Niche interpretations for statistical analysis

Trigger Levels	Upland Swamp trigger level (IMC 2020b) and interpretation (as dot points)*	Threatened Frog TARP (IMC 2020c) and interpretation (as dot points)	Swamp extent and ecosystem functionality TARP - LiDAR and UAV imagery (IMC 2020b)
Level 1	A 2% or otherwise statistically significant decline in species richness or diversity (composition) during a period of stability or increase in species richness/diversity in reference swamps for two consecutive years. • A Level 1 TARP would be triggered with a statistically significant difference (decline) in TSR or species composition over two consecutive impact years of data (i.e. impact detected between 2019-2020 and again 2020-2021 impact years). • The 2% change over two consecutive years was tested at a statistically significant level of 5% (p= ≤0.05).	Reduction in aquatic habitat for 1 year • Observed and measured changes in pool water levels and/or number of breeding pools available from the previous year without the same pattern at control sites.	**Extent** A trending decline in the extent of an upland swamp (combined area of groundwater dependent communities) for two consecutive monitoring periods, greater than that observed in the Control Group, and exceeding the standard error (SE) of the Control Group. **Ecosystem functionality** A trending decline in the extent of any individual groundwater dependent community within a swamp for two consecutive monitoring periods, greater than that observed in the Control Group, and exceeding the SE of the Control Group.
Level 2	A 5% or otherwise statistically significant decline in species richness or diversity (composition) during a period of stability or increase in species richness/diversity in reference swamps for three consecutive years. • A level 2 TARP would be triggered with a statistically significant difference (decline) in TSR or species composition over three consecutive impact years of data (i.e. impact detected in each of 2018-2019, 2019-2020 and 2020-2021 impact years) (not 2018-2021 cumulative impact). • The 5% change over three consecutive years was tested at a statistically significant level of 5% (p= ≤0.05).	Reduction in aquatic habitat for 2 years following the active subsidence period • Observed and measured changes in pool water levels and/or number of breeding pools available from two years in a row without the same pattern at control sites.	**Extent** A trending decline in the extent of an upland swamp (combined area of groundwater dependent communities) for **three** consecutive monitoring periods, greater than that observed in the Control Group, and exceeding the SE of the Control Group. **Ecosystem functionality** A trending decline in the extent of any groundwater dependent community within a swamp for three consecutive monitoring periods, greater than that observed in the Control Group, and exceeding the SE of the Control Group.
Level 3	An 8% or otherwise statistically significant decline in species richness or diversity (composition) during a period of stability or increase in species	Reduction in aquatic habitat for >2 years or complete loss of habitat following the active subsidence period. • Observed and measured changes in pool water levels and/or number of breeding pools	**Extent** A trending decline in the extent of an upland swamp (combined area of groundwater dependent communities) for **four** consecutive monitoring periods,

Trigger Levels	Upland Swamp trigger level (IMC 2020b) and interpretation (as dot points)*	Threatened Frog TARP (IMC 2020c) and interpretation (as dot points)	Swamp extent and ecosystem functionality TARP - LiDAR and UAV imagery (IMC 2020b)
	richness/diversity in reference swamps for four consecutive years. • A level 3 TARP would be triggered with a statistically significant difference (decline) in TSR or species composition over four consecutive impact years of data (i.e. impact detected in each of 2017-2018, 2018-2019, 2019-2020 and 2020-2021 impact years) (not 2017-2021 cumulative impact). • The 8% change over four consecutive years was tested at a statistically significant level of 5% (p= ≤0.05).	available for greater than two years in a row without the same pattern at control sites.	greater than that observed in the Control Group, and exceeding the SE of the Control Group. **Ecosystem functionality** A trending decline in the extent of any groundwater dependent community within a swamp for four consecutive monitoring periods, greater than that observed in the Control Group, and exceeding the SE of the Control Group.
Exceeding expectation	Mining results in a >10% or otherwise statistically significant decline in species richness or diversity (composition) during a period of stability or increase in species richness/diversity in reference swamps for five consecutive years. • Exceeding expectation TARP would be triggered with a statistically significant difference (decline) in TSR or species composition over five consecutive impact years of data (i.e. impact detected in each of 2016-2017, 2017-2018, 2018-2019, 2019-2020 and 2020-2021 impact years) (not 2016-2021 cumulative impact). • The >10% change over five consecutive years was tested at a statistically significant level of 5% (p= ≤0.05).	N/A	**Extent** Mining results in a trending decline in the extent of an upland swamp (combined area of groundwater dependent communities) for **five** consecutive monitoring periods, greater than that observed in the Control Group, and exceeding the SE of the Control Group. **Ecosystem functionality** Mining results in a trending decline in the extent of a groundwater dependent community within a swamp for five consecutive monitoring periods, greater than that observed in the Control Group, and exceeding the SE of the Control Group.

*Note: TARPs restart if a trigger is not detected for 1 year (impacts need to be consecutive to trigger escalating TARPs). TARP interpretations based on discussions with Gary Brassington of IMC on 16 April 2021.

2. Methods

The baseline survey methodology, results of the statistical analysis and revised survey methodologies are detailed in previous annual monitoring reports (Biosis 2019, Niche 2021). The following is a brief description of the survey methodology used by Niche to carry out monitoring in 2021.

2.1 Summary of methods

Table 7 provides a summary of the survey methods implemented as a part of the Program.

Table 7: Summary of survey methodology

Survey type	Methods	Timing
Upland Swamp vegetation monitoring	Vegetation survey (30 quadrats of 0.5 m^2 along a fixed transect, three 15 m transects replicated per swamp), recording species present in each quadrat.	Annually in autumn and spring
Littlejohn's Tree Frog breeding habitat monitoring	Targeted nocturnal survey for Adults, Tadpoles and Eggmasses. An additional assessment of habitat (breeding pool) condition (water capacity, water level, iron flocculant on night of survey).	Annually in winter
Photo-point Monitoring	Photo taken at fixed point, direction and angle at all flora monitoring locations.	Annually in autumn and spring
LiDAR analysis	Mapping of swamp extent (including sub-communities) using LiDAR imagery. As part of the 2021 monitoring, the historical LiDAR was revisited and sub-communities remapped using methodology and models developed in 2020 to ensure consistent and comparable data.	Annually, aircraft survey following completion of latest longwall panel

2.1.1 Rainfall and hydrological data

Existing rainfall data available for Cordeaux Dam No.1 (BoM station no. 68018) was analysed to allow for comparison between monitoring periods. Station no. 68018 is situated within the mining lease and utilised by Cordeaux Colliery to monitor weather and rainfall data. The rainfall data extends across the entire monitoring period 2002-2021. This long-term data set is used to inform a comparison of the prevailing conditions in 2021 to average conditions for the locality through the 19 years rainfall monitoring at the Cordeaux station. This data is supplemented by rainfall data collected in both area 3A (DA3A, 2008-2021) and 3B (DA3B, 2013-2021) by IMC, in order to consider any catchment specific rainfall patterns as relevant.

In addition, temperature and evaporation data has been obtain from Cordeaux Dam No.1 (station no. 68018) to provide an indication of other global trends of relevance to the program (DES 2022). While this data set is limited (2010 – 2022) and interpolated from daily observations for that date, it represents a useful location specific source of information that is otherwise absent from any other nearby localities or meaningful timeframes. Where possible this data has been compared for accuracy in trends in maximum temperature against the long term dataset available for station 68192 (BoM 2022).

As part of longwall progression IMC have installed piezometers across the mining lease area to monitor water levels within Impact and Reference swamps. This piezometer data was supplied by IMC upon request and presented in graphical form to allow visual assessment of water retention within the respective swamps. The piezometers measure the reduced level in meters (mRL) between the surface and an established piezometer (lower than the surface in the borehole). The free water level within the swamp sediments are measured as the relative difference. To aid in the interpretation of the hydrological data, Niche has incorporated the findings of hydrogeological reports made available by IMC, in particular (Watershed HydroGeo 2019).

Rainfall and hydrological data were used to correlate changes observed in swamp/frog data with changes to climate or ability of the swamps/creeks to retain water. These comparisons assist in determining if changes in swamps/creeks are likely a result of mining or a result of broader catchment/landscape scale changes.

2.1.2 LiDAR analysis

The LiDAR analysis method used in 2021 is the same as that detailed in Niche (2021). These methods have also been retrospectively applied to previous LiDAR datasets to ensure valid comparisons are possible, as recommended in Niche (2021). Also as recommended (Niche 2021), the very small control swamps (89, 91, 93, 95 and 96) previously used have been removed from the dataset, with the analysis focussing on control swamps that are part of the swamp floristic monitoring component of the program (where data is available) given their more comparable size to the Impact swamps. Further discussed in section 2.4. Table 9 identifies the Upland Swamps utilised in the LiDAR analysis in 2021.

Table 8: Swamps monitored as part of the LiDAR analysis

Upland Swamp LiDAR Impact sites	Upland Swamp LiDAR Control sites
15A(2), 15B, 1A, 1B, 5, 11, 13, 14, 23	15A(1), 22, 33, 85, 86

2.1.2.1 Upland Swamp Extent Mapping

Upland swamp extents for all years of the monitoring program were detected by first modelling swamp boundaries based on a differential Canopy Height Model (CHM). The boundary was defined by the maximum height of the Banksia Thicket upland swamp vegetation sub-community in accordance with specifications within The Native Vegetation of the Woronora, O'Hares and Metroplitan Catchments (NPWS, 2003) and on-ground experience. The analysis generated comparable datasets from which to interpret change in upland swamp extents year on year.

LiDAR datasets were received for monitoring program years through 2014, 2016, 2017, 2018, 2019, 2020 and 2021. The methods that describe how the spatial analysis was undertaken for mapping upland swamp extents year-on-year can be divided into the following workflow steps:

1. LAS (LiDAR) datasets were created for the relevant LiDAR returns for all supplied tiles for the Study Area.
    a. Ground
    b. Non-ground
2. LAS Datasets were then converted to rasters:
    a. Ground to Digital Elevation Model (DEM)
    b. Non-ground to Digital Surface Model (DSM)
3. A CHM raster was produced by subtracting the DSM from the DEM and symbolised using the height group classes detailed above.

4. Data generalisation was undertaken using statistical analysis to reduce the complexity of the dataset and average pixel relationships. This produced clear vegetation height group boundaries to work with. Discussions were held within the project team about how much generalisation was necessary and beneficial without compromising the results.
5. The CHM raster was reclassified into 1 value that represented the maximum height of the Banksia Thicket upland swamp vegetation sub-community of 6m. Any values greater than 6m were reclassified as no data.
6. A Shrink tool was run which reduces the size of all raster areas by 3 cells – this step reduces noise in the data by isolating clusters of cells outside the main swamp boundary that are low spots in non-swamp vegetation (e.g. spaces between tree crowns).
7. Conversion to polygon allowed for the 'islands' of non-contiguous cells described above to be selected by area size and removed.
8. The isolated swamp boundaries were converted back to raster format in order to run an Expand tool to increase the swamp boundaries by 3 cells – back to their original size.
9. Extenuating areas of low-lying vegetation posed as parts of swamp extent for all years and were trimmed to an agreeable edge with ecologists at the same location for all years to ensure datasets remained comparable and were not outlying due to data anomalies.

2.1.2.2 Upland Swamp Vegetation Sub-community Mapping - 2021

Upland swamp extents were detected by first modelling swamp vegetation sub-community types based on a differential Canopy Height Model (CHM). The CHM classifies swamp vegetation by height according to specifications within The Native Vegetation of the Woronora, O'Hares and Metropolitan Catchments (NPWS, 2003) and on-ground experience.

The following vegetation types were classified as a part of the CHM:

- Banksia Thicket, 2.8 - 6 m
- Tea-tree Thicket, 1.5 - 3.2 m
- Sedgeland-heath Complex, 0 - 1.5 m.

Spatial analysis of swamp vegetation sub-community boundaries (as a measure of ecosystem functionality) using LiDAR data (supplied by IMC) was completed by implementing the following workflow in ArcMap:

1. LAS (LiDAR) datasets were created for the relevant LiDAR returns for all supplied tiles for the Study Area.
   - Ground
   - Non-ground
2. LAS Datasets were then converted to rasters:
   a. Ground to Digital Elevation Model (DEM)
   b. Non-ground to Digital Surface Model (DSM)
3. A CHM raster was produced by subtracting the DSM from the DEM and symbolised using the height group classes detailed above.
4. Data generalisation was undertaken using the focal statistics tool to reduce the noise in the classified data and average pixel relationships. This produced clear vegetation height group

boundaries for further processing. Discussions were held within the project team about how much generalisation was necessary and beneficial without compromising the results.

5. The CHM raster was reclassified into three values that represented the height group classes detailed above. Any values greater than 6 m were reclassified as no data to limit the dataset to relevant vegetation types only.
6. The reclassified CHM raster was converted to polygon without simplifying boundaries and the output coordinate system was defined at this step.
7. Data cleaning was undertaken by detecting polygons that were not neighbouring other polygons and removing them. This simplified manual data cleaning efforts by removing multiple polygons where they were not attached to the main swamp boundaries.

Given the structural (height) similarities within swamp vegetation sub-communities, analysis of canopy heights derived from LiDAR data could not be utilised alone to distinguish between these sub-communities. Therefore, the results of the analysis of canopy heights derived from LiDAR data were verified by Niche ecologists through visual interpretation of high-resolution aerial imagery captured by UAV. This involved discretionary manual editing of polygon boundaries to reflect vegetation sub-communities identified on the aerial imagery. This also allowed for attribution of reasons for changes in swamp extents detected in the analysis of canopy heights derived from LiDAR data.

Upon completion of verification using aerial imagery, the final version of the vegetation sub-communities spatial data was consolidated into single representative swamp extent polygons for each swamp. Area calculations were then run on the final swamp extents and final vegetation sub-community polygons. These calculations were graphed against previous years' results to determine changes in the total swamp size of upland swamps and extent of groundwater dependent upland swamp sub-communities within each swamp.

2.1.3 Photo-point monitoring

Photo point monitoring was conducted at each site (Impact and Control) at a fixed location, designated by a star picket or wooden stake. Photographs are taken on handheld iOS devices in landscape orientation. Every monitoring point had four photographs taken at each of the four main compass directions; north, east, south and west (0°, 90°, 180°, 270°).

Niche have used current (2021) data to interpret any die-back or visual stress on plants (yellowing). An interpretation of the photo-point monitoring is provided in Section 3.4.

2.1.4 Upland Swamp vegetation monitoring

The Upland Swamp vegetation monitoring was conducted by Sian Griffiths (Senior Ecologist), Sarah Hart (Ecologist), David Wilkinson (Ecologist), Amy Legge (Ecologist), Kayla Asplet (Ecologist) and Nathan Browne (Ecology Assistant). Autumn monitoring was undertaken between 14 May 2021 and 10 June 2021 and spring monitoring was undertaken between 12 October 2021 and 23 December 2021. A team of two qualified ecologists completed three transects within one Upland Swamp per day.

2.1.4.1 Transect monitoring program

Vegetation monitoring in Upland Swamps was undertaken along three 15 metre transects within each swamp (see Figure 2, Figure 3, Figure 4). The presence of all species was recorded within thirty 0.5 x 0.5 metre quadrats positioned along the centre line of the 15 metre transect. A maximum score of 30 per transect for a species (or species complex) indicates it is present in all quadrats.

Consistent with the process in previous monitoring, where there was potential for misidentification, or where species cannot be reliably identified to species level in the field, species have been grouped into identification units for analysis. Each of these units is referred to as a species complex.

2.1.5 Littlejohn's Tree Frog monitoring

Targeted surveys for Littlejohn's Tree Frog were undertaken from mid-winter to early spring when the species is known to be breeding in the area and potentially most detectable by audible calls. Timing of surveys was developed with consideration of state and federal survey guidelines (DECC 2009 and CoA 2010), as applicable to Littlejohn's Tree Frog and years of site-specific experience with regard to frog surveys within the Metropolitan Special Areas and specifically, Dendrobium Area 3A and Dendrobium Area 3B. Sites may require repeated survey if seasonal climate conditions result in a lack of detection of the target species during peak calling periods, this was not required in 2021 as the weather was favourable for breeding and detection of species.

The Littlejohn's Tree Frog monitoring was conducted over eight nights, led by Sarah Hart (Ecologist) and David Wilkinson (Ecologist), assisted by Amy Legge (Graduate Ecologist) and Nathan Browne (Ecology Assistant) from 17 August to 7 September 2021. A team of two qualified ecologists completed between one to three transects a night, dependent on transect length and amount of activity being recorded during survey.

Targeted surveys were undertaken along transects encompassing the breeding habitat and riparian zone of the creek (within pools and 5 m either side of the creek) within each of the 11 impact transects, 2 pre-mining transects and 8 control transects in Table 2 (Figure 5). Transects involved counting all target amphibians at all life-stages (Eggmass, Tadpoles and Adults) observed or heard within the transect.

In 2021, extensive observations were made of discoloured Eggmass that were considered to be un-viable. This observation was made in minor amounts and limited locations in 2020 and it is not unusual for some eggs to be unviable either through not being fertilised or exposure to unsuitable environmental conditions. Due to the extensive observations in 2021, an additional recording item was added so that viable and un-viable Eggmass were recorded for analysis. Un-viable Eggmass were recorded where greater than half of an individual clutch of eggs were discoloured and considered un-viable. Eggmass totals have been included as the combined total of viable and non-viable Eggmass, as both indicate breeding activity. Non-viable Eggmass totals are also considered separately and will continue to be examined throughout future iterations of the program as relevant to evaluate whether this is part of an emerging or ongoing trend.

The transects had variable lengths and numbers of breeding pools. The data for number of breeding pools and length of creek was standardised to 100 m for the purpose of data analysis (see section 2.2.3). The location of each count point for observations made during targeted nocturnal surveys and any other incidental sightings were recorded using a GPS.

Notable opportunistic sightings of all amphibian species were recorded, including threatened species such as the Giant Burrowing Frog (*Heleioporus australiacus*).

During the field surveys within Dendrobium Area 3A and Dendrobium Area 3B it was noticed that not all of the previously recorded georeferenced pools matched up exactly with a pool on the ground, likely due to GPS accuracy limitations in the field at the time of pool identification and also during the Littlejohn's Tree Frog surveys. Niche recorded each Littlejohn's Tree Frog breeding pool with the name of the closest previously recorded pool where present and recorded Littlejohn's Tree Frog activity within it. Where any individuals were recorded at distance from a previously identified pool, these were recorded as incidentals and each record georeferenced.

Pool characteristics were also recorded such as pool depth (overall depth capacity of pool, regardless of water level) categorised as: Very Shallow (<25cm), Shallow (25-50cm), Moderate (50-100cm) and Deep (>100cm) and also current depth (water level as a percentage of capacity).

2.2 Statistical analysis

Following data collection in the field, Upland Swamp vegetation and Littlejohn's Tree Frog monitoring data was reviewed and validated prior to analysis.

In BACI studies, the aim is to assess whether any trend in the response variable (e.g. TSR (Upland Swamps), species composition (Upland Swamps) or abundance (frogs) at sites that have been directly impacted (e.g., mining) differs after impact to that measured before and also differs to any global trend (i.e. trends observed at control sites that did not experience an impact). Potential outcomes in this survey design are numerous with trends potentially occurring suddenly as a pulse event, or as is more likely, gradually over time.

2.2.1 Treatments

As summarised in Section 1.3, one control and three impact site treatments are utilised in the survey design and data analysis approaches, detailed in Table 9 below. These treatments are applied across the swamp floristic transects, LiDAR and frog monitoring transect methodologies, consistent with previous iterations of the monitoring program.

Table 9: Control and impact treatments

Treatment	Description
Control	Site is not subject to any potential impacts, with no mining within the 400 m Risk Management Zone (RMZ) of the feature (the distance at which effects on swamp hydrology are considered likely or possible).
Pre-mining	Data collected at Impact sites in the period prior to the post-mining status change is considered to be pre-mining data at this site. Once subject to potential impacts (within RMZ or mined beneath) sites are changed to post-mining status. Where Control sites are changed to Impact sites as a result of longwall progression, data is altered from Control to Pre-mining for the period prior to impact.
Post-mining - within RMZ	Site subject to potential impacts, with mining having occurred within the 400 m RMZ surrounding the ecological feature. Based on previous experience in Dendrobium, effects on water tables in mapped Upland Swamps have not been observed at distances greater than 60 m from a longwall panel (Watershed HydroGeo 2019).
Post-mining - mined beneath	Site subject to potential impacts, with mining having occurred directly beneath the ecological feature.

2.2.2 Upland Swamps

Mining-induced impacts to Upland Swamp vegetation may be evidenced by a change to TSR at different sites, or an overall change in the species composition, as some species may be less affected by impacts than others. In affected areas, these impacts may manifest as the following:

- Change in floristic TSR: the number of individual species, calculated by the total number of unique species detected at each monitoring transect during each season and year. This is a presence-absence measure and does not account for the abundance of each species.

- Changes in the floristic species composition: the assemblage of different individual plant species that make up a vegetation community.
- Changes in Upland Swamp extent: The contraction or expansion of the area of Upland Swamps and the communities that comprise them.

To maintain consistency with external data management and ensure a non-biased approach to data analysis was implemented, Niche engaged The Analytical Edge Statistical Consulting Pty Ltd (TAE) to undertake a review of the statistical analysis and data collection methodology of Upland Swamps following the completion of the 2020 program (Niche 2021). The analysis provides a statistical comparison of impact and control sites with the aim to identify, understand and manage any mining impacts through the implementation of a quantitative assessment against the relevant TARPs.

Statistical analysis was run for the 2021 dataset against one, two, three, four and five yearly comparisons. This was required to understand the TARP triggers and cumulative impacts. This approach was required as not all data are assessed in a single model, and therefore power is lost as data are omitted from the analysis. For example, a small change may never be statistically significant when comparing the data between two consecutive years (as is required to assess TARPs), but might be statistically significant at a different timescale, such as over the entire survey (TAE 2022a). To remedy this, an analysis of cumulative impact in TSR and species composition was undertaken over three, four and five years to enable detection of change over time (see Section 4.1.1.)

The following methodology was designed and applied to the Dendrobium dataset by TAE (2022a,b,c,d,e) in consultation with Niche ecologists.

2.2.2.1 Total Species Richness (TSR)

TSR was calculated for swamp sites as the sum of individual taxa detected at each transect for each survey. Exploratory data analysis was conducted by creating boxplots of total species richness (TSR) at all swamps over the period of monitoring to determine any visually detectable yearly trend in TSR between swamp types (impact or control), any difference in TSR before and after impacts.

A complete analysis of all one, two, three, four and five yearly comparisons was undertaken across the entire historical dataset. The mean TSR of all two-consecutive-year pairs at impact swamps was contrasted against the mean TSR of all Control swamp data from prior to the impact.

Where applicable, a BACI style analysis was completed, whereby differences in group means before impact between the control and impact swamps, and after impact, were tested to explore whether they were different from zero (0). If there was only a single year of before-impact monitoring (e.g., Swamp 1A, Swamp 14, Swamp 23), a control-impact analysis was completed, whereby differences in group means after impact at the Control and Impact swamp was tested to explore whether they were different from 0. Conducting multiple testing such as this can lead to erroneous interpretation of results. Through statistical chance alone 5% of tests may be concluded statistically significant, and this chance is elevated when multiple tests are conducted. Methods exist for multiple correction (e.g. Holm 1979) but this will decrease the power to detect a difference, if one exists. All analyses were conducted in R (v. 4.1.2, R Core Team 2022) (TAE 2022a).

2.2.2.2 Species composition

A list of all unique species detected at each transect in each survey has been recorded. This data has been used to describe the species composition of each swamp and identify changes in species composition over time.

Flora data were used to determine species assemblages – or community composition – at each transect, within each swamp during each survey (i.e., simply a list of all unique species detected during each monitoring event). This multivariate data has been traditionally analysed within a distance-based framework, using methods like principal components analysis or non-metric multidimensional scaling (e.g., Symbolix, 2014). However, amongst other problems, these methods cannot offer a formal framework in which to test the hypothesis that treatment-effects influence species assemblages (Warton et al., 2012, Wang et al., 2012; TAE 2022b).

Instead, model-based approaches can be used when dealing with complex, multivariate data such as species assemblages. Here, multivariate presence-absence models were fitted using the 'manyglm' function in the 'mvabund' package (v.4.1.9, Warton, 2012 in program R (v. 4.1.2, R Core Team 2022). These models fit multiple presence-absence models to each detected species, correcting for the correlation between species (thus violating an assumption of standard Generalised Linear Models (GLMs) using generalized estimating equations (GEEs). Analysis of variance (ANOVA) was used to formally test the significance of explanatory variables (i.e., 'Mining Status'). Separate models were fitted to data collected at each swamp. If 'Mining Status' was found to be statistically significant, univariate tests were completed to determine which species were driving the change in flora community composition (TAE 2022b).

A complete analysis was undertaken across the entire historical dataset. Data were subset in to two-consecutive year periods and analysed within a multivariate framework to determine if species composition differed between the two-year period after impact, compared to prior to species composition prior to impact. For example, if a swamp was impacted in 2013, species composition in 2013 and 2014 at the impact swamp was compared to the species composition prior to the impact. This was then repeated for 2014-2015, 2015-2016, 2017-2018, 2018-2019, 2019-2020 and 2020-2021. Three- and four-yearly comparisons were also undertaken, and for swamps in Area 3B, five-yearly comparisons were investigated (TAE 2022b).

In this approach, not all data are assessed in a single model, and therefore power is lost as data are omitted from the analysis. For example, a small change may never be statistically significant when comparing the data between two consecutive years, but might be statistically significant at a different timescale, such as over the entire survey.

2.2.2.3 Breakpoint analysis

In addition to the limitations in TSR outlined above, this approach doesn't identify any statistically significant 'change points' that might exist in the data. In this case knowledge about when the impact occurred and whether that impact date caused a change in the trajectory of TSR at each swamp. TAE has proposed alternative methods to analyse these data using a broken-stick approach (following Muggeo 2003; Muggeo 2017) and this method has been included in 2021.

TAE (2022c) explains that in a broken-stick model with a single breakpoint, the data are essentially split into two time series: one prior to and one after the breakpoint. A linear model is fit to each portion of the data (i.e., one linear model is fit to the data subset prior to the breakpoint, and one linear model is fit to the data subset after the breakpoint). The placement of the breakpoint is optimized to ensure the error for the fitted models within each segment of the data is minimal. As the number of breakpoints fit to the data is increased, so too is the number of linear models. That is, two breakpoints create three separate linear models (one before the first breakpoint, one between the first and second breakpoints, and one after the second breakpoint). The number of breakpoints fit to the data is a model selection issue, here based on Akaike's Information Criterion (AIC) (Buckland et al. 1997).

Once the final model of breakpoints is determined, the statistical significance of the linear models for each segment can then be explored. Here, the gradient of each segment is reported, along with statistical significance based on 95% confidence intervals. All analyses were conducted in R (v. 4.1.2, R Core Team 2022), using the 'segmented' packaged (v 1.4-0, Muggeo, 2008).

In addition, this additional analysis of the TSR data, breakpoint analysis has also been applied to a limited selection of species in each swamp with identified statistically significant differences in pre-post mining species composition. The same broken-stick methods were used as for the TSR analysis, however applied to the number of detection events for identified target species within specific swamps. As this is an exploratory analysis in order to examine the efficacy of the approach, two species were selected for breakpoint analysis in each swamp. Target species were primarily identified based on three criteria. First, species identified as experiencing the greatest degree of change in the species composition analysis (TAE 2022b). Second, species that have a clear preference for 'wet' or 'dry' soils or habitat associations. Third, species that show a clear trend of increasing or decreasing (or both) detection over the course of monitoring to optimise the likelihood of findings being conclusive.

2.2.2.4 Investigation of differences in seasonal monitoring

Exploratory analysis was recommended in Niche (2021) to determine whether both seasons of data collection are essential to support the data analysis. If no difference is detected, the Program could potentially be adjusted to collect TSR and composition data once a year in spring, without reducing the validity of any statistical analysis. This would also reduce the effects of trampling alongside transect locations. Further discussed in Section 2.4.

Statistical analysis (Annex 3) of spring versus autumn TSR and species composition data has been undertaken in 2021 to determine if there is a difference between seasons (TAE 2022e). This analysis included visual analysis of boxplots of TSR for each control and impact swamp, contrasted by season. Multivariate generalized linear models were then fit to impact-swamp specific data to investigate seasonal differences in species composition. This analysis identified unique species detected in each season, per swamp. This list of unique species detected only in a single season at each swamp was then assessed by Niche Ecologists.

All analyses were conducted in R (v. 4.1.2, R Core Team 2022).

2.2.3 Littlejohn's Tree Frog

Niche have maintained the data collection and method to standardise the varying lengths of transects. As per previous reports, the total number of each life stage is standardised to represent a Catch-per- unit-of-effort (CPUE) per 100 metres of survey effort (n/100 m) along each transect.

For statistical analysis a linear model was fitted to the data of the form Count~Treatment*Year for each of Adults, Tadpoles and Eggmasses separately. This was to test for any interaction between year and treatment and the main effect of year and treatment. Count data were modelled as negative binomial instead of normal to account for the zero-truncated and integer-based nature of counting, and the zero-inflated dataset. For catchment level trends at Dendrobium Area 3A or Dendrobium Area 3B preliminary exploratory analysis examined homogeneity of variance. The variance was corrected by introducing a factorial variance structure, allowing different variance for each level of treatment. If these variances were unresponsive, a log(count+1) transform was conducted, if no effect, the raw data was then used. Site was included as a random term, and its significance was tested by an ANOVA by comparison to the factorial only model. In all cases, Site was not statistically significant and so removed from the final models.

For longer term effects the data were scored by treatment (Pre, RMZ, Mined under), at the Control and Impact sites. A GLM was fitted using a variance structure controlled for different variance between Control and Impact sites. For statistical analysis a linear model was fitted to the data in the form CPUE ~ Mine_status. This reads as: CPUE (catch per unit effort) as a function of Mine Status (Control/Pre-/RMZ/Mined under) and its significance was tested by an ANOVA. This was completed to test whether CPUE (of Adults/Tadpoles/Eggmass) was different between Control and Impact (whether Pre-, RMZ, or mined under) transects. Second to this analysis, a Tukey HSD test was completed to ask precisely which Mine Status were different from Control. The BACI style model was unique per creek site with the Control timing matching that of the Impact site timing in each case. In every case all Control sites were used as the Control. These models were run for Adults, Tadpoles, and Eggmasses separately.

Analysis of Deviance tables for negative binomial generalised linear models describing Counts (of Adults, Tadpoles, and Eggmass) as a function of Longwall (Distance to Longwall), and Size (size of pool) were prepared to test the relationships between distance to longwall and CPUE, as well as flocculant and CPUE. To test the relationship between CPUE and distance of pool to the closest longwall, these analyses used the 2021 monitoring dataset, with all impact sites from 3A and 3B pooled together and sites unimpacted by the Project (Control and Pre-mining transect data) excluded. For flocculant, the analyses used the 2021 dataset with all Impact sites combined and compared against the Control sites (Pre-mining sites were excluded).

All analyses were conducted in R (v. 4.1.2, R Core Team 2022).

2.3 Limitations

Limitations of the Program include the following:

General limitations:

- No two creeks or Upland Swamps are identical, and therefore eliminating all variables between Control and Impact sites is a complex task and not possible in this instance.
- This is the second year Niche have undertaken the Program and as such, some methodologies may be slightly different to previous iterations of the program, despite every effort to maintain consistency.
- Swamp treatments were updated to reflect current mining activity (Section 2.4).

Upland Swamps:

- Spring 2021 Upland Swamps surveys extended into early summer, due to weather restrictions preventing access to the catchment in late spring. This varied from previous years but is not likely to have had an impact on the results.
- Control Sites are located within areas that are not expected to be impacted by mining operations. Survey within Control Sites was limited to lands that were accessible, and where safety concerns could be minimised.
    - This Project employs the use of multiple Control sites for each Impact site to establish multiple lines of evidence to differentiate between catchment wide influences, such as low rainfall, and potential mining impacts. The Program also utilised long term monitoring data for many of these sites, and additional data sets such as groundwater monitoring conducted by IMC.
- The transect data only indicated the presence/ absence of a species across the transect. This limits the ability to investigate some other aspects of vegetation monitoring such as diversity/abundance.

- Some plant species are cryptic or inconspicuous unless flowering or in fruit. Plant species complexes were developed that combine plant species that are known to be easily confused in the field. These species complexes are treated as one species in the data analysis, more commonly joining species of the same Genus and ecological function that are difficult to identify in the field across seasons and that occur in close proximity to one another.
- Though standards are employed to reduce the occurrence of observer bias (such as obtaining a list of species previously recorded at each swamp), there will inevitably be some observer bias that may result in different species recorded identified along transects. Particularity for closely related or similar species, this is maintained as the species complex to assist in eliminating risk to data.

Littlejohn's Tree Frog:

- The limited dataset provided from previous iterations of the monitoring program to 2019 for Littlejohn's Tree Frog analysis restricts the ability to analyse trends on the smaller scale as the data was represented as an average across standardised transects and presented as one number. Since 2020 the raw data has been maintained such that data can be examined at the individual pool level.
- Only visiting each site once across the survey period may not be a clear representation of the population in the system. This is also dependent on the temperature and rainfall throughout the breeding cycle. A general trend may be observed that if Adults are present, there will be fewer Tadpoles, and this may change over the course of the survey timing. Maturation times for Tadpoles of the species having been observed to take around 4 months (Anstis 2002) but dependent on seasonal temperatures, and other factors. Klop-Toker et al. (2021) suggest between 3 to 4 months in summer and 5 to 11 months in winter.
- It is possible that broadly speaking surveys earlier in the breeding season may be more likely to detect more Eggmass and Adults compared to later, which would have metamorphed into Tadpoles. However recent work by (Klop-Toker et al. 2021) suggests the species breeds nearly year-round, with breeding most typically triggered by rain events, with multiple breeding opportunities each year likely. Therefore, the relative timing of surveys across a season is not considered a limitation in and of itself.
- To allow for potential variation in conditions described above, and to remain consistent with the previous monitoring approach, surveys were planned that each night contains at least one control creek and one impact creek to justify the variation across the breeding season.
- Trends or results in lifecycle stages are not considered in isolation and form part of a weight of evidence approach whereby all lifecycle stages are considered, with analysis and interpretation of the biological data augmented by assessment of physical habitat conditions (water levels) and identification of gross indicators of environmental change (bedrock cracking, flocculant).

LiDAR

- The mapping of sub-communities was mainly undertaken via use of LiDAR, supported by aerial imagery interpretation. Minimal ground-truthing was undertaken to validate the mapping. There are therefore likely to be at least minor errors in the swamp extent mapping.
- Given the updated CHM developed for the 2020 analysis (as detailed in Section 2.1.2), to enable results of total swamp extent and swamp sub-community mapping to be comparable to previous years, the updated CHM developed by Niche in 2020 was compared to historical LiDAR datasets and outputs recreated. Therefore, total swamps extents, swamp sub-community mapping and TARP triggers are likely to be different to that presented in previous monitoring reports (Biosis 2020, Niche 2021).
- No LiDAR data for 2015 was available and so has not been included in the historical analysis.
- Limited data for control swamps 86 and 22 is available (2014 and 2021 only). Data for these control sites are presented in this report and are used to inform the assessment of the results. To avoid unequal comparisons and biasing averages (i.e. higher averages in years where data is available compared to when it is not available) these sites are not included in the control group averages or standard error calculations used in the assessment against performance measures.

- In 2021 the updated CHM (Niche 2021) has been applied to the available historical LiDAR data to enable valid comparisons across the program years. As the updated CHM has been applied retrospectively in place of the previous analysis, there may be differences to findings of previous monitoring reports and as such, TARP levels triggered.

The current Project data collection and methods of analysis are considered suitable to address the relevant monitoring TARPs. For future recommendations see Section 4.4.

2.4 2021 review and updates to the Program

As part of the commitment to continuous improvement, Niche has reviewed the methodology and recommendations from the previous year's report in order to identify any areas of improvement or methods to augment the Program. Niche have undertaken the Program, as far as practicable, using the same methods as previous monitoring reports to ensure valid comparisons to previous years of data collection and analysis. Some changes to the approach have required updates relevant to the current year of mining activity within Dendrobium Area 3 and to improve the approach to data collection.

A review of the existing program has been made in order to evaluate and where possible improve the robustness of the survey design, as well as improve consistency in assessment approach. These improvements build upon those identified and described in detail in the 2020 iteration of the monitoring program (Niche 2021), which have been carried forward and are not repeated in detail here. In addition to these changes, a number of additional assessment methods have been included in 2021 in order to augment the overall assessment and detailed analysis, contributing to an increased confidence in the findings. These review outcomes and changes are outlined below in Table 10.

Table 10: Review outcomes and updates to the Program

Review item	Summary of actions and finding	Summary of outcomes and justification
Existing program		
Consideration of paired vs pooled control site data for swamp floristic analysis.	Previously control site data has been pooled for analysis, including iterations of the program prior to Niche (2021). Niche has undertaken a review of the impact and control swamp/transect attributes and data collection to date in order to explore whether the pairing of control and impact sites may lead to an improved level of assessment for the program. The range of physical and spatial attributes considered as part of the review are presented in Annex 1. The review identified that as a group the control sites provide a strong level of comparability for analysis to the impact sites, although a high degree of variation is observed across all monitoring sites when considered individually. While there are similarities across many of the sites, a strategy that satisfactorily pairs the sites based on similarity of multiple attributes does not present itself. It is possible to create pairings based upon a single attribute alone, however the result of this is a somewhat arbitrary rather than ecologically based grouping strategy (e.g. swamp extent or transect length). In addition, this would serve to reduce sample sizes and ignore other important attributes (e.g. swamp type, or number of breeding pools). It also results in more limited periods of control site data collection. In a continuation of the practice applied throughout previous iterations of the monitoring program, all controls are used for each area (for both Swamps and Creeks).	Overall, there are a greater number of limitations in pursuing a paired impact and control strategy to the design and analysis. In part, this may be a factor of the original program design (circa 2003), that does not appear to have explicitly pursued a paired control strategy. The program has maintained the approach of pooling the control site data, with the following advantages: • Increasing the sample size (more replicates) for Control data. • This provides more power to the variability at the control sites, allowing for comparison with Impacts sites of high variability. • Maintaining consistency with previous iterations of the monitoring program. As control sites within Area 3 become impacted by longwall progression and are changed to impact sites, additional control sites will continue to be added to the program. Additional methods of analysis have also been included across all aspects of the 2021 iteration of the Program to provide a more in-depth and comprehensive assessment of any impacts to ecological features associated with Longwall mining. Outside of statistical analysis and where useful, comparisons of physically similar sites are made to inform data interpretations and the analysis approach of the Program.

Review item	Summary of actions and finding	Summary of outcomes and justification
The use of NDC and ND2 as control frog monitoring transects has been reviewed using the available frog detection and observation data to verify the assumptions of the original program design.	Transects NDC and ND2 (Native Dog Creek) have been used as a control transects throughout the program since 2007 and 2012 respectively as part of the original program design. Biosis (2013) states that the justification for inclusion is that "*Native Dog Creek and the tributaries of Native Dog Creek (ND1 and ND2) are used as control sites in the threatened frog monitoring program despite being located within the 400m RMZ of Longwall 7 and Longwall 8 of the Elouera Colliery. Despite there being several impacts to the upper reaches of Native Dog Creek, threatened frog monitoring has consistently detected Littlejohn's Tree Frog during the seven years of post-mining surveys (2007-2013) and has therefore been maintained as a control site*". Biosis (2013) also notes that no impacts have been documented along ND1 and ND2. This justification has been examined in detail as part of this review, following observations of flocculant observed along these transects, including within major pools. As there are known impacts to Native Dog Creek and as observations of flocculant are used elsewhere within the Program as an indicator of potential deleterious changes to habitat conditions, it would seem unlikely that these transects would be suitable controls. This has triggered a detailed examination of the detection data below in order to further test the statement that continued detection justifies the inclusion of these transects as control sites. The lack of data prior to impacts along these transects associated with the Elouera Colliery is a limitation to examining the decision of Biosis (2013) and post Elouera impact detection data. To overcome this, the detection data for NDC and ND2 have been statistically analysed against the control group data, and the results from each transect have also been considered in the context of the most similar control sites (transect length, number of breeding pools and pool size distribution), as well as ND1 where impacts have not been observed, to assess whether the level of detection is suggestive of any impacts to Littlejohn's Tree Frog along transect ND1 and ND2. The statistical analysis identified a significantly lower detection level of Adults (p-value <.0001) at NDC and ND2, and Eggmass (p-value <.0001) at NDC than the control group (data was insufficient to analyse Eggmass at ND2). While it is true that the detection of the adult lifecycle-stage of Littlejohn's Tree Frog at NDC appears consistent with that recorded at similar control sites, the detection of Tadpoles is somewhat lower. On average, approximately half that of the similar control with the lowest level of detection. Although lower, this does indicate that some degree of reproduction is occurring. However, the detection of Eggmass is highly reduced when	Without pre-impact data it is not possible to positively attribute the very limited Eggmass detection at NDC or ND2 with an impact, but the factors discussed are suggestive that these transects are not optimal control transects. For the 2021 iteration of the monitoring program, transects NDC and ND2 have been removed from the analyses as control transects for the following key reasons: • Impacts associated with the Elouera Colliery have been previously recorded and NDC. In 2021, flocculant was recorded at all pools along this transect. • A statistically significant negative relationship between the presence of flocculant and detection of Littlejohn's Tree Frog has been established in section 3.6. • Statistically significant differences in detection were identified between NDC and ND2 when compared to the Control group. • The detection of Tadpoles is consistently lower at NDC than similar controls, and detection of Eggmass highly reduced when compared to similar controls. • Observations of flocculant were made at over half the breeding pools identified along ND2. • Comparisons of detection are more limited at ND2 and although levels were lower than that of WC11, they were higher than pre-mining data from La4a. When compared to impact sites 6CDL and WC17, detection of Adults were comparable or above these sites, but Tadpoles and Eggmass slightly lower. It is harder to disentangle potential impacts at transect ND2 from the likely more transient and less utilised habitat conditions pre-mining. However, when taken overall the factors considered are suggestive of observations that are more aligned with those at the impact transects than control transects. When taken together, the weight of evidence suggests that transects NDC and ND2 do not represent un-impacted stream conditions or Littlejohn's Tree Frog populations. As such these transects are not considered suitable as controls.

Review item	Summary of actions and finding	Summary of outcomes and justification
	compared to the similar controls. This low level of detection is not only typified by no detection at all in most years but also lacks the occasional peaks in detection seen at similar control sites over the 14 years of monitoring at NDC. This is despite the presence of larger pools and relatively high water availability at this transect which should be favourable for breeding. Transect ND2 is a short transect along a small tributary that is connected to Native Dog Creek (within transect NDC) and in 2021 flocculant was observed in four of the seven pools. ND2 has a limited number of highly comparable controls and the overall results of the monitoring program suggest that these smaller tributaries or areas of habitat may present more transient breeding habitats than those of larger transects. Detection at ND2 has therefore been compared to control site WC11 and seven years of pre-mining data from La4a as the most suitable transects for comparison, augmented with comparisons to post-mining transects 6CDL and W17. Detection of all life-cycle stages of the Littlejohn's Tree Frog at ND2 are lower than that of WC11, but comparable or slightly above that of pre-impact data from La4a. The detection of Eggmass and Tadpoles at NDC2 is somewhat lower than that 6CDL and WC17, although the detection of Adults is comparable. The observations of flocculant at ND2 are more comparable to that of the post-mining transects than control transects. Detection of all life-cycle stages of the Littlejohn's Tree Frog at ND1 remain comparable with that of similar control transects, with no observations of flocculant made in 2021.	In 2021, NDC and ND2 are treated at pre-mining transects only, as such the results are presented and contribute to the overall picture of trends in 2021 but are not considered in specific detail. The dataset for NDC and ND2 will provide a highly useful basis for comparison when these transects become post-mining as part of the current program in coming years. This change brings the assessment in line with the rest of the program, with observations of flocculant being used elsewhere as an indicator of potential deleterious changes to habitat conditions. Transect ND1 remains a control for the program as impacts associated with the Elouera Colliery have not been observed along this transect and no observations of flocculant were recorded in 2021. In addition to this, the detection of all life-cycle stages of the Littlejohn's Tree Frog at ND1 remain comparable with that of similar control transects. It is recommended that additional control transects from un-mined areas are added to the program to eventually supplement the loss of transects along Native Dog Creek that will become post-mining transects.

Transect	Transect length	Number breeding pools	Pools with flocculant (2021)	Average detection across program		
				Adults	Eggmass	Tadpoles
NDC vs similar controls						
SC7(1)	474	20	1	8.8	19.0	67.9
SC7(2)	436	9	0	7.2	15.9	143.2
SC7A	453	22	0	10.4	33.3	367.9
ND1	742	26	0	12.5	35.2	204.5
NDC	**555**	**18**	**18**	**7.0**	**0.2**	**37.2**
ND2 vs similar controls and pre- and post-mining transects						
WC11 (control)	176	6	0	3.0	7.8	151.2
La4a (pre-mining 2007-2015)	209	3	0	0.3	0.0	0.0
6CDL (pre and post-mining)	89	8	1	0.5	5.9	262.5
WC17 (pre and post-mining)	177	7	7	1.4	0.5	36.2

<table>
<tr><th>Review item</th><th>Summary of actions and finding</th><th>Summary of outcomes and justification</th></tr>
<tr><td></td><td colspan="2"><table><tr><td>ND2</td><td>123</td><td>7</td><td>4</td><td>2.0</td><td>0.0</td><td>7.9</td></tr></table></td></tr>
<tr><td>The use of Swamp 15A(1) as a control swamp was reviewed at the conclusion of 2020 round of monitoring.</td><td>Swamp 15A(1) has been utilised as a control swamp consistently throughout the program since 2005.

It is acknowledged that Swamp 15A(1) is connected to 15A(2). Longwall mining in 2012 occurred to a distance of approximately 90 m from Swamp 15A(2), and just over 400 m from Swamp 15A(1).

Niche has been provided with information and expert assessment (Watershed HydroGeo 2019) from IMC establishing that piezometers within 15A(1) have not experienced hydrological impacts associated with Longwall mining and is unlikely to experience hydrological impacts from existing longwalls (further detail is provided in Section 3.2).

In light of this, Swamp 15A(1) will continue to be used as a control swamp for the program until Longwall mining encroaches within 400 m of the swamp.

This outcome and justification is the same as that detailed in IMC's response to the Biodiversity and Conservation Division's (BCD) feedback on the Dendrobium Areas 3A and 3B: Terrestrial Ecology Monitoring Program Annual Report 2020 (South32 IMC 2021), dated 30 August 2021, to the satisfaction of the Department of Planning Industry and environment (DPIE) (2021).</td><td>The program has maintained the approach of maintaining Swamp 15A(1) as a control swamp for the following reasons:
• Longwall mining has not encroached within 400 m of swamp 15A(1).
• Swamp 15A(1) is upstream of longwall activity and is unlikely to experience impacts from downstream longwalls.
• A review of piezometer data in Dendrobium concluded that effects on swamp water tables have not been observed at distances greater than 60 m from a longwall panel (Watershed HydroGeo 2019).
• The Swamp 15A(1) transects are outside of the 60 m groundwater impact buffer and are therefore unlikely to be impacted by existing longwalls.

This same review did not identify impacts at any of the piezometers within Swamp 15A(1) or Swamp 15A(2) as of late 2018 (Watershed HydroGeo 2019). Several years following longwall progression beneath Swamp 15B in 2012 and entering the RMZ of Swamp 15A(2) in 2012.</td></tr>
</table>

Review item	Summary of actions and finding	Summary of outcomes and justification
Review of control sites used for LiDAR analysis	Previous iterations of the monitoring program have utilised a number of very small control swamps (89, 91, 93, 95 and 96), these swamps were considered to provide limited comparability to the larger more complex Impact and control swamps that were part of the program. Another recommendation from the 2020 monitoring report was to analyse the same Impact and Control swamps that are monitored for TSR and composition, bringing this component of the monitoring program in line with other components of the monitoring program.	In line with the recommendations of Niche (2021) very small control swamps have been removed from the program in 2021 and the analysis has focussed on analysing swamps that are used in the floristic monitoring program, where data is available, to improve the comprehensiveness of the overall assessment and interpretation.
Additional analyses and methods in 2021		
Littlejohn Tree Frog additional statistical analysis	Two avenues for further analysis to better understand trends apparent within the Program are the distance of each longwall and the presence of flocculant. These analyses follow observations in the field and in the detection dataset that counts of Littlejohn's Tree Frogs are lower in mined under areas, where any impacts to water quantity are likely to be greatest, and also in pools with flocculant present.	Consideration of the distance to longwall for each pool allows assessment of possible relationships between these factors, separate to the broader control and impact classification applied at the transect level. These observations have been statistically tested and the results are reported in Section 3.6.3.3.
Apply the updated CHM across previous years of LiDAR data.	Due to the lack of justification and understanding of the previous analysis (pre-2020), Niche developed a robust method for LiDAR analysis of swamp extent and mapping of sub-communities for use in 2020 and future monitoring reports (Niche 2021). A recommendation from the 2020 annual monitoring report was to apply this CHM across the previous years of available LiDAR data to ensure comparability to previous datasets to facilitate a more robust understanding of change over time and address the relevant TARPs.	In 2021 the updated CHM has been applied to the available historical LiDAR data to enable valid comparisons across the Program years. Patterns of change observed across the Program are therefore described in Section 3.3. As the updated CHM has been applied retrospectively in place of the previous analysis, there may be differences to findings of previous monitoring reports and as such, TARP levels triggered.
Swamp floristic monitoring breakpoint analysis	One limitation to the assessment of TSR data is that this approach doesn't identify any statistically significant 'change points' that might exist in the data. In this case knowledge about when the impact occurred and whether that impact date caused a change in the trajectory of TSR at each swamp.	TAE has proposed alternative methods to analyse these data using a broken-stick approach (following Muggeo 2003; Muggeo 2017) and this method has been included in 2021. In addition, the breakpoint analysis has also been applied to a limited selection of species in each swamp with identified statistically significant differences in pre-post mining species composition.
Recommendations for future monitoring		
Investigation of differences in seasonal monitoring at swamps	Observations of trampling effects along transects were observed in 2020 (Section 3.4), which has the potential to result in a degree of impact to swamp vegetation and soil compaction in these localised areas. Conceivably, these trampling effects alongside transects may have the potential to impact upon data collection.	It is acknowledged that the removal of autumn surveying would mean species detected only in autumn could potentially be missed. However, analysis of the 17 year dataset suggests that the potential number of species would be small (1-7 at individual swamps) and there is no

Review item	Summary of actions and finding	Summary of outcomes and justification
	Exploratory analysis was recommended in Niche (2021) to determine whether both seasons of data collection are essential to support the data analysis. If no difference is detected, the Program could potentially be adjusted to collect TSR and composition data once a year in spring, without reducing the validity of any statistical analysis. This would also reduce the effects of trampling alongside transect locations. Statistical analysis (Annex 3) of spring versus autumn TSR and species composition data has been undertaken in 2021 to determine if there is a difference between seasons (TAE 2022e). Visual analysis of boxplots of TSR for each control and impact swamp, contrasted by season, was undertaken, with no strong visual differences in TSR between spring and autumn for any swamp identified. Typically, more species were detected in spring and fewer species are detected only in autumn. Although a subset of species were only detected in autumn at individual swamps (ranging between 1-7 species). Notably however, none of these species are restricted to occurrence in autumn and in many cases have been detected at other swamps in spring. Multivariate generalized linear models fit to impact-swamp specific data to investigate seasonal differences in species composition did not identify seasonal differences.	functional reason why these species would not be detected in spring if present. Furthermore, when inspecting individual species, most species were more readily detected in spring compared to autumn, with the spring surveys typically recording a greater number of species than autumn at the swamps. In summary, no strong argument to maintain the autumn round of transect data collection was identified and the analysis undertaken suggests that 'spring only' data collection and analysis would not compromise the validity of the program or fundamentally alter the monitoring results. The argument to undertake transect data collection only once per year in spring is supported by the fact that no seasonal differences were detected in TSR or in species composition for any swamp. It should be noted that this change would be likely to result in fine scale differences in the statistical analysis of previous years, however given the factors previously established this would be unlikely to alter the overall results or represent a limitation to the program. It is recommended that future data collection in spring only is considered for the transect monitoring, with subsequent data analysis restricted to the spring seasons of data collection.
LiDAR analysis processing	The current workflow for delineating swamp vegetation subcommunity boundaries using LiDAR data derives a single data product, the value of canopy height. This data is then classified and manually verified against aerial imagery by the GIS team alongside ecologists. Niche have undertaken preliminary investigation into potential additional data products that could be derived from LiDAR data to enhance the analysis workflow and reduce the potential for subjectivity. The exploratory analysis found that canopy density values can be calculated with some additional analysis workflow steps. These values give a strong indication of areas of canopy that are thinning over time, potentially suggesting dieback.	Niche recommend a new analysis workflow model be developed and implemented for the 2022 Program. The new model allows multiple criteria analysis through overlay of canopy height and canopy density LiDAR derived products matched with NDVI moisture index values acquired by South32's new fleet of UAVs to better inform ecosystem functionality of the swamps. The combination of these three datasets allows for subcommunity classification according to predefined set of rules. This new multiple criteria approach to subcommunity boundary delineation will reduce the amount of time required to complete manual verification of the data and generate greater value from the data that South32 collects as it relates to usage and project outcomes.

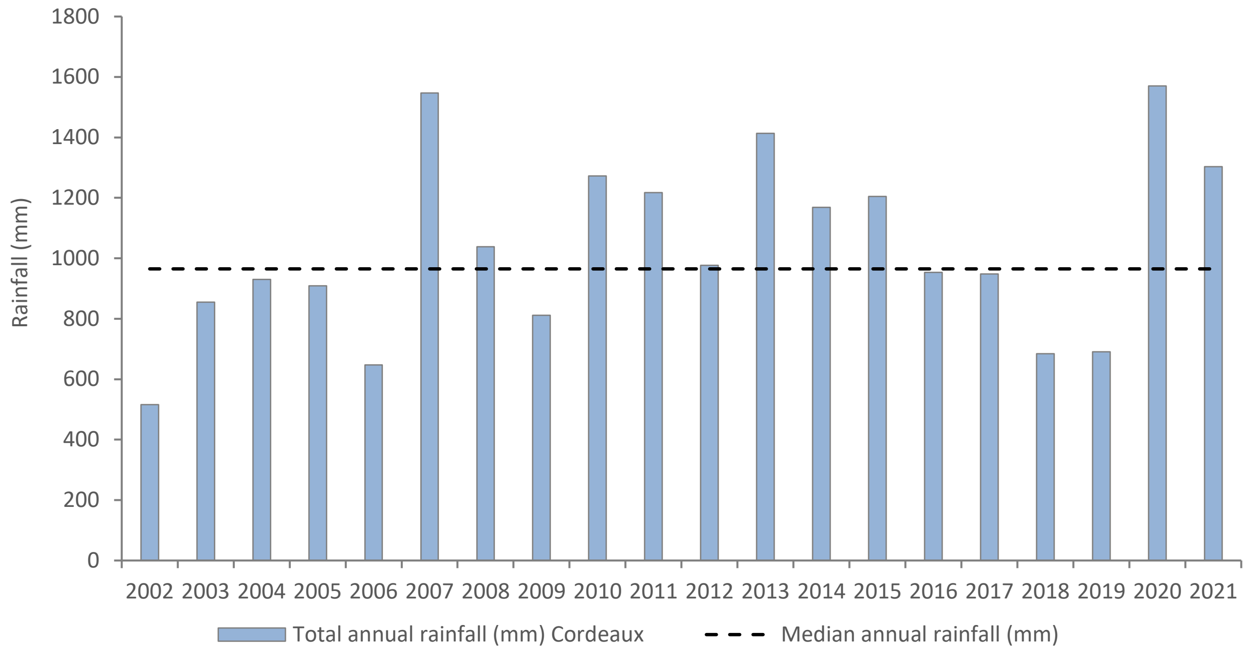
3. Results

The statistical analysis of Upland Swamps and Littlejohn's Tree Frog, raw threatened frog data and photo point monitoring are provided in Annexes 3 to 6. An overview and assessment of these results is provided in the following sections.

3.1 Rainfall

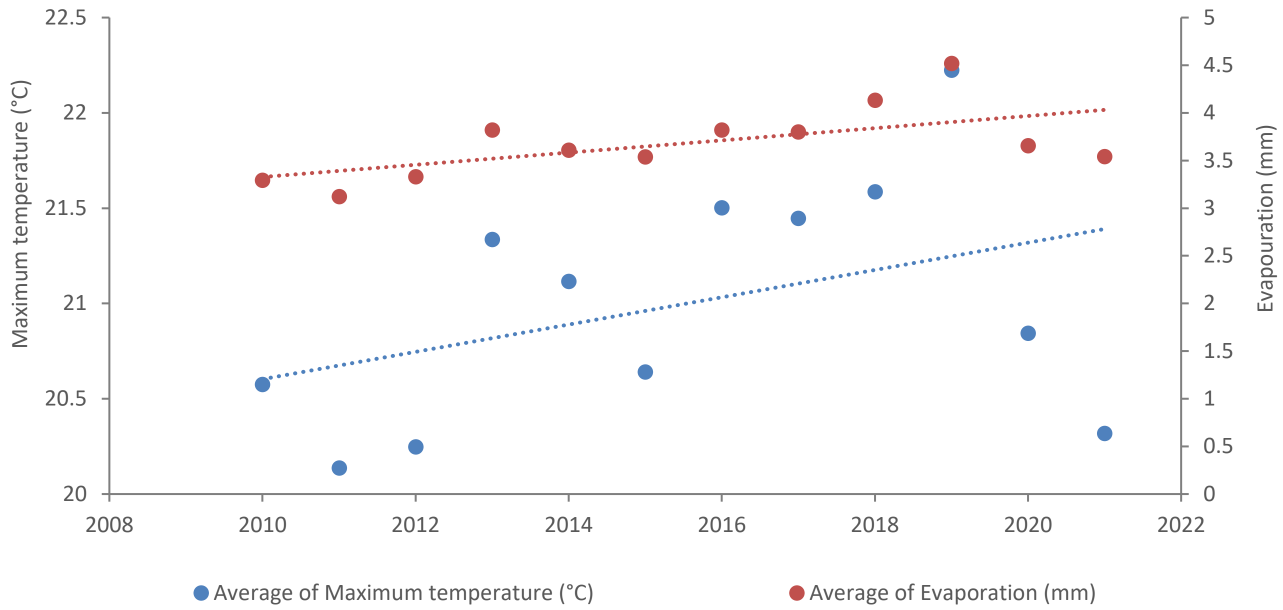
Rainfall is an important factor influencing change in Upland Swamps and creek habitat conditions. A visual analysis of rainfall data is useful when determining potential reasons for changes to Upland Swamps or creeks at the catchment scale.

Available rainfall data recorded at the IMC Cordeaux rainfall gauge is presented in Graph 1, showing annual rainfall recorded over the nineteen years of the ecological monitoring program (2002 – 2021). The median annual rainfall for this period from the Cordeaux IMC rainfall gauge (965 mm) is also shown. Graph 1 shows that rainfall during the 2021 iteration of the monitoring program was above average, the fourth highest recorded at the station (1302.9 mm). Above average rainfall was also recorded in 2020, the highest level recorded throughout the program (1570.8 mm). This trend of above average rainfall marks a departure from the extended period of below average rainfall that occurred between 2016 and 2019, with the extended drought conditions being particularly acute in 2018 and 2019.



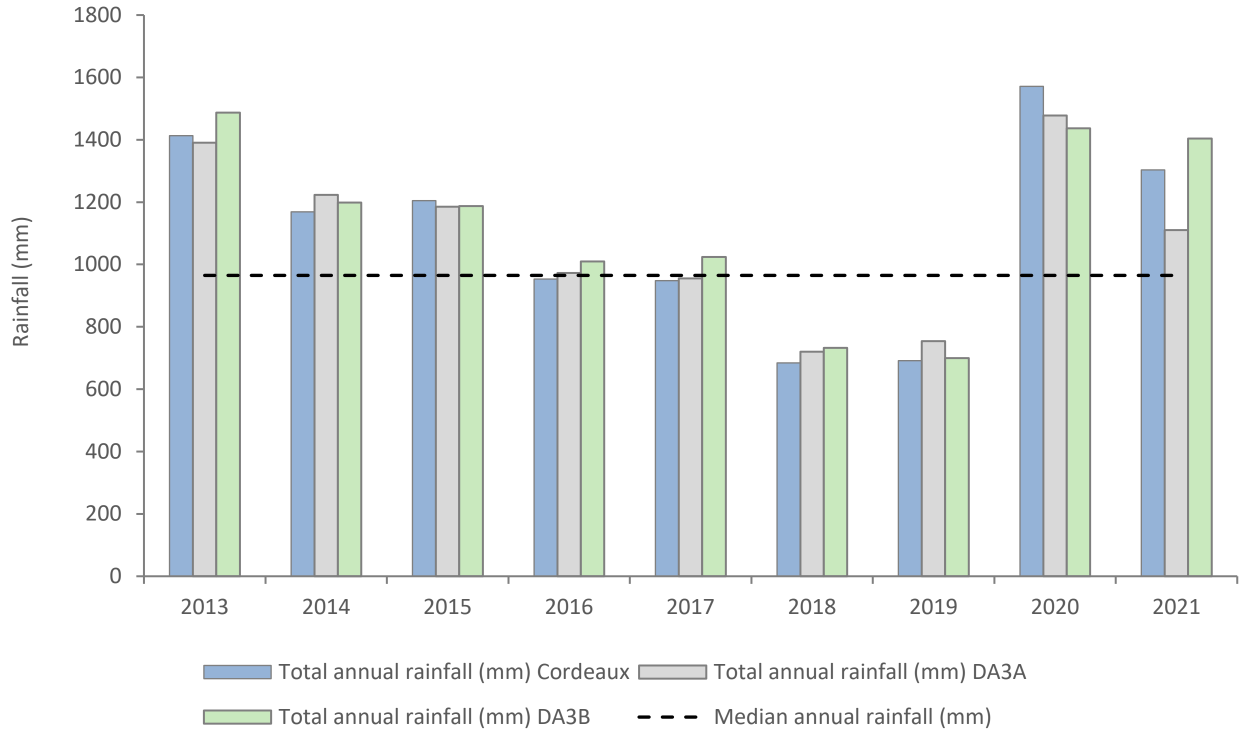
Graph 1: Annual rainfall data from 2002 to 2021 (IMC Cordeaux rainfall gauge)

As an additional indicator of other global factors relevant to ecological values, an examination of average maximum temperature and evaporation per year has been made (Graph 2). Whilst variable year on year, available data for the last 11 years indicates an overall increase in average maximum temperatures and evaporation (BoM 2022). Only a limited dataset is available from Cordeaux Dam (BoM station 68018), however when examined against other available datasets (BoM station 068192), a similar overall trend of increase is observed in annual average maximum temperature, since 1970.



Graph 2: Annual average maximum temperature and evaporation from 2010 to 2021 (station 68018)

Rainfall data recorded at the IMC DA3A and DA3B gauges are presented in Graph 3 for comparison between Areas 3A and 3B. Graph 3 shows that the annual rainfall data at each gauge tend to cluster together year on year, indicating generally similar conditions across the locality. Variation between the data recorded between gauges DA3A and DA3B indicate year on year variability between the areas, with no consistent pattern of one area recorded more rainfall than the other. The level of variation in rainfall between the sites is also variable, ranging from 1.5 mm to 96 mm in magnitude. In 2021, a total of 1110 mm was recorded at gauge DA3A, however this dataset does not include the months of November and December and is not directly comparable to DA3B, although even this level of recorded rainfall exceeds the median level of annual rainfall recorded between 2002 and 2021 at the Cordeaux gauge. A total of 1404 mm was recorded at gauge DA3B, also exceeding the median level of annual rainfall, indicating prevailing wet conditions in DA3A and DA3B during 2021, as in 2020.

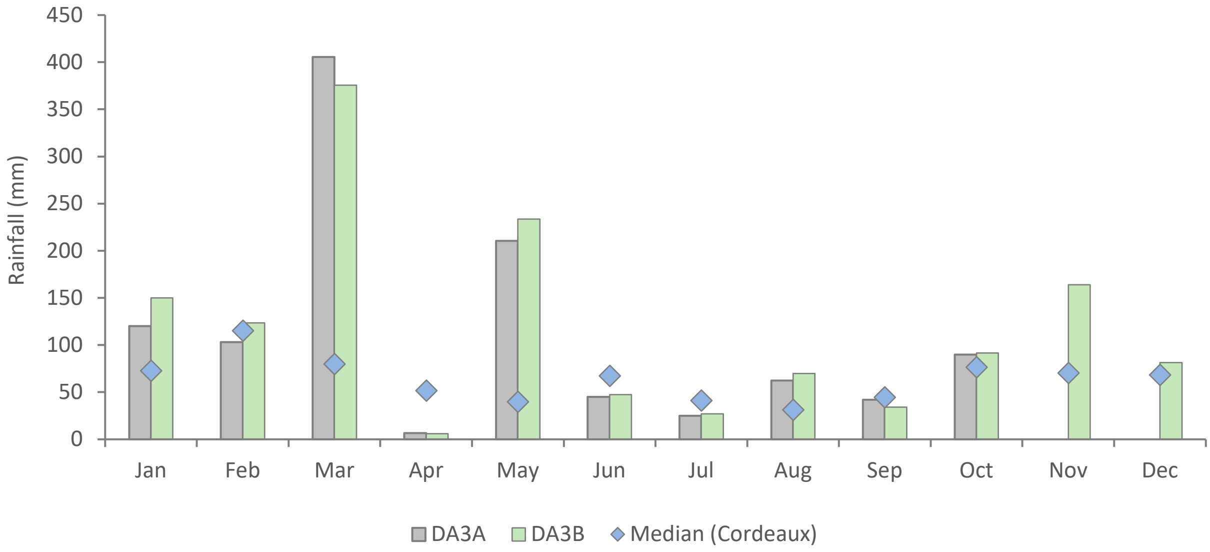


Note: Rainfall data for DA3A does not include the months of November and December in 2021.

Graph 3: Annual rainfall data from 2013 to 2021

Total monthly rainfall recorded at DA3A and DA3B in 2021 is shown in Graph 4. Typically, the rainfall recorded in Dendrobium Areas 3A and 3B are similar, with some variation month to month. Most notably the majority of rainfall in 2021 fell during autumn, specifically March and May, with rainfall in both Dendrobium Areas 3A and 3B exceeding the median rainfall values for these months. Other months throughout the year generally recorded rainfall comparable to or above the median rainfall values, with the low rainfall recorded in April the exception. These results demonstrate prevailing wet conditions throughout the year, including the autumn, winter and spring survey seasons, with most rainfall falling in autumn.

The swamp floristic monitoring data and frog monitoring data should be considered in the context of these results.



Graph 4: Total monthly rainfall data recorded during 2021

Note: Rainfall data for DA3A does not include the months of November and December in 2021.

3.2 Hydrological review

Impacts to upland swamp communities may occur through a reduction in water level or an increased rate of drainage following subsidence. IMC have piezometers placed within the Upland Swamps as part of groundwater monitoring to monitor these pathways of potential impact. Niche has been provided with information and expert assessment from IMCs consultants, which has undertaken a geographical review of mining effects on upland swamps associated with the mine (Watershed HydroGeo 2019). This expert assessment has informed the interpretation of the ecological upland swamp data detailed in this report. The major findings of this report relevant to the ecological monitoring program are summarised below:

- The majority of impacts recorded occurred where swamps were mined under by a longwall.
- Most of the effects occurred when a longwall passed directly beneath or within 60 metres of the site, with the maximum recorded distance at which a piezometer within a swamp recorded a response was 55 metres.
- Two piezometers that are lithologically similar detected effects at 95 and 125 metres from a longwall, however these were not located within swamps, and the majority of piezometers within that distance range did not record any effects.
- While the majority of upland swamp piezometers within 60 metres of a longwall showed a response to mining, conversely the effects of mining have not been detected in upland swamp piezometers that are greater than 60 metres from a longwall.

Potential impacts to upland swamp communities identified or anticipated on the basis of hydrological information provided are summarised below for Dendrobium Area 3A and Dendrobium Area 3B in Table 11. Where relevant and useful, individual datasets from piezometers are examined to inform the assessment of ecological data. In 2021 all impact swamps, with the exception of 15A(2), have been mined beneath. Swamp 15A(2) is not within the 60 metres of a longwall and piezometers within this swamp were not identified as impacted in (Watershed HydroGeo 2019). At least one piezometer at each of these swamps that have been mined beneath have been identified as being affected by mining (Watershed HydroGeo 2019), with the exception of swamps 14 and 23 which were directly mined under subsequent to the preparation of the review. On the basis of the findings of the review, swamps 14 and 23 may also be subject to some degree of hydrological effect, being within 60 metres of a longwall and directly mined under.

Table 11: Impact treatment swamp hydrological impacts

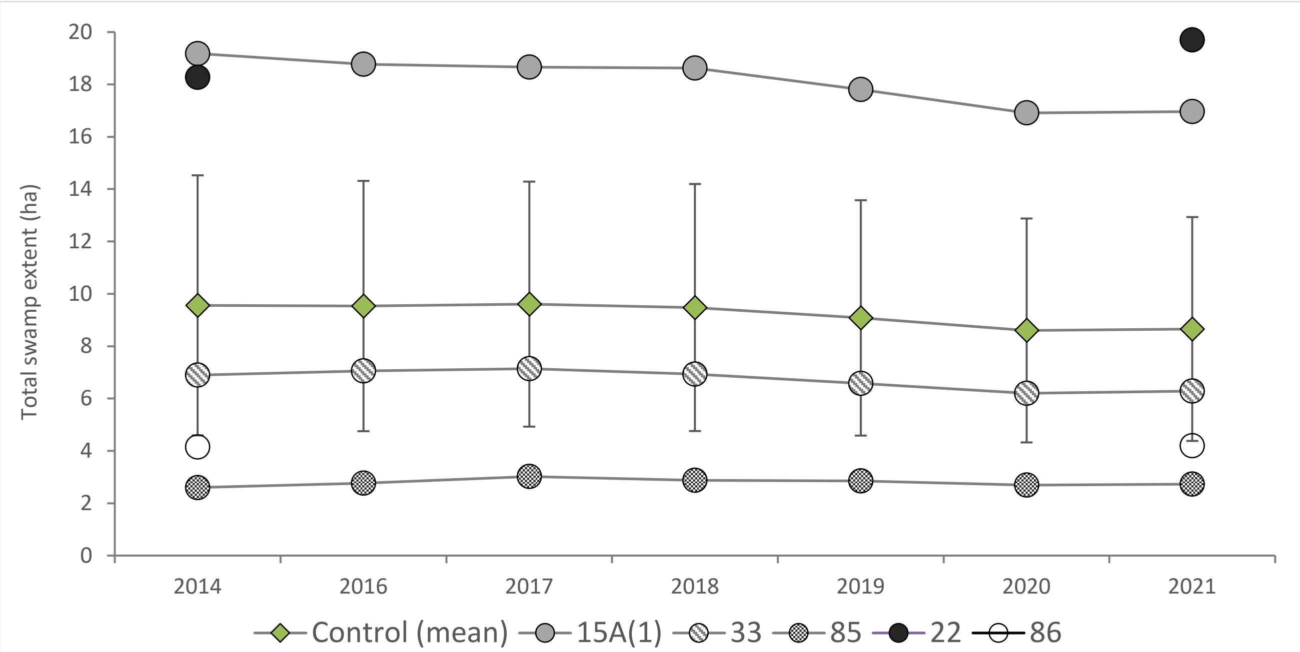
Swamp	Distance from longwalls (2021)	Impact shown in any swamp piezometer (Watershed HydroGeo 2019)	Mining within RMZ	Mined beneath
1A	Directly mined under	Yes	February 2013	April 2013
1B	Directly mined under	Yes	February 2013	February 2013
5	Directly mined under	Yes	May 2013	July 2013
11	Directly mined under	Yes	May 2016	March 2017
13	Directly mined under	Yes	July 2017	November 2018
14	Directly mined under	Not available	December 2018	November 2019
15A(2)	90 m from longwall	No	October 2012	-
15B	Directly mined under	Yes	September 2010	August 2012
23	Directly mined under	Not available	June 2018	June 2019

3.3 LiDAR mapping of upland swamp extents

As detailed in the methods (Section 2.1.2), in 2021 the CHM used to determine the total swamp extent in 2020 was applied to all previous years LiDAR (where available), which enables more direct comparisons of data and detection of trends in total swamp extent. These raw results are presented in Annex 2. Trends across the upland swamps monitored during this period are graphically presented and described in the following sections, an assessment against the relevant TARPs is provided in Section 3.3.3.

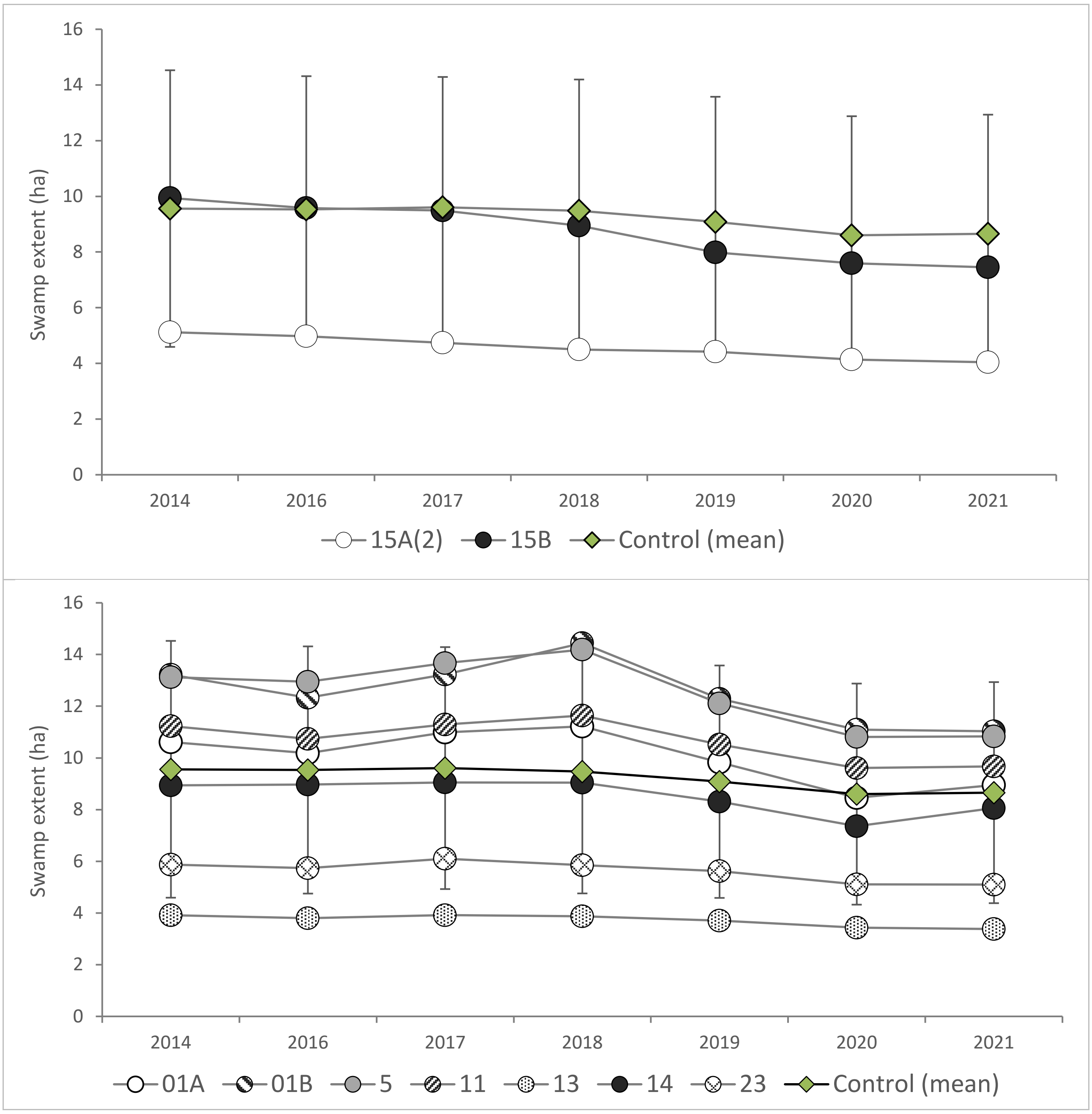
3.3.1 Total swamp extent

Graph 5 displays the change in swamp extent across each of the individual control swamps between 2014 and 2021. Also shown is the average swamp extent across the control swamps, and the standard error of the mean. Data for swamps 22 and 86 is only available for 2014 and 2021, as such these sites are excluded from the control group mean to avoid skewing the data between years when there is data and years when there is no data for these sites. The extent of each control swamp is shown to fluctuate to some extent year on year, although the level of change is typically less than 0.5 hectares over each year, with the swamps extents at each site being overall relatively stable between 2014 and 2021. The mean of the control sites plotted below reflects the broad trends of the individual control swamps, with a small decline evident between 2017 and 2020, following reduced rainfall in this period, before stabilising or increasing slightly in 2021. Swamp 15A(1) differs slightly in that where swamps 33 and 85 increase slightly between 2014 and 2017, Swamp 15A(1) decreases slightly in this period. All control swamps with complete data series showed a minor increase in extent between 2020 and 2021, being greatest at Swamp 33 (0.08 ha).



Graph 5: Total swamp extent at Control swamps from 2014 to 2020

Graph 6 displays the change in swamp extent across each of the individual impact swamps between 2014 and 2021 in Dendrobium Areas 3A and 3B. Also shown is the average swamp extent across the control swamps, and the Standard Error of the mean, as described above. Two broad patterns of change are evident across the impact swamps. The majority of the impact swamps follow a similar trend to that of the control sites described above, although the degree of fluctuation and change year on year is typically greater than that observed at the control group so that a similar but more exaggerated pattern of change is observed at the impact sites. In addition, many of the impact sites record an increasing extent between 2016 and 2018, with the control group peaking in 2017. Swamps 15A(2) and 15B in Area 3A show a different trend, with a consistent decline over the 2014 to 2021 period, strongest at Swamp 15B. Overall, the larger impact swamps appear to experience a greater degree of year-on-year variation than the smaller swamps. Half of the impact swamps (01B, 13, 15A(2), 15B and 23) did not follow the trend of minor increases in swamp extents between 2020 and 2021, instead recording relatively small declines, with the greatest being recorded at Swamp 15B (0.15 ha). It is not possible to confidently disentangle whether these differences in patterns of change between impact and control sites are due to underlying landscape scale factors or a result of mining due to the somewhat limited dataset, in particular the lack of pre-impact data for many of these swamps.



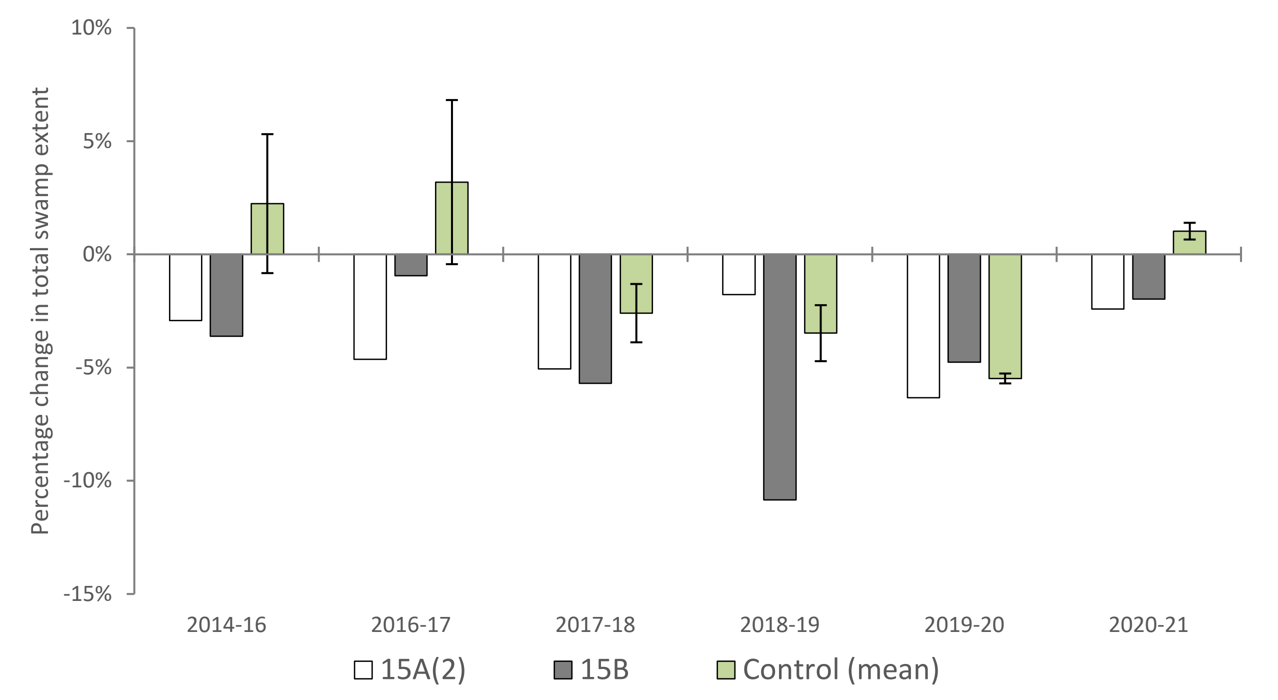
Graph 6: Total swamp extent at impact swamps from 2014 to 2020, impact swamps in Dendrobium Area 3A are shown above and Dendrobium Area 3B below

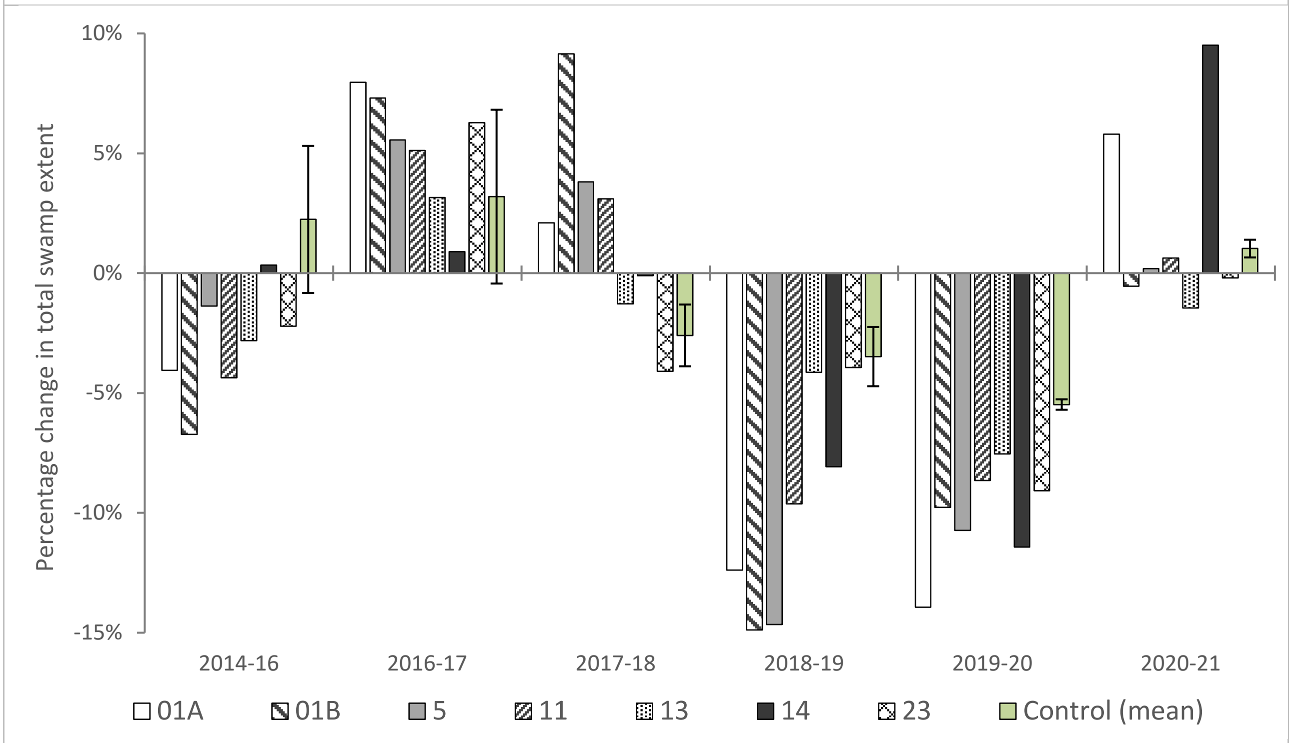
Comparisons of total swamp extent change over consecutive years are presented in Graph 7 below for Dendrobium Areas 3A and 3B. In Dendrobium Area 3A, swamps 15A(2) and 15B have recorded declines in swamp extent for each consecutive period. Consecutive years where these are greater than that experienced at the control group and the standard error of the group are:

- Swamp 15A(2): 2014-2016, 2016-2017, 2017-2018, and then 2019-2020, 2020-2021.
- Swamp 15B: 2014-2016, 2016-2017, 2017-2018, 2018-2019.

In Dendrobium Area 3B three impact swamps have experienced declines in extent beyond that of the control group and the standard error of the group over Consecutive years. These include:

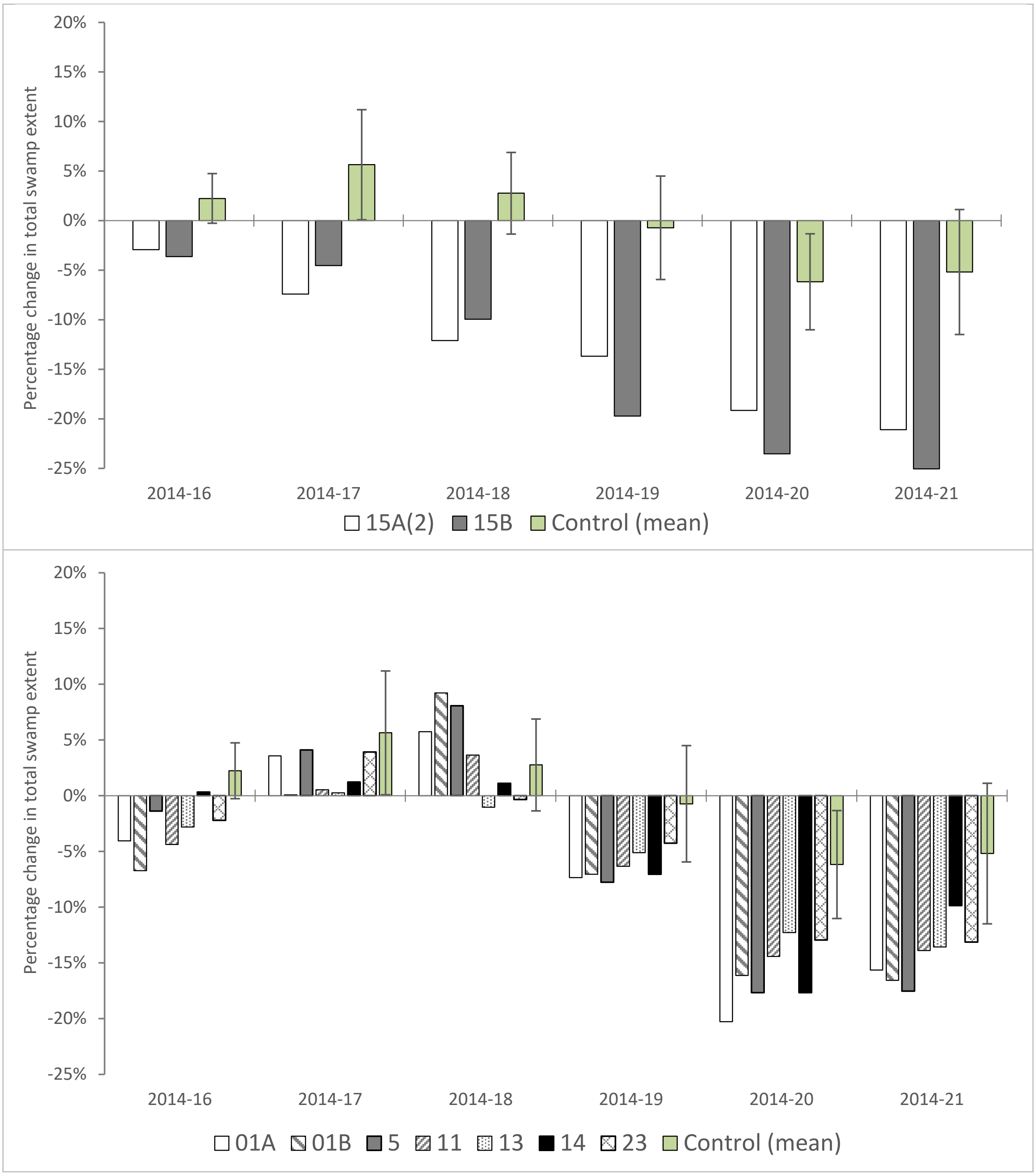
- Swamp 13 and 23: 2019-2020, 2020-2021.
- Swamp 14: 2018-2019, 2019-2020.
- Swamp 01B: 2018-2019, 2019-2020, 2020-2021.





Graph 7: Percentage change in total swamp extent at impact swamps, comparing consecutive years, impact swamps in Dendrobium Area 3A are shown above and Dendrobium Area 3B below.

Graph 8 below shows the percentage change at impact swamps in Dendrobium Areas 3A and 3B compared to the baseline data collection year of 2014. In Dendrobium Area 3A, impact swamps 15A(2) and 15B have shown a consistent decline over the monitoring period, with Swamp 15B experiencing the greatest decline in extent. While there has been an overall decline in the average swamp extent of the control group between 2014 and 2021, this is smaller in scale to that of the impact swamps and is not represented as a consistent year-on-year decline. In Dendrobium Area 3B, the impact swamps have shown an overall tendency to follow the pattern of change at the control group. Although as described in previous sections, many of the impact swamps have tended to have experienced more exaggerated gains or losses in swamp extent than the control group when compared to baseline. The major exception to this is the 2014 to 2016 period where all impact swamps recorded reduced extents, in contrast to the control group.



Graph 8: Percentage change in total swamp extent at impact swamps, comparing each year to baseline (2014), impact swamps in Dendrobium Area 3A are shown above and Dendrobium Area 3B below.

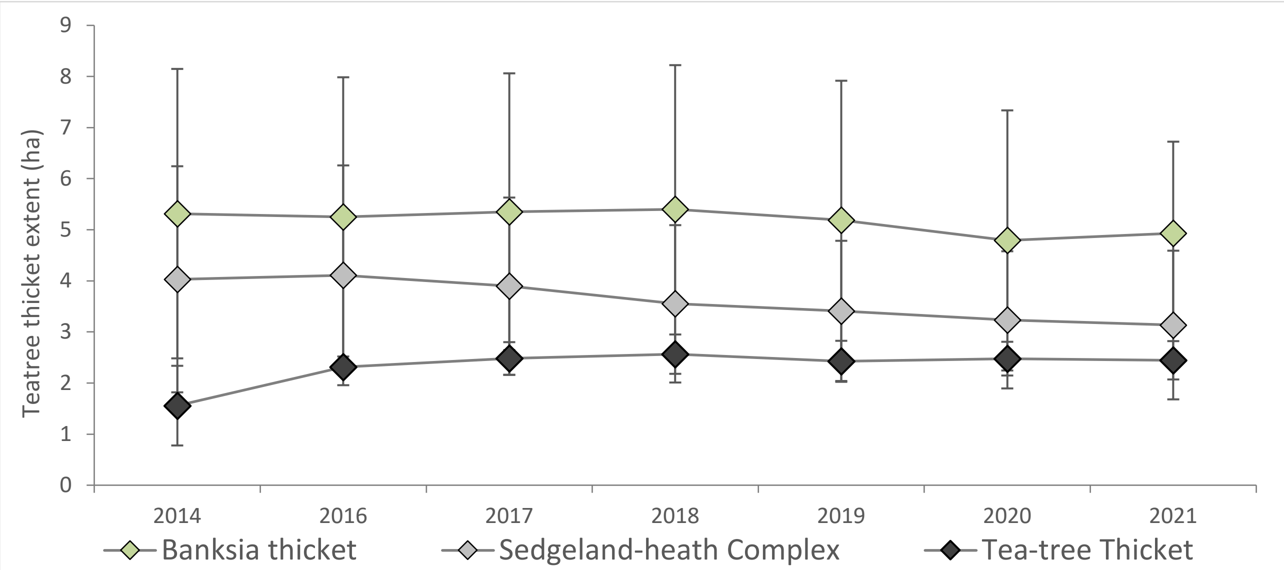
3.3.2 Ecosystem functionality

Upland Swamps within the Study Area are primarily comprised of three vegetation sub-communities:

- Upland Swamps: Banksia Thicket (MU42)
- Upland Swamp: Tea-tree Thicket (MU43)
- Upland Swamp: Sedgeland-heath Complex (MU44) (Cyperoid Heath, Restioid Heath, Sedgeland).

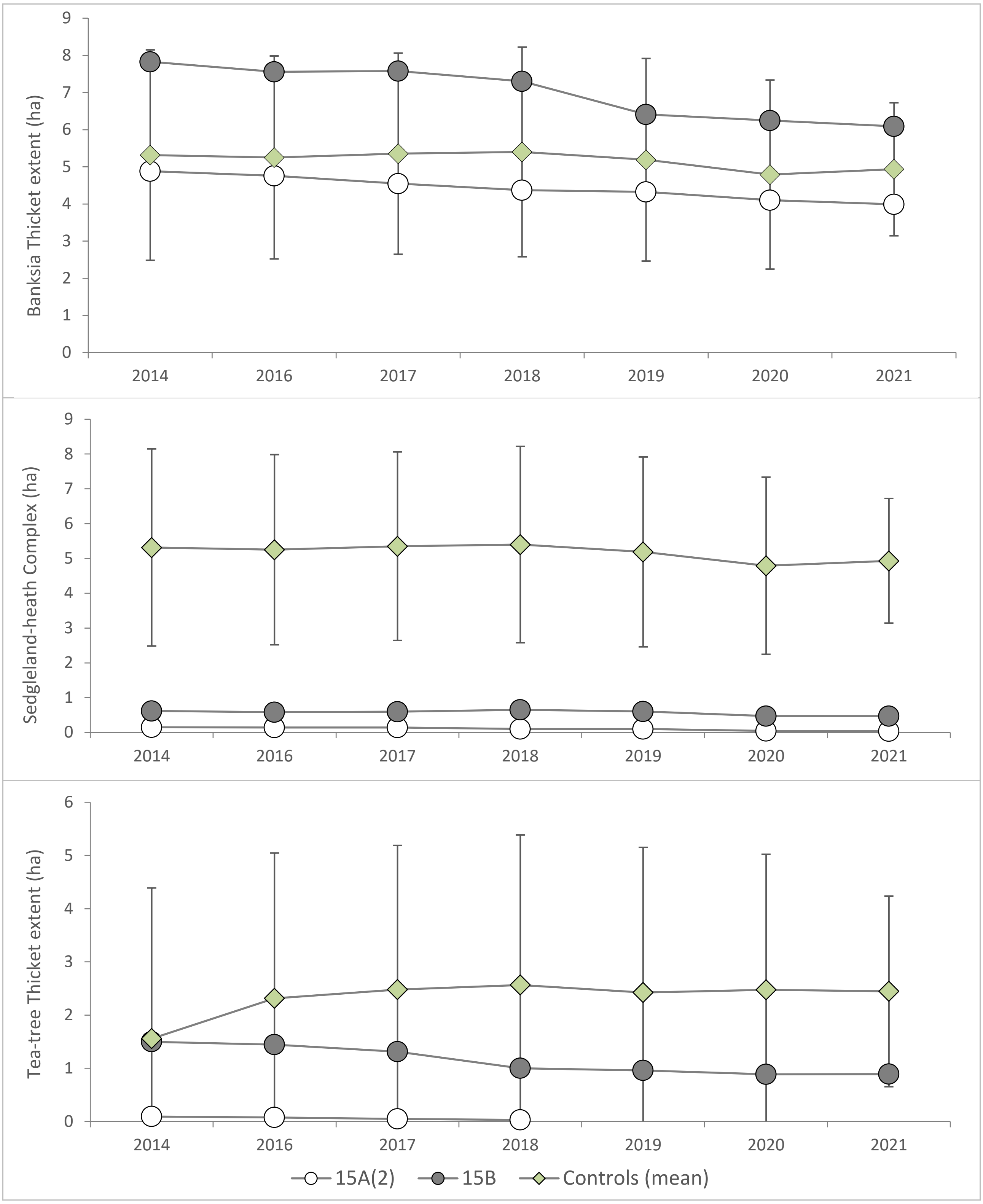
In line with the TARPs, ecosystem functionality of Upland Swamps is to be measured via the sizes of the groundwater dependent communities contributing to the Upland Swamps. Specifically, any changes in the proportion of Banksia Thicket, Tea-tree Thicket and Sedgeland-heath Complex within the monitored Upland Swamps.

The average subcommunity extent of the control group swamps are presented in Graph 9. Banksia Thicket has the largest extent across the control swamps and this community has seen a small overall decline in average extent between 2014 and 2021. Some year-on-year fluctuations are evident, similar to that seen in the overall swamp extent change described in previous sections. This trend is seen at all control sites with the exception of Swamp 85 which recorded an increase in 2021 and an overall increase across the monitoring period. Both the Sedgeland-heath Complex and Tea-Tree Thicket sub-communities show differing patterns of change to each other and also to the Banksia Thicket subcommunity. There has been a consistent trending decline in Sedgeland-heath Complex during this period, most evident in the 2017 and 2018 years. This is seen across all control sites except Swamp 86 which recorded a minor overall increase, although this site is only represented by two data points (2014 and 2021). In contrast, there has been a general trend of increasing extent within the Tea-Tree Thicket subcommunity. Swamps 33 and 86 are the exceptions to this pattern recording a minor overall increase across the monitoring period. It should be noted that Swamps 85 and 86 were burnt during the 2013 bushfire. Post bushfire recovery is likely to have had an impact on the subcommunity extents for these swamps.



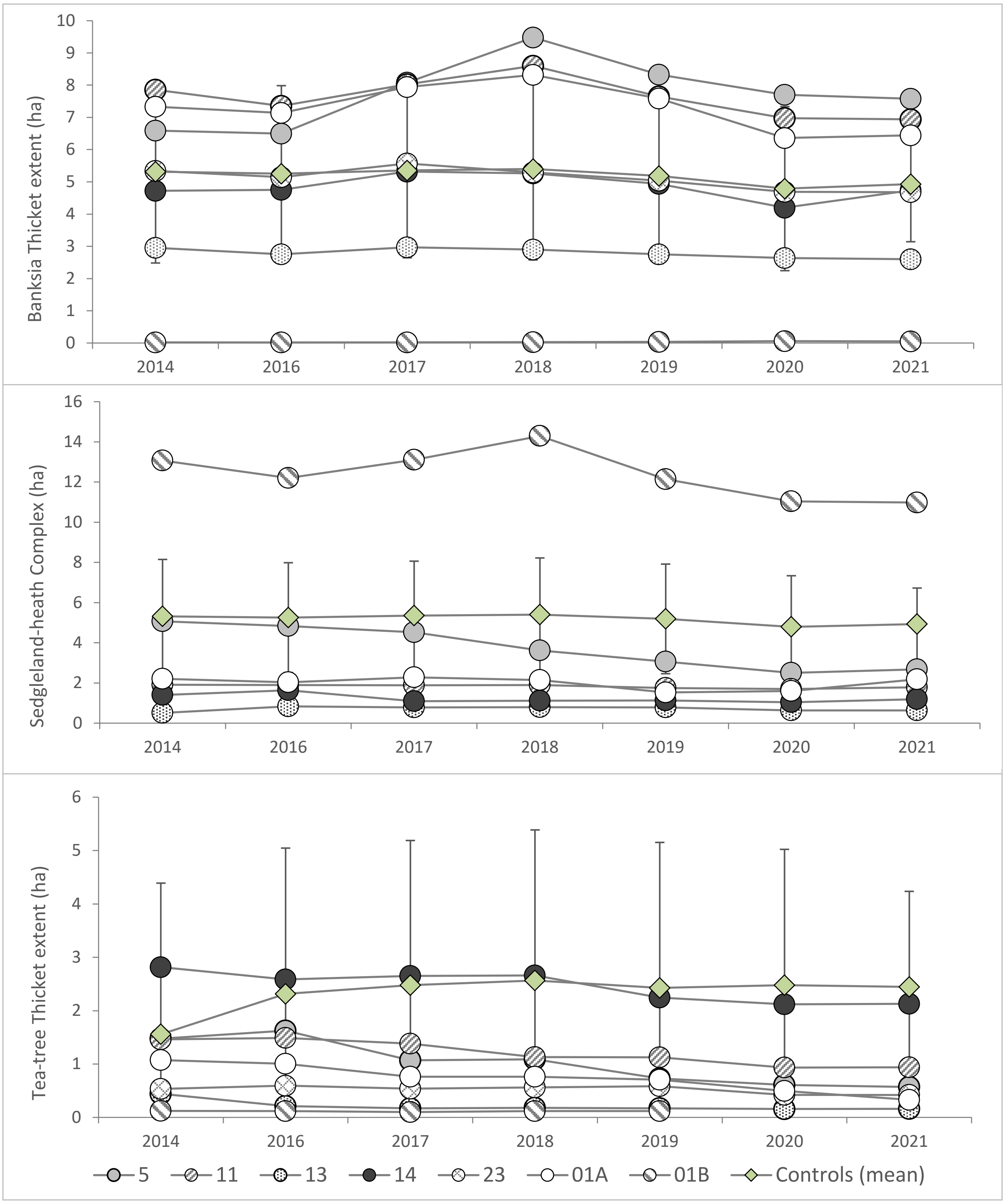
Graph 9: Average subcommunity extents from the control sites between 2014 and 2021

Dendrobium Area 3A swamps 15A(2) and 15B have recorded trending declines across each of the subcommunities between 2014 and 2021, with these declines being strongest at Swamp 15B (Graph 10). Tea-Tree Thicket is observed to decline in extent to the point that it is no longer represented at Swamp 15A(2) in 2018. It is important to note that this does not necessarily mean a wholescale change in the subcommunity composition has occurred. It likely indicates that the vegetation in these areas is now dominated by taller growing species or individuals that have reached a height that better correspond with the Banksia Thicket definitions in the canopy height model applied, which may indicate a transition in vegetation community.



Graph 10: Subcommunity change in Dendrobium Area 3A impact swamps between 2014 and 2021, Banksia Thicket top, Sedgeland-heath Complex middle and Tea-Tree Thicket bottom

In Dendrobium Area 3B, the Banksia thicket subcommunity has shown a similar pattern of change to that of the control group and to that of the overall swamp extents described in the previous section, again with the year-on-year fluctuations being generally more exaggerated than the controls especially at the larger swamps (Graph 11). The findings are similar for the Sedgeland-heath Complex subcommunity, although impact Swamp 5 shows a trending decline, while swamps 13 and 14 remain relatively stable. For Tea-Tree Thicket, swamps 11 and 14 show a trending decline whereas the other swamps show similar, if more exaggerated, patterns of change to that of the control group (Graph 11).

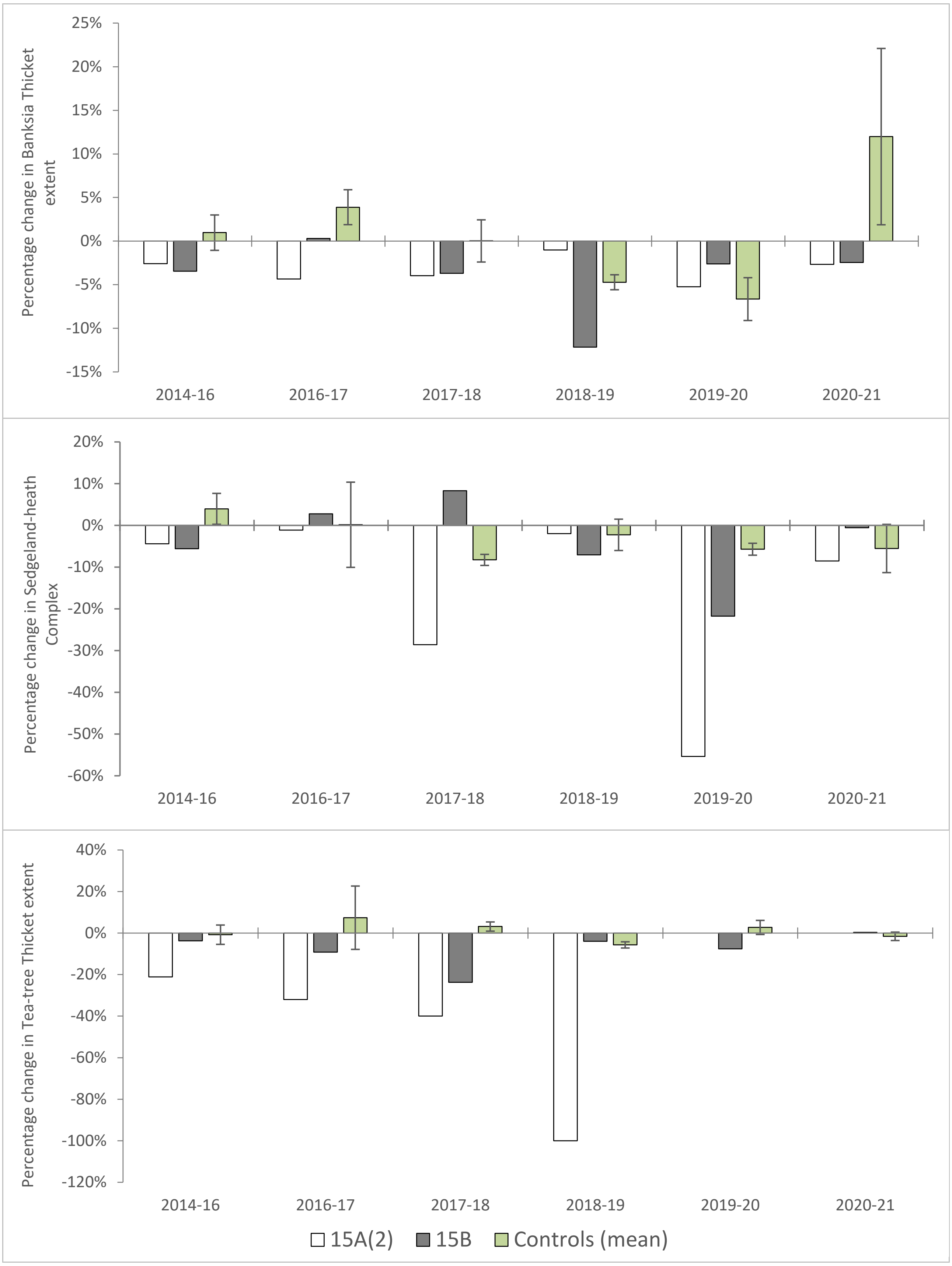


Graph 11: Subcommunity change in the Dendrobium Area 3B impact swamps between 2014 and 2021, Banksia Thicket top, Sedgeland-heath Complex middle and Tea-Tree Thicket bottom

Graph 12 displays comparisons of the change in subcommunity extents over consecutive years in Dendrobium Area 3A. Declines greater than that experienced at the control group and standard error of the group in Dendrobium Area 3A over consecutive periods are identified in Table 12.

Table 12: Declines in extent beyond that of the control group and the standard error of the group over consecutive periods in Dendrobium Area 3A

Swamp	Banksia Thicket	Sedgeland-heath Complex	Tea-Tree Thicket
Swamp 15A(2)	• 2014-2016, 2016-2017, 2017-2018.	-	• 2014-2016, 2016-2017, 2017-2018, 2018-2019.
Swamp 15B	• 2017-2018, 2018-2019.	• 2018-2019, 2019-2020	• 2016-2017, 2017-2018

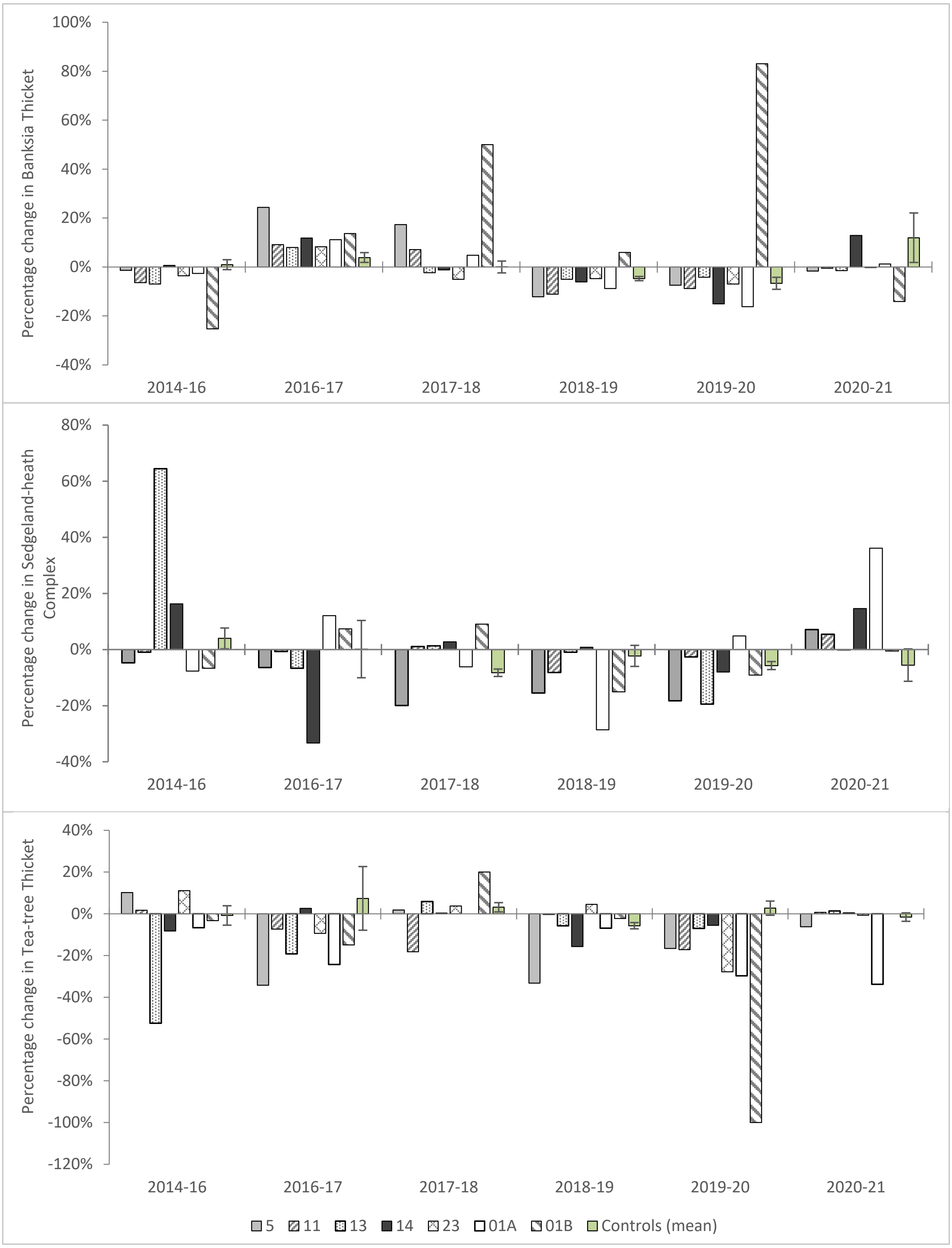


Graph 12: Subcommunity change in the 3A impact swamps between 2014 and 2021 comparing consecutive years with Banksia Thicket top, Sedgeland-heath Complex middle and Tea-Tree Thicket bottom

Graph 13 displays comparisons of the change in subcommunity extents over consecutive years in Dendrobium Area 3B, in order to directly address the project TARPs. Declines greater than that experienced at the control group in Dendrobium Area 3B are identified in Table 13.

Table 13: Declines in extent beyond that of the control group and the standard error of the group over consecutive periods in Dendrobium Area 3B

Swamp	Banksia Thicket	Sedgeland-heath Complex	Tea-Tree Thicket
5	-	• 2017-2018, 2018-2019, 2019-2020	• 2018-2019, 2019-2020, 2020-2021.
11	-	-	-
13	-	-	• 2014-2016, 2016-2017.
14	-	-	• 2018-2019, 2019-2020.
23	-	-	-
01A	• 2018-2019, 2019-2020.	-	• 2014-2016, 2016-2017. • 2019-2020, 2020-2021.
01B	-	• 2018-2019, 2019-2020.	• 2019-2020, 2020-2021 (no longer recorded).



Graph 13: Subcommunity change in the Dendrobium Area 3B impact swamps between 2014 and 2021 comparing consecutive years with Banksia Thicket top, Sedgeland-heath Complex middle and Tea-Tree Thicket bottom

3.3.3 Assessment against performance measures summary

The TARPs for Dendrobium Area 3A do not include an assessment of LiDAR, as such Dendrobium Area 3A swamps are not discussed in this section.

This section addresses TARPs within Dendrobium Area 3B, using the updated CHM analysis for all available years of LiDAR data run in 2021, as such there may be differences in TARP levels triggered between this report and pre-2020 iterations of the program. This approach ensures ongoing consistency and comparability across program years.

An assessment of the swamp extent TARPs for swamps monitored in Dendrobium Area 3B are included in Table 14. No swamp extent TARP levels have been triggered at swamps 11, 1A or 5 over the course of the monitoring program. In 2021 a level 1 TARP has been triggered at swamp 13 and 23 (shown in orange). A Level 2 TARP (shown in red) has been triggered at Swamp 1B in 2021, following a level 1 TARP being triggered at Swamp 1B in 2020. A level 1 TARP was triggered at Swamp 14 in 2020, however this ceased in 2021 following an increase in extent at this swamp in 2020-2021.

Table 14: Swamp extent TARP summary

Swamp name	2014-16	2016-17	2017-18	2018-19	2019-20	2020-21
Swamp 11						
Swamp 13						2019-2020, 2020-2021
Swamp 14					2018-2019, 2019-2020	
Swamp 1A						
Swamp 1B					2018-2019, 2019-2020	2018-2019, 2019-2020, 2020-2021
Swamp 5						
Swamp23						2019-2020, 2020-2021

Note: Level 1 = orange, Level 2 = red. Consecutive periods of decline beyond that experienced at the control group and standard error of the group are provided.

An assessment of the ecosystem functionality TARPs for swamps monitored in Dendrobium Area 3B are included in Table 15. Swamps 11 and 23 have not triggered any TARP levels throughout the Program. In 2021 swamp 1A and 1B recorded a level 1 TARP due to reductions in Tea-tree Thicket. Level 1 TARPs have been recorded at these swamps previously in 2020, Banksia Thicket at Swamp 1A and Sedgeland-heath Complex at Swamp 1B, both of which ceased in 2021. A reduction in Tea-tree Thicket has also occurred in 2021 at Swamp 5, triggering a level 2 TARP, following a level 1 TARP being triggered in 2020. Level 1 and 2 TARPs were first triggered at Swamp 5 in 2019 and 2020 for Sedgeland-heath Complex, before this subcommunity recorded an increase in 2021. In 2017, swamps 13 and 1A triggered level 1 TARPs for Tea-tree Thicket, however these both ceased in the following year.

Table 15: Swamp sub-community TARP summary

Swamp name	2014-16	2016-17	2017-18	2018-19	2019-20	2020-21
Swamp 11						
Swamp 13		TT: 2014-16, 2016-17				
Swamp 14					TT: 2018-19, 2019-20	
Swamp 1A		TT: 2014-16, 2016-17			BT: 2018-19, 2019-20	TT: 2019-2020, 2020-2021
Swamp 1B					SH: 2018-19, 2019-20	TT: 2019-2020, 2021-2021 (no longer recorded)
Swamp 5				SH: 2017-18, 2018-19	SH: 2017-18, 18-19, 2019-20 TT: 2018-19, 2019-20	TT: 2018-19, 2019-20, 2020-21.
Swamp23						

Note: Level 1 = orange, Level 2 = red. Consecutive periods of decline beyond that experienced at the control group and standard error of the group are provided.

3.4 Photo point monitoring

There are four photos at each monitoring site, taken north, south, east and west, at three monitoring sites within each Upland Swamp. Photo point monitoring over time can be a visual indicator of change. The current photo points are provided in Annex 6 and may be compared to previous monitoring reports.

Photo point monitoring has been utilised throughout the report to further describe trends observed in other data analysis (see Section 3.5). When Control Upland Swamps are compared to Impact Upland Swamps over the same time period (five years), there is a noticeable difference in the growth of many of the shrubs from small and barely in the photograph to now dominant in the image. For example at Swamp 33 there are small *Banksia robur* individuals during 2015 monitoring (Plate 1) and in the 2021 monitoring they have grown higher than the standard photo height and are much more obvious in the image (Plate 2).

In Swamp 86 (Control Swamp) the shrub layer present can be observed to have grown in size and appears to have encroached inwards towards the swamp, with sedgeland species appearing to be giving way to more shrub species in 2021. These comparisons over time suggest a change in composition for this swamp at least in the margins, with more *Banksia ericifolia* and fewer sedges (Plate 3 and Plate 4) to show potential natural variation. As noted earlier, Swamp 86 (and Swamp 85) is experiencing post bushfire recovery, having been burn in 2013, which is likely to be impacting the species composition for this swamp.

At Control Swamp 15A(1) the main factor to notice (potentially highlighting variation within the swamps), is the bright green understory staying healthy in both 2015 (Plate 5) and 2021 (Plate 6).

At impact Swamp 15B, regeneration of the *Gleichenia dicarpa / microphylla* sp. complex (Pouched coral fern) can be observed between spring 2020 and 2021 following two years of drought breaking above average rainfall (Plate 7 and Plate 8).

Plate 1: Swamp 33 F3 North Spring 2015

Plate 2: Swamp 33 F3 North Spring 2021

Plate 3: Swamp 86 F3 South Spring 2015

Plate 4: Swamp 86 F3 South Spring 2021

Plate 5: Swamp 15A(1) F1 South Autumn 2015

Plate 6: Swamp 15A(1) F1 South Autumn 2021

Plate 7: Swamp 15B -V1 Spring 2020

Plate 8: Swamp 15B -V1 Spring 2021

3.5 Upland Swamps

The analysis of TSR and composition data of the Impact Upland Swamps is detailed in this section, with reference to TARPs. Initially an overview of Dendrobium Area 3 data is provided, followed by assessment against TARPs for Dendrobium Areas 3A and 3B and an analysis of TSR and composition trends at each swamp.

3.5.1 Dendrobium Area 3A

TARP trigger levels and the relevant recommended corrective actions are discussed within this section for Dendrobium Area 3A monitoring sites (Swamp 15A(2) and Swamp 15B). A summary of the results against TARP triggers (identified in Table 4) for Dendrobium Area 3A is presented in Table 16. If a TARP is triggered it may not necessarily require corrective management actions (CMAs). This trigger system allows detection of change and indicates where to focus further investigation to determine what has triggered the TARP. The higher the TARP trigger is, the more important the level or duration of change is and greater the implications to the health of the swamp. Level 1 TARPS in Dendrobium Area 3A cannot be retrospectively reported on as these apply to visual trends observed on the ground with regards to Upland Swamp vegetation and not statistically significant differences in the data collected.

In 2021 both swamps 15A(2) and 15B have recorded TARP triggers. The only change from the 2020 iteration of the monitoring program (Niche 2021), is that a Level 2 TSR TARP at Swamp 15A(2) is no longer triggered.

Table 16: Summary of TARP triggers for Upland Swamps in Dendrobium Area 3A in 2021

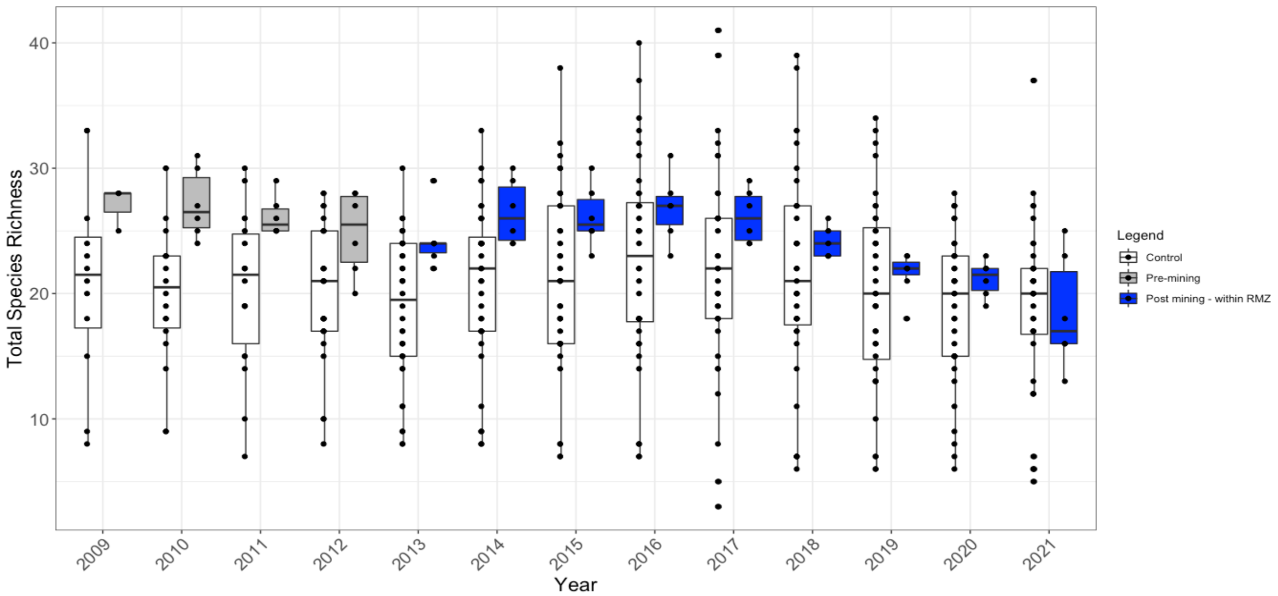
Swamp	Results 2021	Details
Swamp 15A(2)	• TSR: None. • Composition: **Level 2 TARP** triggered.	Section 3.5.1.1
Swamp 15B	• TSR: **Level 2 TARP** triggered • Composition: **Level 2 TARP** triggered	Section 3.5.1.2

3.5.1.1 Swamp 15A(2)

Monitoring at Swamp 15A(2) began in 2009 and the Upland Swamp was impacted as Longwall 8 entered within the RMZ in 2013 (Table 1). A total of 66 unique species have been detected in Swamp 15A(2) since monitoring began, of which 8% were detected only once.

3.5.1.1.1 TSR

Over the course of the monitoring period, TSR at control sites was more variable, and generally lower, than TSR at the impact swamp. An increase in TSR, proportionally similar to that experienced at the controls occurred post-impact (2014-2016). However since 2017, TSR at swamp S15A(2) appears to have declined to lower levels than before impact, although a degree of decline is observed at the control sites in the 2017 to 2019 period also. In 2021, median TSR at Swamp S15A(2) is lower than that of the control sites for the first time since monitoring began (Graph 14).



The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentile), and the whiskers of the boxplot cover 1.5 times the IQR of the data. Boxes shaded white are Control Upland Swamps, boxes shaded grey are Impact Upland Swamp 15A(2) that are Pre-mining, boxes shaded blue are Post-mining - within RMZ. Solid black points are the observations (TAE 2021a). See Table 1 for mining progress, number and status of Upland Swamps at the year surveyed.

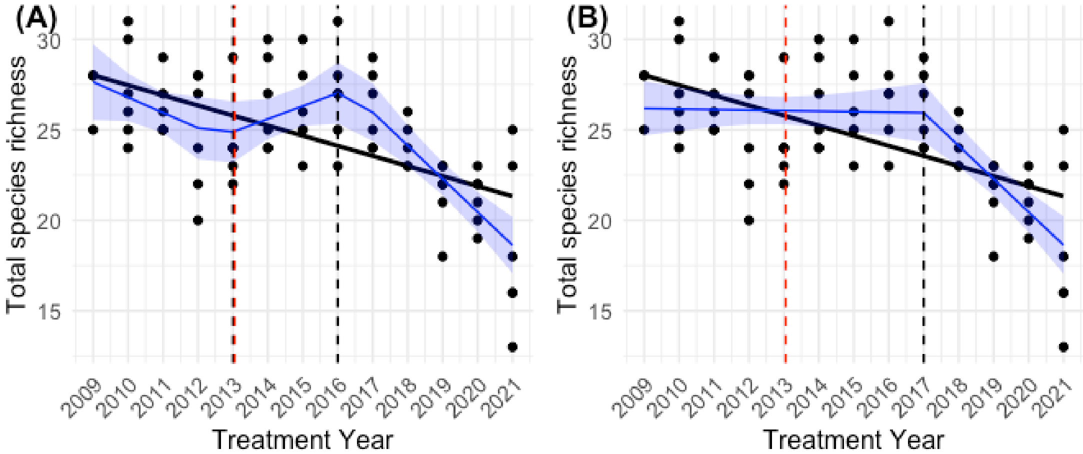
Graph 14: Boxplot of the TSR for each transect at Impact Upland Swamp 15A(2), contrasted against Control Upland Swamps.

When the mean difference in TSR between Swamp S15A(2) and the control swamps are considered, TSR has declined to become more similar to the control swamps over time. A statistically significant difference between TSR at Swamp S15A(2) and the control swamps first occurred in 2016-2017, again in 2018-2019 and 2019-2020 (Table 17). No statistically significant difference between TSR at Swamp S15A(2) and the control swamps was observed in the 2020-2021 period.

Table 17: Comparison of mean TSR between swamp S15A(2) and control swamps over 2-year periods

Comparison	Test statistic	D.f.	P-value
2013–2014	0.54	3.04	0.627
2014–2015	0.82	3.84	0.46
2015–2016	1.66	3.31	0.187
2016–2017	3.28	3.37	**0.039**
2017–2018	2.72	1.76	0.129
2018–2019	5.45	2.71	**0.016**
2019–2020	6.52	3.58	**0.004**
2020–2021	3.31	1.22	0.15

Additional breakpoint analysis found that the best fitting model based on AIC model selection had two breakpoints, although, model selection uncertainty was high, and the second-best fitting model is also shown. The first breakpoint (Graph 15, A) identified corresponds to when the impact occurred, suggesting that the TSR initially increased at the swamp in the three years post-mining, and then decreased after 2016 (Graph 15). However only the decline in TSR following 2017 (Graph 15) was found to be statistically significant. Meaning that while trends in TSR may have occurred coincident with the year of mining, the statistically significant breakpoint in the dataset does not align with this date and has occurred some years post.



Best (A) and second-best (B) breakpoint analysis as determined by AIC model section (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Graph 15: Breakpoint analysis showing best fitting models at Impact Upland Swamp 15A(2).

3.5.1.1.2 Species composition

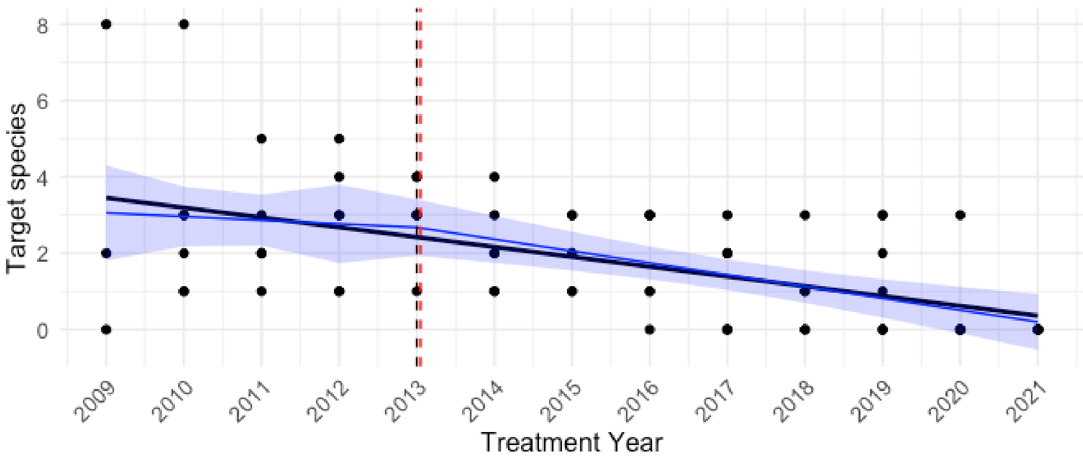
Post-impact species composition data at Swamp S15A(2) was first identified as being statistically different to pre-impact data in 2019-2020 (Table 18). This again occurred in the latest (2020-2021) monitoring period (p-value: 0.013). The percentage of deviance relates to the five most influential species (species that have experienced the greatest level of change). In 2021 these species are *Baeckea imbricata, Boronia parviflora, Bauera microphylla rubioides* sp. complex*, Leptospermum polygalifolium trinervium* complex and *Baloskion gracile*. All of these species were found to be more common prior to impact. These species are known to grow in heath or damp areas. This trend suggests a loss of species that prefer moist soils. The visual comparison in Plate 9 and Plate 10 supports this, demonstrating the decline in health of *Hakea teretifolia* condition over time since impact at Swamp 15(A)2, a moisture tolerant species.

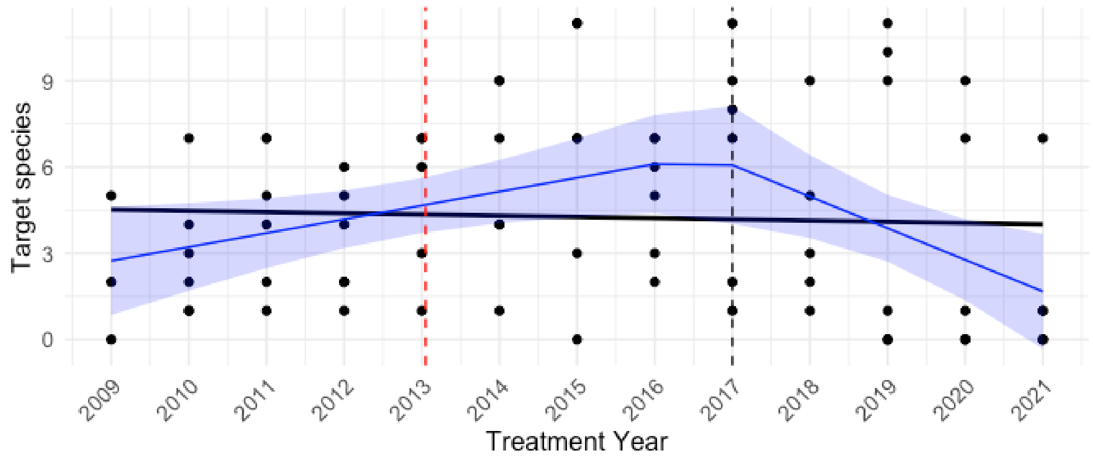
Table 18: Species composition at swamp S15A(2) over 2-year periods

Comparison	P-value (pre-post mining)	Percentage of deviance
2013–2014	0.738	0.497
2014–2015	0.652	0.545
2015–2016	0.537	0.52
2016–2017	0.433	0.417
2017–2018	0.375	0.452
2018–2019	0.131	0.383
2019–2020	**0.022**	0.392
2020–2021	**0.013**	0.395

Plate 9: Swamp 15A(2) F2 North Autumn 2015 **Plate 10: Swamp 15A(2) F2 North Autumn 2021**

Additional breakpoint analysis of two key species identified as having strong trends over time at this swamp have been completed to examine whether the statistically significant breakpoints in these trends temporally align with mining activities. *Baeckea imbricata* was identified as a species that was more common prior to impact, compared to after impact, slowly trending to zero detection events by 2021. There has been a statistically significant decline in the number of detection events of this species since monitoring began, however the linear model was best fit to the data, indicating a trending decline pre-dating any mining activities (Graph 16). Although the second-best fitting model does show a breakpoint coincident with mining in 2013. *Bauera microphylla/ rubioides* sp complex was also identified as a species that was more common prior to impact, compared to after impact. The best fitting model suggests there is one breakpoint, whereby up to 2017 there was a statistically significant increase in the number of detection events of this species, after which there has been a statistically significant decline. Consideration of trends in these two species alone at this swamp suggest that factors other than mining may be primarily driving these trends.





Best break point analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Break points indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Graph 16: Breakpoint analysis showing best fitting models for *Baeckea imbricata* (above) and *Bauera microphylla/ rubioides sp complex* (below) at Swamp 15A(2)

3.5.1.1.3 Performance measures summary

A summary of the TARP triggers identified throughout the life of the program is provided in Table 19. Since 2014, a TSR Level 2 TARP has been triggered three times and a species composition Level 2 TARP triggered once. In 2017 a TSR Level 2 TARP was triggered. In 2019 there was a statistically significant difference in TSR, which triggered a Level 2 TARP for the second time. In 2020 there was another statistically significant difference which triggered the Level 2 TARP for a third time. This was not statistically significant in 2021 and has not triggered a continuing Level 2 TARP. A species composition TARP was first triggered in 2020 and has been triggered again in 2021.

Table 19: TARP trigger summary (2014-2021) for Swamp 15A(2)

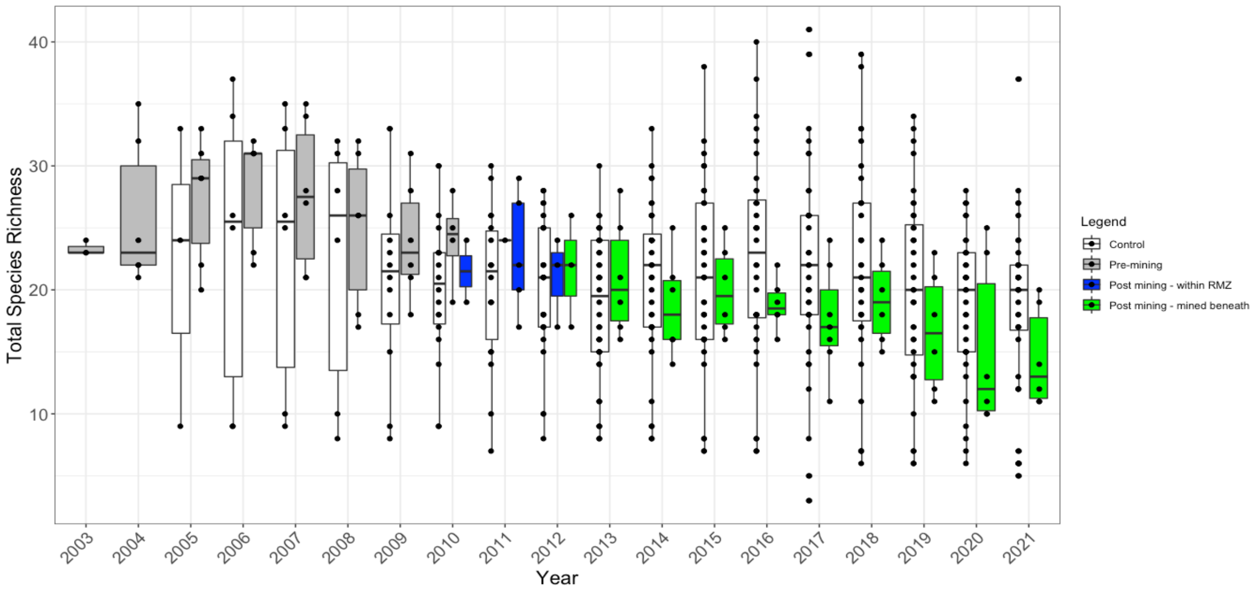
Years	TSR TARP	Composition TARP
2014	None	None
2015	None	None
2016	None	None
2017	**Level 2** • 2016-2017	None
2018	None	None
2019	**Level 2** • 2018-2019	None
2020	**Level 2 (two consecutive years)** • 2018-2019 • 2019-2020	**Level 2** • 2019-2020
2021	None	**Level 2 (two consecutive years)** • 2019-2020 • 2020-2021
Total times triggered	**3**	**2**

3.5.1.2 Swamp 15B

Monitoring at Swamp 15B began in 2003, and mining within the RMZ commenced in 2010, with the Upland Swamp directly mined beneath in 2012. A total of 65 unique species were detected in Swamp 15B across all monitoring periods, of which 15% were detected only once.

3.5.1.2.1 TSR

TSR recorded across the monitoring period at Swamp 15B is shown in Graph 17. TSR has been consistently more variable at the control sites than at Swamp 15B. Since impact, TSR at this swamp appears to have declined to lower levels than before impact. While year on year fluctuations in TSR at Swamp 15B are evident, there is a strong overall trend of decreasing TSR since 2016, including the post-impact period (2012-2021). The control swamps have shown a greater degree of variability than Swamp 15B, however the mean TSR in controls appears to have experienced an overall period of relative stability between 2003 – 2020, whilst TSR at Swamp 15B has declined.



The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentile), and the whiskers of the boxplot cover 1.5 times the IQR of the data. Boxes shaded white are Control Upland Swamps, boxes shaded grey are Impact Upland Swamps that are Pre-mining, boxes shaded blue are Post-mining - within RMZ, and boxes shaded green are Post-mining - mined beneath. Solid black points are the observations. See Table 1 for mining progress, number and status of Upland Swamps at the year surveyed.

Graph 17: Boxplot of the TSR for each transect at Impact Upland Swamp 15B, contrasted against Control Upland Swamps

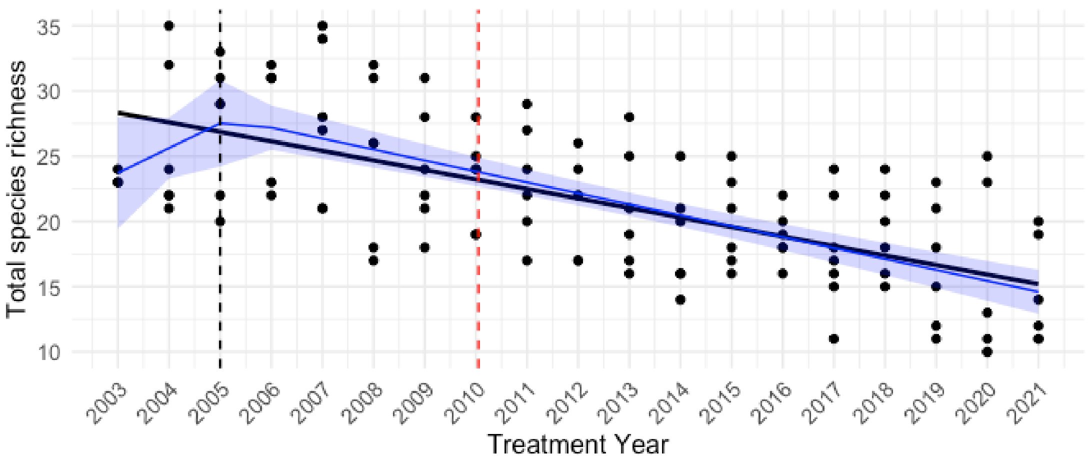
The TSR analysis (Table 20) first shows a statistically significant difference in TSR between Swamp 15B and the control swamps in 2012-2013 (the period following mining directly beneath in 2012). Since 2015, a statistically significant difference in TSR has continued to be detected. This trend has continued in the 2020-2021 period (p-value = 0.001).

Table 20: Comparison of mean TSR between swamp S15B and control swamps over 2-year periods

Comparison	Test statistic	D.f.	P-value
2010–2011	2.33	4.09	0.079

Comparison	Test statistic	D.f.	P-value
2011–2012	2.14	1.86	0.175
2012–2013	3.25	3.14	**0.045**
2013–2014	1.8	1.11	0.302
2014–2015	6.98	2.57	**0.01**
2015–2016	4.46	1.32	**0.094**
2016–2017	12.16	4.06	**0**
2017–2018	6.71	1.59	**0.037**
2018–2019	10.14	3.74	**0.001**
2019–2020	14.31	4.18	**0**
2020–2021	11.12	3.25	**0.001**

Additional analysis identified that the breakpoint in TSR data for Swamp 15B does not correspond to when the impact occurred, suggesting TSR was declining at this swamp prior to impact, and this trajectory has not changed (Graph 18).



Best breakpoint analysis model as determined by AIC model section (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Graph 18: Breakpoint analysis showing best fitting models at Impact Upland Swamp 15B

3.5.1.2.2 Species composition

Post-impact species composition data at Swamp S15B was first identified as being statistically different to pre-impact data in 2012-2013 after approaching the level of significance in 2011-2012 (the period following mining within the RMZ of the swamp in 2010). A statistically significant difference in species composition pre-post mining has continued to be detected in each two-year period since then, including in the 2020-2021 monitoring period (p-value: 0.001) (Table 21). The percentage of deviance relates to the five most influential species (species that have experienced the greatest level of change). In 2021 these species are *Epacris obtusifolia, Gonocarpus* sp. complex*, Pultenaea divaricata, Sprengelia incarnata* and *Platysace linearifolia.* All of these species were found to be more common prior to impact. As in previous years, this list of species includes those that are known to grow in heath or damp areas as well as those associated with dry sclerophyll forest and more sandy soils.

Table 21: Species composition at Swamp S15B over 2-year periods

Comparison	P-value (pre-post mining)	Percentage of deviance
2010–2011	0.146	0.481
2011–2012	0.072	0.463
2012–2013	**0.029**	0.44
2013–2014	**0.008**	0.438
2014–2015	**0.001**	0.437
2015–2016	**0.002**	0.465
2016–2017	**0.001**	0.405
2017–2018	**0.001**	0.357
2018–2019	**0.001**	0.392
2019–2020	**0.001**	0.377
2020–2021	**0.001**	0.338

In 2020 it was concluded that the change in species composition does not appear to reflect the Upland Swamp drying and transitioning toward woodland, given the loss of both ‘wet’ and ‘dry’ species. Rather, the swamp may be experiencing some degree of die-back. As evidenced in the comparison of UAV imagery of the swamp vegetation in Plate 11 and Plate 12 below from 2020 (Niche 2021).

Plate 11: Control Upland Swamp 15A(1), showing healthy vegetation (2020)

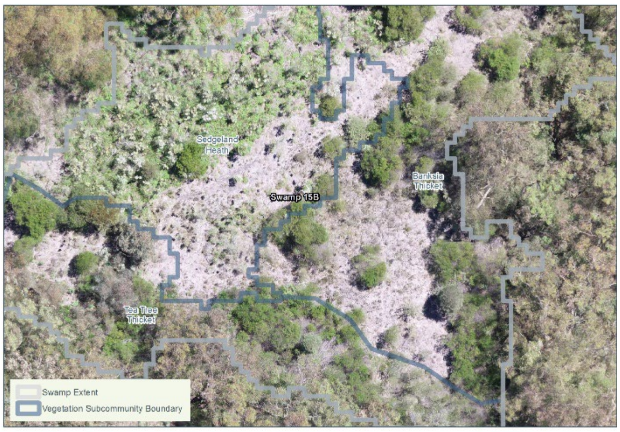
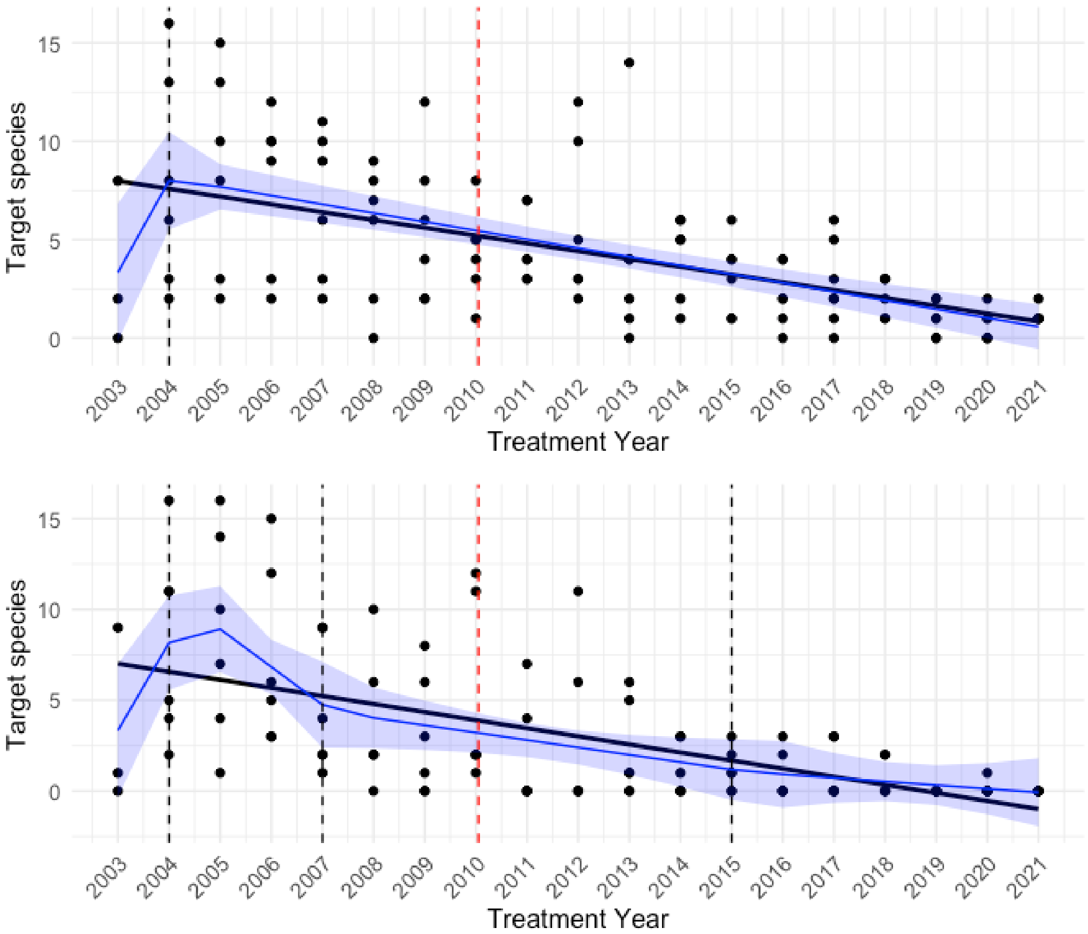


Plate 12: Impact Upland Swamp 15B, showing areas of die-back (2020)

Additional analysis of two key species identified as having strong trends over time at this swamp have been completed to examine whether the statistically significant breakpoints in these trends temporally align with mining activities (Graph 19). *Leptospermum juniperinum* was identified as steadily declining throughout the monitoring period. The best fitting model had one breakpoint representing a statistically significant increase to 2004, before statistically significantly declining in detection. *Epacris obtusifolia* was identified as a species that was more common prior to impact, compared to after impact. The best fitting model had 3 breakpoints, but model selection uncertainty was high. These statistically significant break points identified do not align with the commencement of mining, with declines pre-dating mining activity. Consideration of trends in these two species alone at this swamp, suggest factors other than mining may be primarily driving these trends, noting there has been no trending increase in the eleven years of post-mining data collections. The key breakpoint (2004) for both species pre-dates mining activities at this swamp (Graph 19).



Best break point analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Break points indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Graph 19: Breakpoint analysis showing best fitting models for *Leptospermum juniperinum* (above) and *Epacris obtusifolia* (below) at Swamp 15B

The most commonly recorded species at Swamp 15B is the *Gleichenia dicarpa / microphylla* sp complex (Pouched coral fern). Visual trends of this ‘wet’ species can be used as an indicator of the response to lack of water. When healthy the species is a rich vibrant green and when dying becomes yellow to grey with continued desiccation. For example, Plate 15, Plate 16 and Plate 15 show decline in health of *Gleichenia dicarpa/ microphylla sp complex* between 2015 and 2021 (shown by green foliage browning over time) and remaining desiccated in 2021. This is consistent with the general trends observed in the transect monitoring data, ecosystem functionality and total swamp extent. Although it is noted that signs of regeneration of *Gleichenia dicarpa/ microphylla sp complex* have been observed elsewhere in the swamp (Section 3.4).

Plate 13: Swamp 15B F5 South Autumn 2015

Plate 14: Swamp 15B F5 South Autumn 2020

Plate 15: Swamp 15B F5 South Autumn 2021

3.5.1.2.3 Performance measure summary

Using all Control Upland Swamps in the analysis for a historical overview, a TSR TARP has been triggered seven times and composition TARP triggered nine times at Swamp 15B (Table 22). In 2013 a TSR Level 2 TARP was triggered, a second Level 2 was triggered in 2015 and a third Level 2 was triggered in 2017 with additional Level 2 TARPs triggered each year to 2021, representing five years in a row with a statistically significant difference in post-impact TSR compared to pre-impact TSR, with Graph 17 showing this to be part of a trend of declining TSR over time. A level 2 TARP for species composition was first triggered in 2013, one year since being mined beneath (2012), after approaching the adopted level of statistical significance in 2012. This level 2 TARP has continued to be triggered since 2013 (nine consecutive years).

The breakpoint analysis does suggest that this swamp may have been undergoing changes in floristic composition prior to mining occurring, although no trend other than decline is observed in the post-mining period. Importantly, the TSR and swamp extent analysis consider differences relative to the control swamps, which have remained relatively stable during this period of decline at Swamp 15B.

When the TSR and species composition triggers are taken together with the observations of drying conditions, trending decline in swamp extent and sub-communities (Section 3.3), these factors suggest a change in species present at the swamp and an impact due to mining. As discussed above, species composition is changing via loss of species with preferences for both wet and dry habitats, nevertheless this indicates a loss of richness and change in community composition and hence continues to trigger a Level 2 TSR and composition TARP.

Table 22: Historical TARP triggers for Swamp 15B

Years	TSR TARP	Composition TARP
2011	None	None
2012 (mined beneath)	None	None
2013	Level 2 • 2012-2013	Level 2 • 2012-2013
2014	None	Level 2 (two consecutive years) • 2012-2013 • 2013-2014
2015	Level 2 • 2014-2015	Level 2 (three consecutive years) • 2012-2013 • 2013-2014 • 2014-2015
2016	None	Level 2 (four consecutive years) • 2012-2013 • 2013-2014 • 2014-2015 • 2015-2016
2017	Level 2 • 2016-2017	Level 2 (five consecutive years) • 2012-2013 • 2013-2014 • 2014-2015 • 2015-2016 • 2016-2017
2018	Level 2 (two consecutive years) • 2016-2017 • 2017-2018	Level 2 (six consecutive years) • 2012-2013 • 2013-2014 • 2014-2015 • 2015-2016 • 2016-2017 • 2017-2018
2019	Level 2 (three consecutive years) • 2016-2017 • 2017-2018 • 2018-2019	Level 2 (seven consecutive years) • 2012-2013 • 2013-2014 • 2014-2015 • 2015-2016 • 2016-2017 • 2017-2018 • 2018-2019
2020	Level 2 (four consecutive years) • 2016-2017 • 2017-2018 • 2018-2019 • 2019-2020	Level 2 (eight consecutive years) • 2012-2013 • 2013-2014 • 2014-2015 • 2015-2016

Years	TSR TARP	Composition TARP
		• 2016-2017 • 2017-2018 • 2018-2019 • 2019-2020
2021	Level 2 (five consecutive years) • 2016-2017 • 2017-2018 • 2018-2019 • 2019-2020 • 2020-2021	Level 2 (nine consecutive years) • 2012-2013 • 2013-2014 • 2014-2015 • 2015-2016 • 2016-2017 • 2017-2018 • 2018-2019 • 2019-2020 • 2020-2021
Total times triggered	**7**	**9**

3.5.2 Dendrobium Area 3B

A summary of the results against TARP triggers for Dendrobium Area 3B in 2021 are presented in Table 13, inclusive of the outcomes from the LiDAR assessment detailed in Section 3.3.3.

The trigger system allows detection of change and indicates where to focus further investigation to determine what has triggered the TARP. The higher the TARP trigger the more severe the impact with greater implications to the health of the swamp as impacts are detected over longer timeframes.

In 2021, TARPs have been triggered at swamps 13, 1A, 1B, 5 and 23. The majority of these TARPs triggered relate to the LiDAR assessment, with only swamp 1B and 23 having triggered TARPs based upon TSR or species composition analysis. It is noted that the methodology and approach to LiDAR analysis has been improved in 2021 and as such it has anticipated that there may be differences in TARP trigger levels in 2021 when compared to previous reports. Two swamps, swamps 11 and 14 have not recorded any TARP triggers in 2021.

Changes from the 2020 iteration of the monitoring program (Niche 2021) include the following:

- Swamp 13 has recorded a Level 1 swamp extent TARP trigger in 2021 for the first time.
- Swamp 1A has recorded a Level 1 ecosystem functionality trigger for 2021 (unassessed in 2020).
- Swamp 1B has recorded a Level 1 TSR trigger for 2021 for the first time, after being statistically significant in 2020. An exceeding expectation trigger remains for species composition. A Level 2 swamp extent TARP was triggered in 2021, as was ecosystem functionality (not assessed in 2020).
- Swamp 5 has recorded a Level 2 ecosystem functionality TARP trigger in 2021 (unassessed in 2020).

Table 23: Summary of TARP triggers for Upland Swamps in Dendrobium Area 3B in 2021

Swamp	TARP	2021	Note
11	TSR	None	A statistically significant difference has been detected in the 2021 analysis, with breakpoint analysis identifying a statistically significant decline post-mining, although this also coincided with the drought. Currently, no TARP has been triggered however this will be re-examined in detail in 2022.
	Composition	None	Statistically significant differences between pre and post mining have been detected over 4 years since 2018, however the species experiencing the greatest degree of change display a mix of preferences for wet and dry conditions, with no unified pattern of increasing dry preference species or declining wet preference species. Two species selected for breakpoint analysis indicate statistically significant trends that commenced in the pre-mining period.
	Extent	None	No TARP triggers to date.
	Ecosystem functionality	None	No TARP triggers to date.
13	TSR	None	No statistically significant difference in TSR was identified in 2021.
	Composition	None	While species composition has been statistically significantly different to pre-mining for two consecutive monitoring periods, the habitat preferences of the species experiencing the greatest degree of change are not indicative of drying conditions, neither are the two species selected for breakpoint analysis.
	Extent	**Level 1**	A Level 1 TARP has been triggered for the first time.
	Ecosystem functionality	None	No TARP triggered in 2021.
14	TSR	None	No TARP triggers to date.
	Composition	None	No TARP triggers to date.

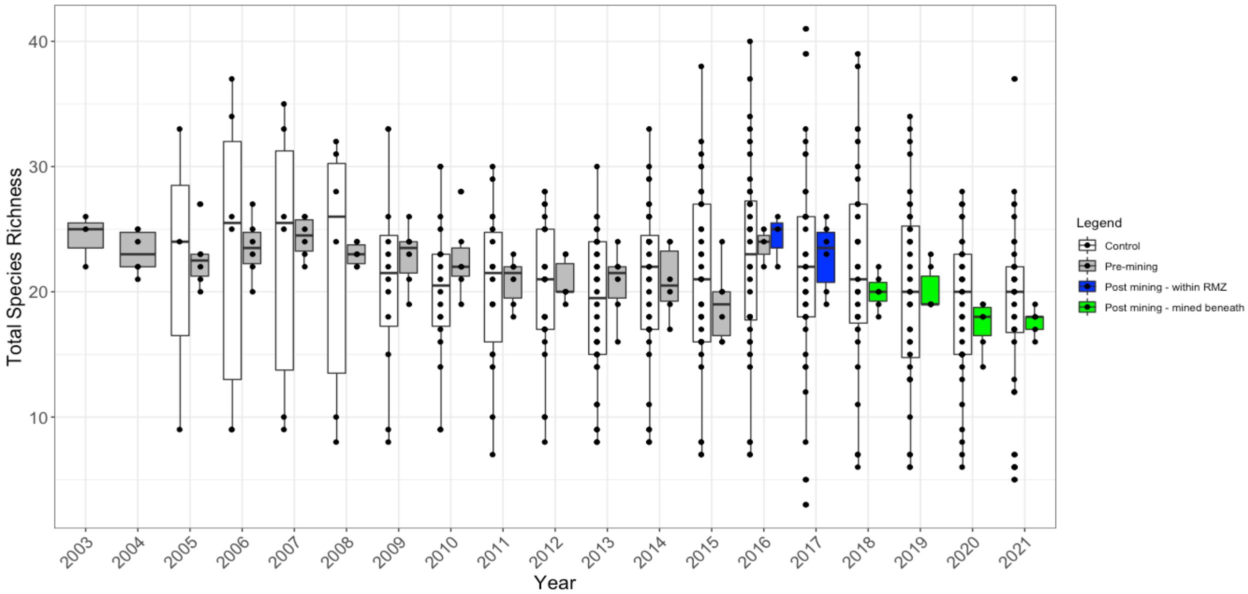
Swamp	TARP	2021	Note
	Extent	None	No TARP triggered in 2021.
	Ecosystem functionality	None	No TARP triggered in 2021.
1A	TSR	None	No TARP triggers to date.
	Composition	None	No TARP triggers to date.
	Extent	None	No TARP triggers to date.
	Ecosystem functionality	**Level 1**	A decline in Tea-tree Thicket greater than that experienced at the control group in 2019-2020 and 2020-2021 has been identified in 2021.
1B	**TSR**	**Level 1**	A Level 1 TARP has been triggered for the first time.
	Composition	**Exceeding expectation**	An exceeding expectation TARP has been triggered following seven consecutive years of species composition data being different to pre-mining data.
	Extent	**Level 2**	A decline in swamp extent greater than that experienced at the control group has been detected in 2018-2019, 2019-2020 and 2020-2021.
	Ecosystem functionality	**Level 1**	A decline in Tea-tree Thicket greater than that experienced at the control group in 2019-2020 and 2020-2021 has been identified in 2021.
5	TSR	None	No TARP triggers to date.
	Composition	None	No TARP triggers to date.
	Extent	None	No TARP triggers to date.
	Ecosystem functionality	**Level 2**	A decline in Tea-tree Thicket greater than that of the control group was detected in 2018-19, 2019-20 and 2020-21.
23	**TSR**	**Level 2**	A Level 2 TARP has been triggered, with a statistically significant difference between Swamp 23 and the control swamps detected over three consecutive years.
	Composition	None	No TARP triggers to date.
	Extent	**Level 1**	A Level 1 TARP has been triggered for the first time.
	Ecosystem functionality	None	No TARP triggers to date.

3.5.2.1 Swamp 11

Monitoring at Swamp 11 began in 2003 as a Control Upland Swamp for the Upland Swamps being monitored in Dendrobium Area 3A, since mining within the RMZ commenced in 2016 and Swamp 11 was directly mined beneath in 2017. A total of 61 unique species have been detected to date at Swamp 11, of which 8% were detected only once.

3.5.2.1.1 TSR

TSR at control sites has been more variable than that of Swamp 11 (Graph 20). A gradual overall decrease in TSR is observed in the pre-impact TSR data (2003-2015). An increase in TSR was recorded immediately following mining within the RMZ of the swamp in 2016 to the highest levels recorded at this swamp, which has since declined to levels recorded immediately before impact (2015). A similar, but proportionally lower, pattern in decreasing median TSR has also been experienced at the control sites, although median TSR values appear to have remained consistent since 2019.



The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentile), and the whiskers of the boxplot cover 1.5 times the IQR of the data. Boxes shaded white are Control Upland Swamps, boxes shaded grey are Impact Upland Swamps that are Pre-mining, boxes shaded blue are Post-mining - within RMZ, and boxes shaded green are Post-mining - mined beneath. Solid black points are the observations. See Table 1 for mining progress, number and status of Upland Swamps at the year surveyed.

Graph 20: Boxplot of the TSR for each transect at Impact Upland Swamp 11, contrasted against Control Upland Swamps

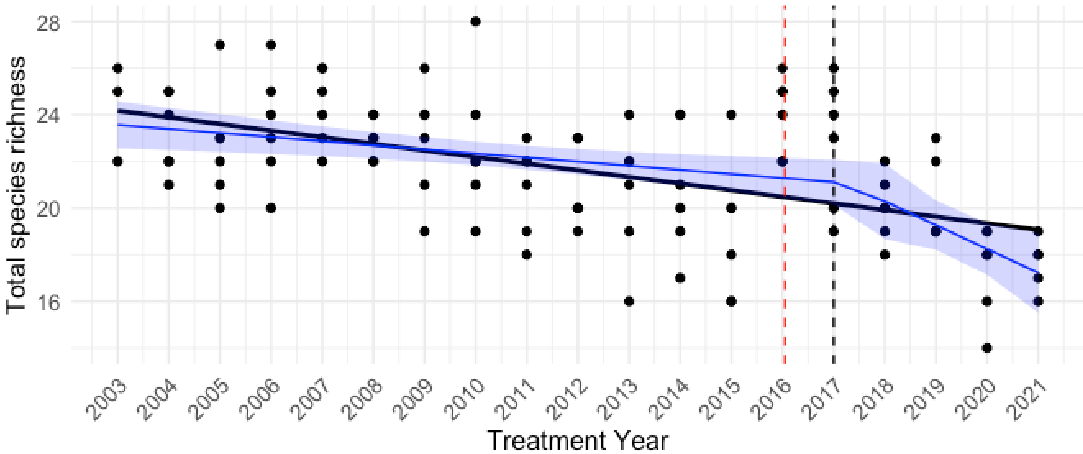
In 2021 a statistically significant difference between pre- and post-impact TSR data has been detected for the first time (p-value: 0) (Table 24).

Table 24: Comparison of mean TSR between Swamp 11 and control swamps over 2-year periods

Comparison	Test statistic	D.f.	P-value
2016–2017	-0.86	3.32	0.446
2017–2018	0.9	1.18	0.513
2018–2019	1.56	1.35	0.313
2019–2020	1.58	1.39	0.303

Comparison	Test statistic	D.f.	P-value
2020–2021	6.24	10.19	**0**

Additional breakpoint analysis has identified that prior to impact, the TSR at this swamp was declining, however the speed of that decline statistically significantly increased in the year post mining (Graph 21).



Best breakpoint analysis model as determined by AIC model section (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Graph 21: Breakpoint analysis showing best fitting models at Impact Upland Swamp 11

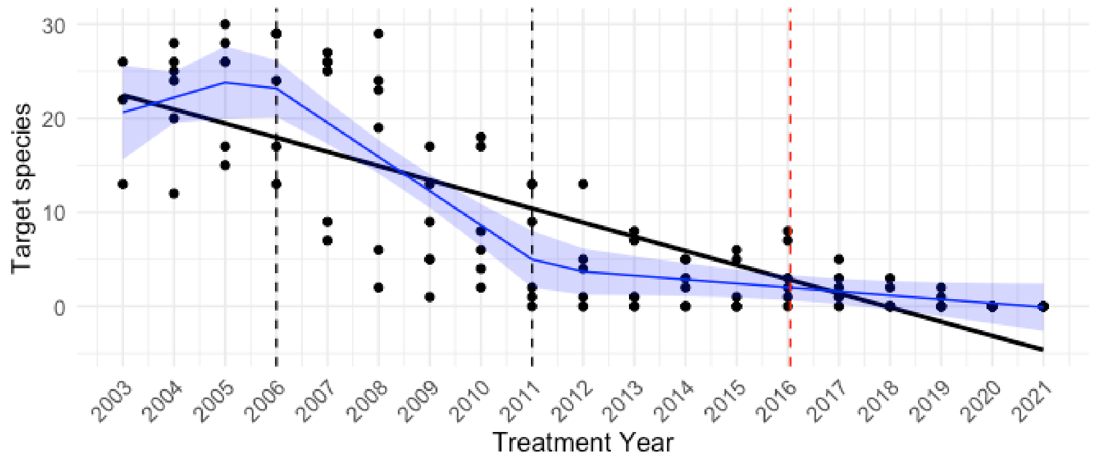
3.5.2.1.2 Species composition

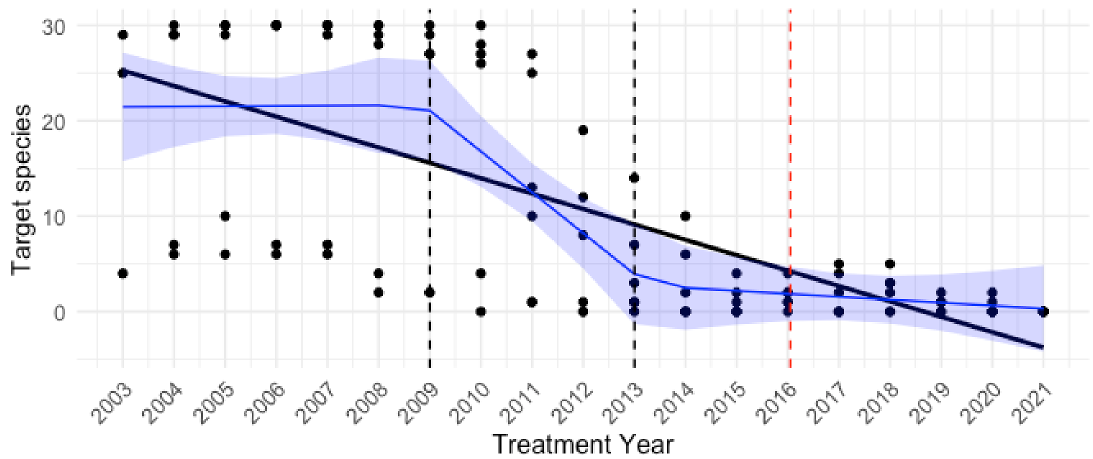
A statistically significant difference between pre and post impact species composition data has been detected in each monitoring period since 2017-2018 (Table 25), including the most recent 2020-2021 period (p-value: 0.001). The percentage of deviance relates to the five most influential species (species that have experienced the greatest level of change). In 2021 these species are *Almaleea paludosa, Epacris obtusifolia, Boronia parviflora, Sphaerolobium Stackhousia* species complex and *Gonocarpus* sp. complex. All of these species were found to be more common prior to impact. As in previous years, this list of species includes those that are known to grow in heath or damp areas as well as those that may be associated with dry sclerophyll forest and more sandy soils.

Table 25: Species composition at Swamp 11 over 2-year periods

Comparison	P-value (pre-post mining)	Percentage of deviance
2016–2017	0.243	0.35
2017–2018	**0.038**	0.334
2018–2019	**0.005**	0.462
2019–2020	**0.001**	0.494
2020–2021	**0.001**	0.606

Additional analysis of two key species identified as having strong trends over time at this swamp have been completed to examine whether the statistically significant breakpoints in these trends temporally align with mining activities (Graph 22). *Almaleea paludosa* was identified as a species that was more common prior to impact, compared to after impact, with the species no longer detected in 2020. The best fitting model had two breakpoints with the period of decline between 2006 and 2011 statistically significant, after which detection was approximately stable. *Boronia parviflora* was also identified as a species that was more common prior to impact, compared to after impact. The best fitting model had 2 breakpoints, with the decline in 2009 to 2013 statistically significant, after which detection of the species was approximately stable. These statistically significant break points identified do not align with the commencement of mining, with declines pre-dating mining activity. Consideration of trends in these two species alone and at this swamp, suggest that factors other than mining may be primarily driving these trends in these two species.





Graph 22: Breakpoint analysis showing best fitting models for *Almaleea paludosa* (above) and *Boronia parviflora* (below) at Swamp 11.

Best break point analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Break points indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

3.5.2.1.3 Performance measure summary

The statistically significant change in composition does not necessarily indicate a mining induced negative change across Swamp 11, just that a change is occurring. The change in species composition is due to species that are generally restricted to wet or swamp environments, but also those that have a greater range of tolerances and may also be associated with dry sclerophyll or woodland environments. Given that many of the species that are experiencing the greatest change in composition can tolerate varying conditions, the change in occurrence of these species do not indicate a vegetation composition change that can be attributable to impacts from mining, i.e. from drying conditions.

In previous years, the change in species composition has not resulted in a statistically significant decline in TSR, indicating a shift in species assemblage, rather than dieback. However, in 2021 a statistically significant difference in TSR between Swamp 11 and the Control swamps has been identified, with additional breakpoint analysis identifying a statistically significant decline in TSR post-mining. This decline also coincides with the drought in 2017 – 2019, although no recovery has been identified in 2020 – 2021. A visual review of the pattern of change in TSR identifies similar pattens of change in the pre-mining dataset, and a similar (if lower magnitude) pattern at the control swamps. When this is taken together with swamp extent and subcommunity analysis which has not triggered any TARP's and as no visual indicators of gross environmental change (dieback) have been identified, the statistically significant difference in TSR identified in 2021 is not considered to trigger a TARP. However, this should be re-evaluated in detail in subsequent years to ascertain whether any indicators of mining impacts emerge in the dataset.

The change in species composition over time has resulted in a statistically significantly difference in 2018, 2019 and 2020, but not 2021. This change in species composition identified may be due to the variety of sub-communities within the swamp shifting in distribution. It is noted that the limited species assessed in the breakpoint analysis indicate trends that commenced prior to mining activity.

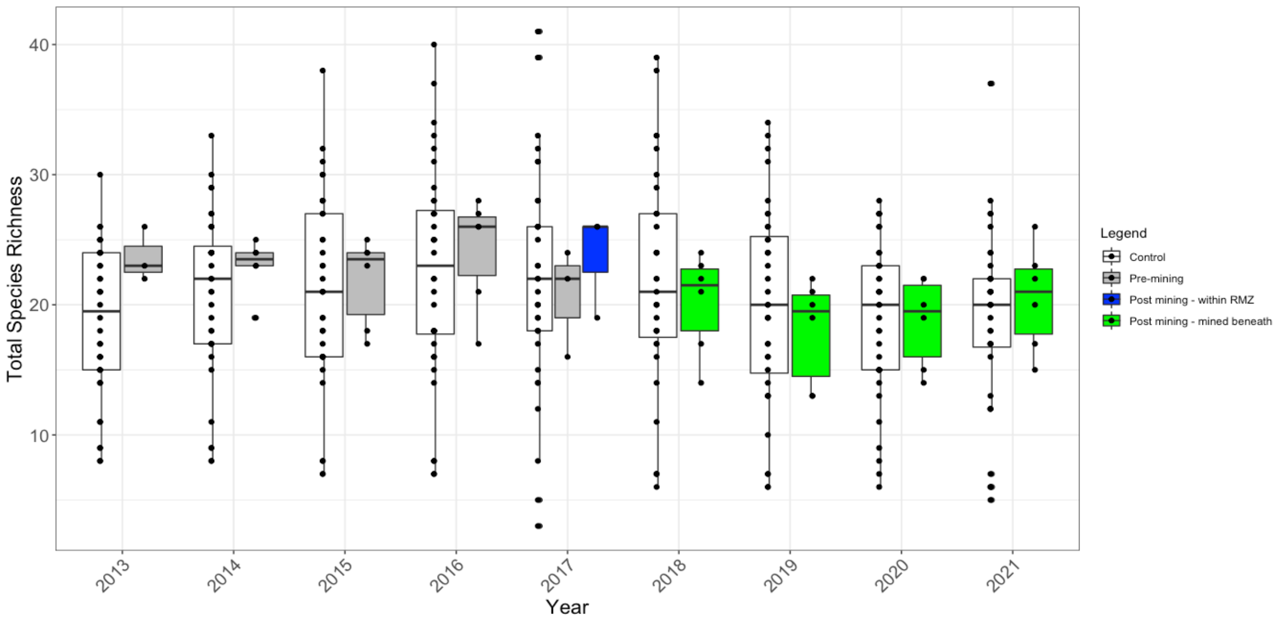
It is reasonable to expect natural species turnover to occur at a swamp, especially after an extended drought period. However, a statistically significant change in species composition indicates a long-term shift in the flora species comprising the swamp. As detailed above, the change in composition may be explained by the transects being within or along the border of a swamp sub-community in transition, where there are portions of swamp sub-communities present along the same transect, with potential drying out of some areas and moisture building in other areas across a complex Upland Swamp. When taken together, the multiple lines of assessment do not suggest an impact as a result of mining, as such a TARP for species composition is not considered to be triggered. However, changes in species composition at this swamp should be monitored in the coming years to determine if a differing trend emerges.

3.5.2.2 Swamp 13

Monitoring at Swamp 13 began in 2013. Mining within the RMZ commenced in 2017 and the swamp was directly mined beneath in 2018. A total of 66 unique species were detected in Swamp 13 across the monitoring period, of which 21% were detected only once.

3.5.2.2.1 TSR

The TSR at control sites has been more variable than TSR at impact Swamp 13. Prior to impact, TSR at Swamp 13 was typically higher than the control swamps, and post-impact there has been a decline in TSR at Swamp 13 that has been proportionally greater than the decline in TSR at the control swamps within the same period, such that the post impact median TSR at Swamp 13 has tended to be similar to that of the control swamps (Graph 23).



The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentile), and the whiskers of the boxplot cover 1.5 times the IQR of the data. Boxes shaded white are Control Upland Swamps, boxes shaded grey are Impact Upland Swamps that are Pre-mining, boxes shaded blue are Post-mining - within RMZ, and boxes shaded green are Post-mining - mined beneath. Solid black points are the observations. See Table 1 for mining progress, number and status of Upland Swamps at the year surveyed.

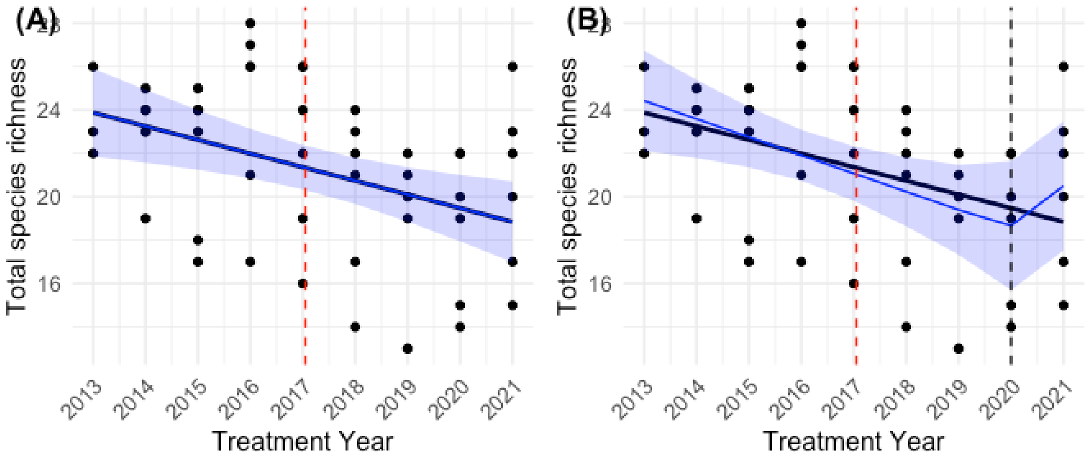
Graph 23: Boxplot of the TSR for each transect at Impact Upland Swamp 13, contrasted against Control Upland Swamps.

No statistically significant difference between pre and post impact TSR data was detected in 2021 (Table 26). To date, a statistically significant difference has only been detected in the 2018-2019 monitoring period.

Table 26: Comparison of mean TSR between Swamp S13 and control swamps over 2-year periods

Comparison	Test statistic	D.f.	P-value
2017–2018	2.6	3.24	0.075
2018–2019	4.55	3.56	**0.014**
2019–2020	2.79	2.83	0.073
2020–2021	1.49	3.16	0.227

Additional breakpoint analysis has identified that the linear declining trend in TSR at this swamp was best fit to the data (Graph 24, A), which commenced prior to mining and did not change trajectory post-mining (Graph 24). The second-best fitting model (Graph 24, B) identifies a statistically significant increase following 2020.



Best breakpoint analysis model as determined by AIC model section (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Graph 24: Breakpoint analysis showing best fitting models at Impact Upland Swamp 13

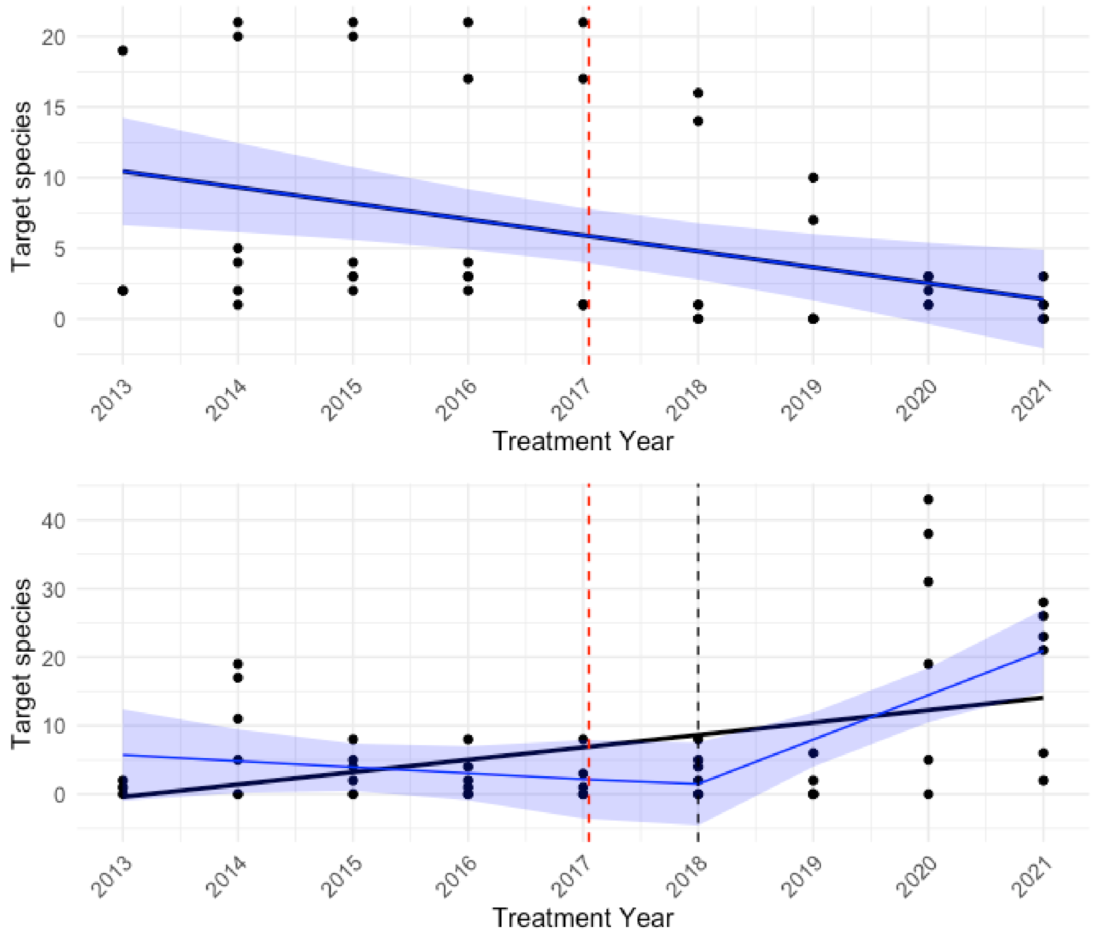
3.5.2.2.2 Species composition

A statistically significant difference between pre- and post-impact species composition was first detected in 2020 (Table 27). A statistically significant difference in species composition was detected for a second time in 2021 (p-value: 0.039). The percentage of deviance relates to the five most influential species (species that have experienced the greatest level of change). In 2021 these species are *Lepidosperma filiforme urophorum* sp. complex, *Dampiera stricta*, *Tetraria capillaris*, *Dillwynia floribunda retorta* sp. complex and *Almaleea paludosa*. All of these species were found to be more common prior to impact. As in previous years, while this group of species includes those most associated with 'wet' habitats, a number of these species are wide ranging and can tolerate varying conditions. As such, these species are not considered to be an overall indicator of changing swamp vegetation composition due to drying, thus the change in occurrence of the above species since the commencement of monitoring do not indicate a trend in vegetation composition change that can be attributable to impacts from mining and/or drying conditions.

Table 27: Species composition at Swamp 13 over 2-year periods

Comparison	P-value (pre-post mining)	Percentage of deviance
2017–2018	0.551	0.534
2018–2019	0.168	0.476
2019–2020	**0.038**	0.359
2020–2021	**0.039**	0.327

Additional analysis of two key species identified as having strong trends over time at this swamp have been completed to examine whether the statistically significant breakpoints in these trends temporally align with mining activities (Graph 25). *Dillwynia floribunda retorta complex* was identified as a species that was more common prior to impact, compared to after impact, although there is high between-transect variability. The best fitting model was the linear model (i.e. no statistically significant breakpoints were identified). *Xyris species complex* was also selected for analysis with the number of detection events of *Xyris species complex* declining slightly until 2020, after which the number of detection events of this species were much higher. The best fitting model had one breakpoint, with the increase since 2018 being statistically significant. As the *Xyris species complex* has a preference for wetter conditions and *Dillwynia floribunda retorta complex* is more likely to be associated with dryer conditions, these findings do not indicate drying conditions within Swamp 13.



Best break point analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Break points indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Graph 25: Breakpoint analysis showing best fitting models for *Dillwynia floribunda retorta complex* (above) and *Xyris species complex* (below) at Swamp 13.

3.5.2.2.3 Performance measure summary

Using all Control Upland Swamps in the analysis for a historical overview a TSR TARP has not yet been triggered to date. In 2019 TSR was statistically different to 2018, however a TARP was not triggered, as the statistically significant difference did not repeat in 2020 (two consecutive years of change required to trigger a Level 1 TARP). Additional breakpoint analysis has identified no statistically significant decline in TSR following mining, with the analysis suggesting declining TSR commenced in the pre-mining period and has not changed trajectory following mining.

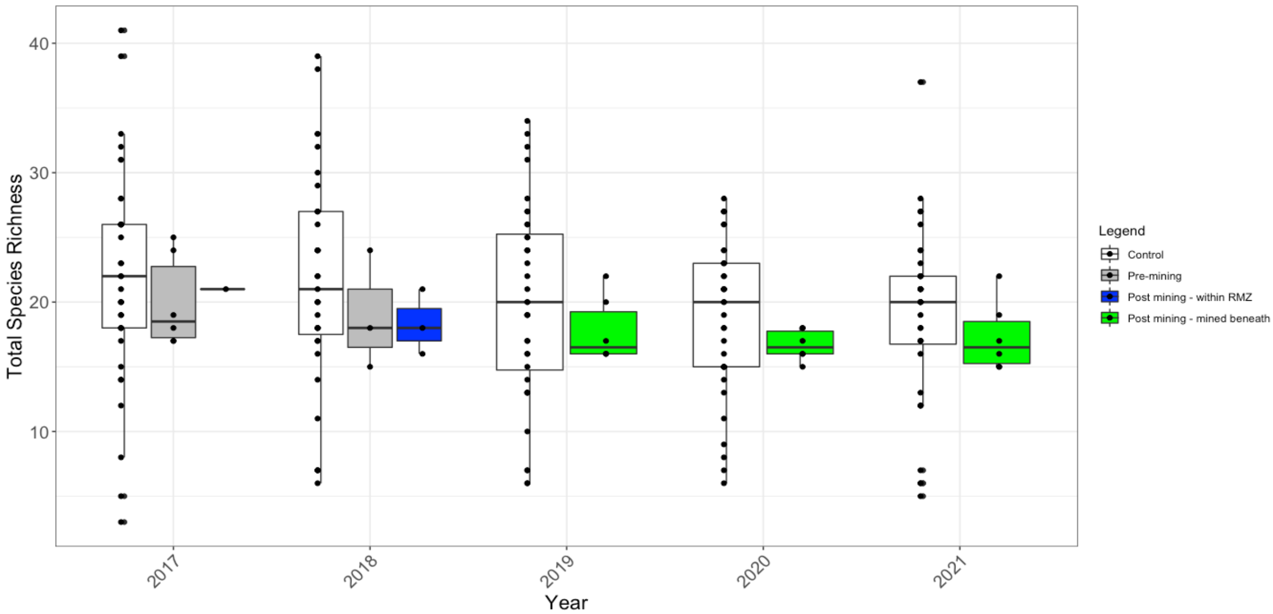
In 2021, a species composition TARP has been triggered for the first time, following consecutive statistically significant differences being detected in 2020 and 2021. It is reasonable to expect natural species turnover to occur at a swamp, especially after an extended drought period, however, a statistically significant change in species composition indicates a likely long-term shift in the flora species comprising the Upland Swamp. The change in species composition has included a reduction in species able to tolerate a range of conditions and do not indicate an overall loss of species with preference for 'wet' habitats. Further, the breakpoint analysis of two species experiencing statistically significant trends in detection do not indicate drying conditions. As such, the change in occurrence of these species do not indicate a vegetation composition change that can be attributable to impacts from mining and/or drying conditions and no TARP is triggered.

3.5.2.3 Swamp 14

Monitoring at Swamp 14 began in 2017 with one year of pre-mining baseline monitoring, mining within the RMZ commenced in 2018 and Swamp 14 was mined beneath by 2019. A total of 39 unique species were detected, of which 10% were detected only once.

3.5.2.3.1 TSR

The combined data for all Upland Control Swamps were more variable than Swamp 14. TSR at Swamp 14 has been lower than that of the control swamps in each year of monitoring. A decrease in median TSR occurred between 2017 and 2018 at both the control swamps and Swamp 14. The median TSR at controls and Swamp 14 appear to be stable from 20019 - 2020 (Graph 26).



The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentile), and the whiskers of the boxplot cover 1.5 times the IQR of the data. Boxes shaded white are Control Upland Swamps, boxes shaded grey are Impact Upland Swamps that are Pre-mining, boxes shaded blue are Post-mining - within RMZ, and boxes shaded green are Post-mining - mined beneath. Solid black points are the observations. TAE 2021a. See Table 1 for mining progress, number and status of Upland Swamps at the year surveyed.

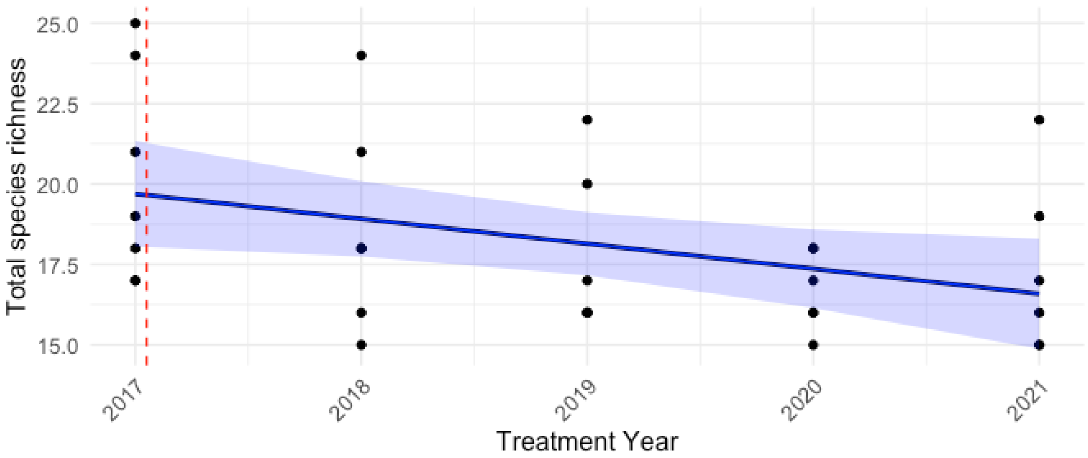
Graph 26: Boxplot of the TSR for each transect, at Impact Swamp 14, contrasted against Control Upland Swamps

No statistically significant difference between TSR at Swamp 14 and the control data was detected in 2021 (Table 28). To date, no statistically significant difference has been detected at Swamp 14. Due to the limited data series, additional breakpoint analysis will be completed in future iterations of the monitoring program as more data is collected.

Table 28: Comparison of mean TSR between swamp S14 and control swamps over 2-year periods

Comparison	Test statistic	D.f.	P-value
2018–2019	-0.14	2.27	0.898
2019–2020	-0.63	1	0.64
2020–2021	-1.02	1.48	0.446

Breakpoint analysis has identified that the linear declining trend in TSR at this swamp was best fit to the data, which did not change trajectory when mining entered the RMZ (2018) or beneath the swamp (2019), as shown in Graph 27.



Best breakpoint analysis model as determined by AIC model section (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Graph 27: Breakpoint analysis showing best fitting models at Impact Upland Swamp 14

3.5.2.3.2 Species composition

In 2021, a statistically significant difference between pre and post impact species composition has been detected for the first time (p-value: 0.029), as shown in Table 29. The percentage of deviance relates to the five most influential species (species that have experienced the greatest level of change). In 2021 these species are *Lepyrodia muelleri scariosa* complex*, Epacris obtusifolia, Lepyrodia anarthria, Leptomeria acida, Symphionema paludosum*, all of which were more common pre-mining. These species are generally associated with 'wet environments', except *Leptomeria acida* which is more associated with dry sclerophyll forest and sandy soils. Given these species include both 'wet' and 'dry' tolerant species, they are not considered to be indicative of changing swamp vegetation composition under drying conditions, thus the change in occurrence of the above species since the commencement of monitoring do not indicate a trend in vegetation composition change that can be attributable to impacts from mining.

Table 29: Species composition at Swamp 14 over 2-year periods

Comparison	P-value (pre-post mining)	Percentage of deviance
2018–2019	0.419	0.625
2019–2020	0.264	0.487
2020–2021	**0.029**	0.536

3.5.2.3.3 Performance measure summary

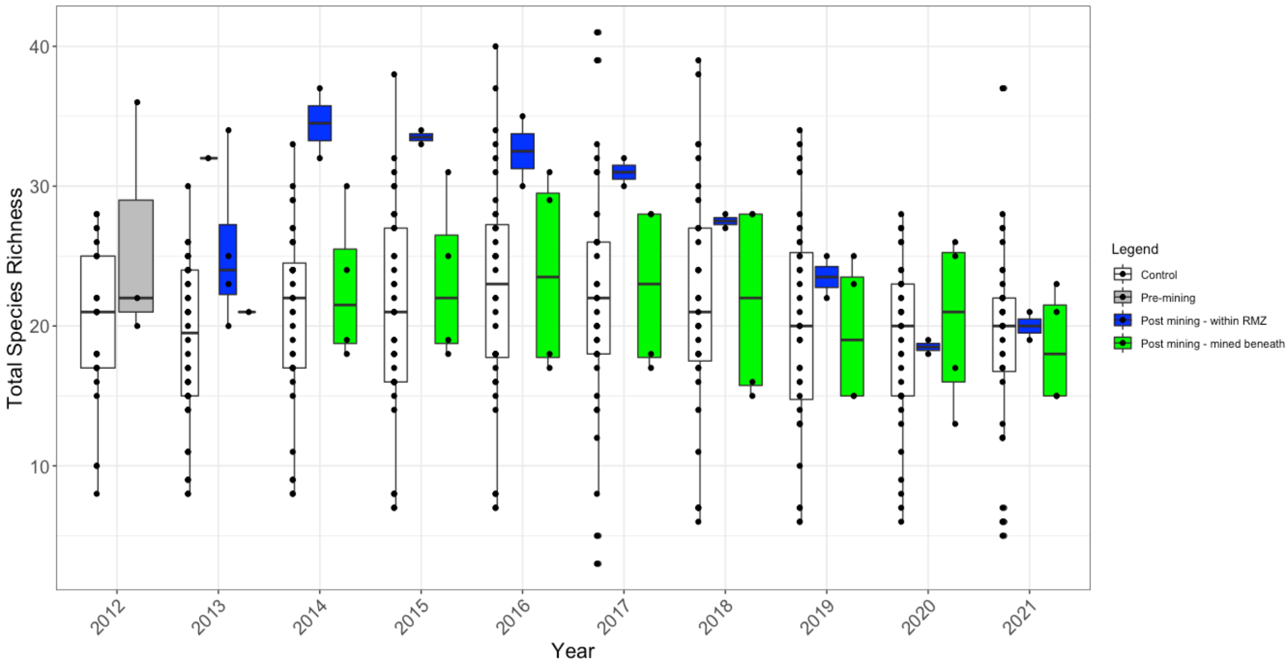
There were no TARPs triggered for Swamp 14 in 2021 or historically. A statistically significant difference in species composition was detected in 2021 for the first time, this will not trigger a TARP level unless a consecutive statistically significant difference is detected in 2022. Monitoring should continue for Swamp 14, as trends may become more apparent with increased time since mining and/or increased availability of monitoring data.

3.5.2.4 Swamp 1A

Monitoring at Swamp 1A began in 2012, with one year of pre-mining baseline monitoring. Mining within the RMZ commenced in 2013 and Swamp 1A was mined beneath in 2014. A total of 67 unique species were detected, of which 7% were detected only once.

3.5.2.4.1 TSR

In the one year prior to impact, the TSR at the Swamp 1A was slightly higher than of the control swamps (Graph 28). Overall, TSR at the control swamps has been more variable than TSR at Swamp S1A, and has been relatively stable across the monitoring period. In 2014, immediately after mining within the RMZ, post mining (within RMZ) TSR at Swamp 1A rose, before declining progressively to 2020, then rising slightly in 2021. Whereas the post mining (mined beneath) TSR has fluctuated year on year but remained relatively stable, although in 2021, the median TSR value is below that of the pre-impact data.



The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentile), and the whiskers of the boxplot cover 1.5 times the IQR of the data. Boxes shaded white are Control Upland Swamps, boxes shaded grey are Impact Upland Swamps that are Pre-mining, boxes shaded blue are Post-mining - within RMZ, and boxes shaded green are Post-mining - mined beneath. Solid black points are the observations. See Table 1 for mining progress, number and status of Upland Swamps at the year surveyed.

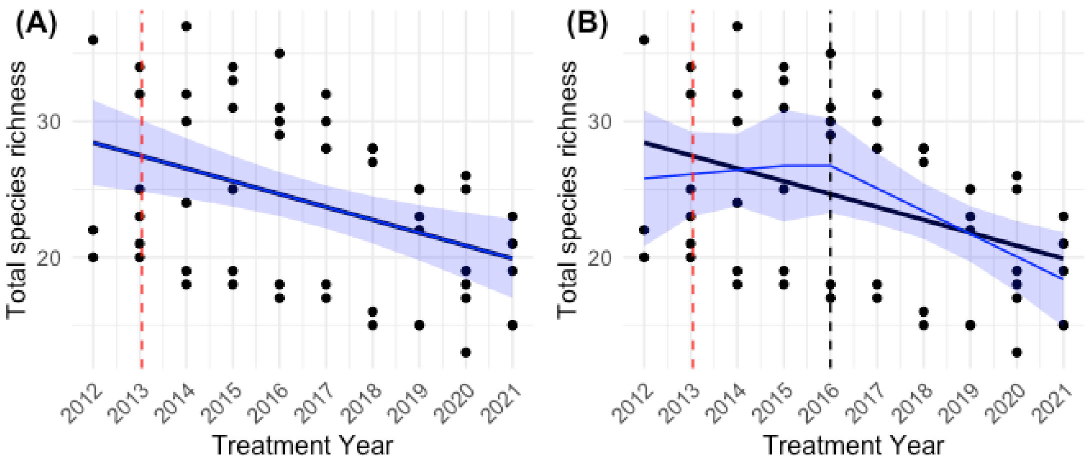
Graph 28: Boxplot of the TSR for each transect, at Impact Swamp 1A, contrasted against Control Upland Swamps

In 2015, TSR was statistically significantly different between Swamp 1A and the control sites (Table 30), but this did not continue into 2016. The following year in 2017 a statistically significant difference was again detected, but only in this year. No further statistically significant differences have been detected, including in 2021.

Table 30: Comparison of mean TSR between swamp S1A and control swamps over 2-year periods

Comparison	Test statistic	D.f.	P-value
2013–2014	-10.38	1	0.061
2014–2015	-145.5	1	**0.004**
2015–2016	-6.71	1	0.094
2016–2017	-10.41	1	**0.061**
2017–2018	-3.94	1	0.158
2018–2019	-2.39	1	0.253
2020–2021	-1	1	0.5

Model uncertainty in the additional breakpoint analysis was high, the linear trend indicating no breakpoints was best fit to the data (Graph 29, A). However, model selection uncertainty was high, and the second-best fitting model (Graph 29, B) included one breakpoint. No breakpoints were found to be statistically significant, and the breakpoint identified (Graph 29, B) did not coincide with the year of mining.



Best breakpoint analysis model as determined by AIC model section (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Graph 29: Breakpoint analysis showing best fitting models at Impact Upland Swamp 1A

3.5.2.4.2 Species composition

No statistically significant difference in pre and post mining species composition data has been recorded to date, including in 2021 (Table 31). However, in 2021, the species composition is approaching the level of statistical significance (p-value: 0.078) and should be revisited in future monitoring.

Table 31: Species composition at Swamp 1A over 2-year periods

Comparison	P-value (pre-post mining)	Percentage of deviance
2013–2014	0.775	0.483
2014–2015	0.905	0.538

Comparison	P-value (pre-post mining)	Percentage of deviance
2015–2016	0.825	0.504
2016–2017	0.747	0.447
2017–2018	0.606	0.409
2018–2019	0.639	0.407
2019–2020	0.26	0.338
2020–2021	0.078	0.298

3.5.2.4.3 Performance measure summary

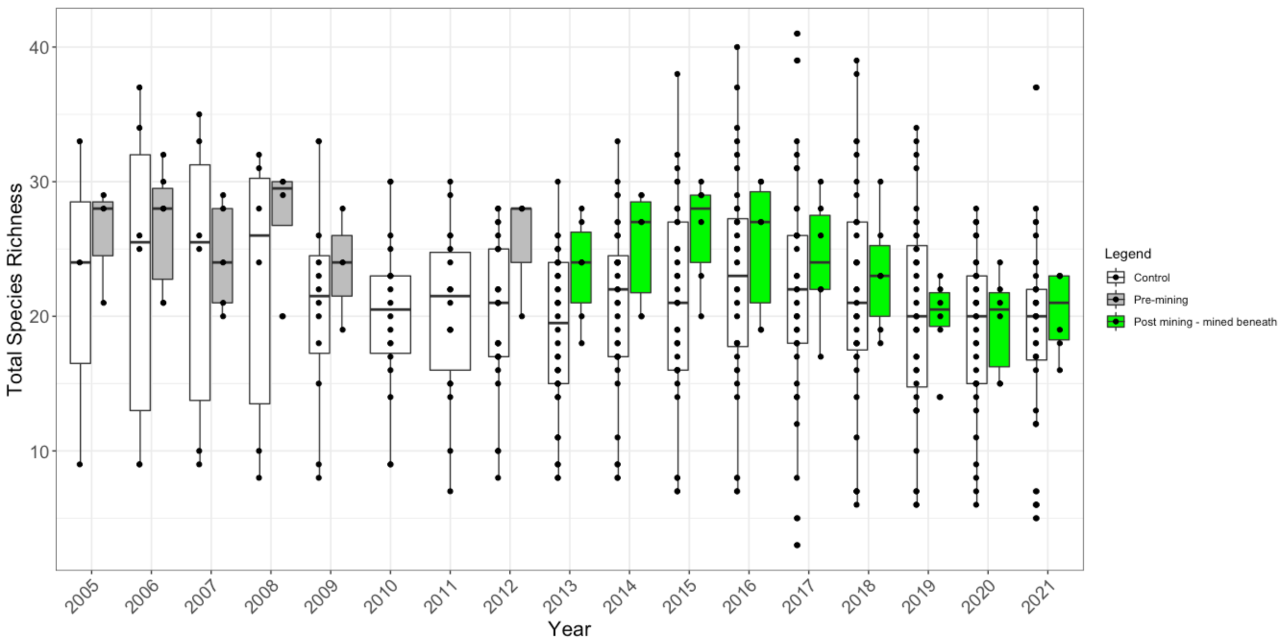
The statistically significant decline in TSR in 2015 and 2017 indicate a potential impact from mining, with Swamp 1A then appearing to continue to experience reduced TSR (Graph 28) in subsequent years. Although the breakpoint analysis indicates that a linear pattern of declining TSR is best fit to the data, suggesting that this may be part of an ongoing trend, the trajectory of which has not changed statistically significantly with mining. No TARPs have been triggered as this decline was not repeated in consecutive monitoring periods and no statistically significant difference in species composition has been identified.

3.5.2.5 Swamp 1B

Monitoring at Swamp 1B began in 2005, with six years of pre mining baseline monitoring completed (2005-2009), followed by a gap of two years not being monitored and then one year prior to mining completed (2012). Mining entered within the RMZ of Swamp 1B in 2013 and was mined beneath in 2014. A total of 65 unique species were detected over the monitoring period, of which 8% were detected only once.

3.5.2.5.1 TSR

Pre mining, the within year variability in TSR at control sites was more variable than at Swamp 1B, with this impact swamp often having a lower mean TSR than that of the control swamps. Since 2016, TSR at this swamp appears to have declined to lower levels than before impact (Graph 30).



The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentile), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

Boxes shaded white are Control Upland Swamps, boxes shaded grey are Impact Upland Swamps that are Pre-mining and boxes shaded green are Post-mining – mined beneath. Solid black points are the observations. See Table 1 for mining progress, number and status of Upland Swamps at the year surveyed.

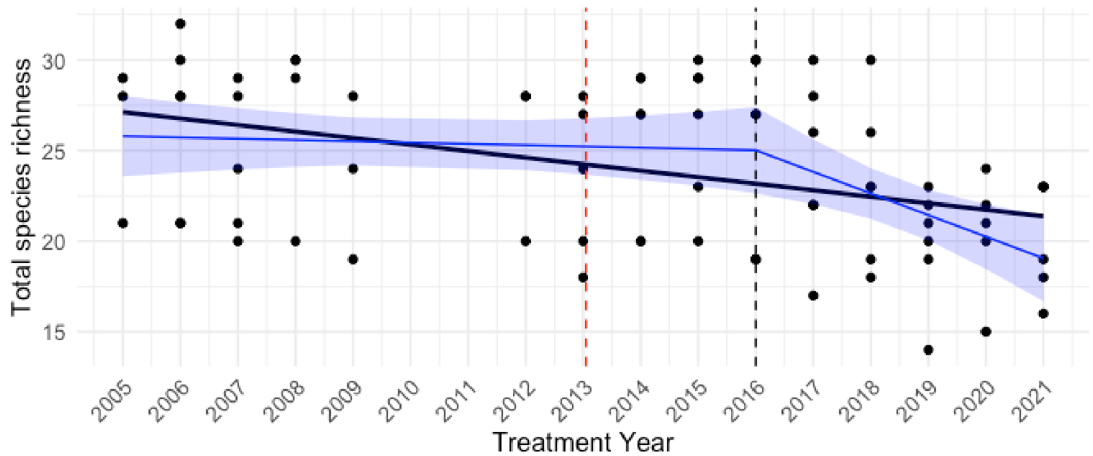
Graph 30: Boxplot of the TSR for each transect at Impact Swamp 1B, contrasted against control swamps.

The mean TSR for Swamp 1B was statistically significantly different to that of control swamps in 2017 and again in 2020 and then again in 2021 (p-value: 0.009) for the second consecutive year (Table 32).

Table 32: Comparison of mean TSR between swamp S1B and Control swamps over 2-year periods

Comparison	Test statistic	D.f.	P-value
2013–2014	-1.7	5.39	0.146
2014–2015	-1.82	4.66	0.133
2015–2016	-0.41	1.5	0.731
2016–2017	1.49	5.52	0.192
2017–2018	2.56	5.95	**0.043**
2018–2019	2.73	2.08	0.107
2019–2020	4.59	5.09	**0.006**
2020–2021	3.84	5.87	**0.009**

Additional breakpoint analysis identified that the best fitting model had one breakpoint in 2016 (Graph 31). TSR at this swamp was relatively stable until TSR declined statistically significantly from 2016, which did not coincide with the year of mining. Decline post 2016 would align with the commencement of the drought in 2017-2019, although no trend other than decline is currently observed in the data, including the 2020 and 2021 years.



Best breakpoint analysis model as determined by AIC model section (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Graph 31: Breakpoint analysis showing best fitting models at Impact Upland Swamp 1B

3.5.2.5.2 Species composition

The species composition assessment shows a statistically significant change in species composition over seven consecutive years since 2015 (the year following being mined beneath), including 2021 (Table 33). The percentage of deviance relates to the five most influential species (species that have experienced the greatest level of change). In 2021, three of these species were *Lepidosperma limicola, Epacris obtusifolia* and *Almaleea paludosa*. These species are associated with 'wet' or swamp environments and were less common in 2021. The other two species were *Grevillea oleoides* and *Caesia parviflora var parviflora*, which were more common in 2021. These species are associated with swamps and heath, but may also be associated with heath, dry sclerophyll or woodland environments.

Table 33: Species composition at Swamp 1B over 2-year periods

Comparison	P-value (pre-post mining)	Percentage of deviance
2013–2014	0.123	0.458
2014–2015	**0.016**	0.562
2015–2016	**0.004**	0.482
2016–2017	**0.002**	0.421
2017–2018	**0.001**	0.454
2018–2019	**0.001**	0.389
2019–2020	**0.001**	0.392
2020–2021	**0.001**	0.274

It is reasonable to expect natural species turnover to occur at the swamp, however, a statistically significant change in species composition has been detected over seven consecutive years, indicating a long-term shift in the flora species comprising Swamp 1B. The changes to species composition at Swamp 1B indicate a loss of species that prefer wet soils, progressively over time. With species preferring or able to tolerate drier soils becoming more prevalent after impact. However, photo point monitoring in Swamp 1B (Plate 16 and Plate 17) does not show signs of gross visual trends of decline in health or die-back of the Upland Swamp.

Plate 16: Swamp 1B F1 South Autumn 2015

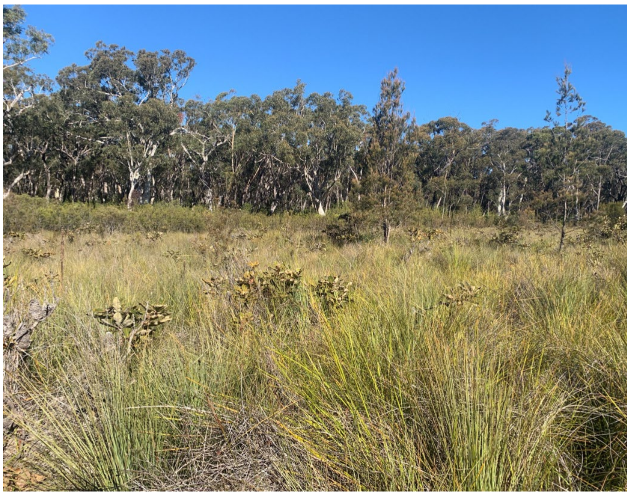
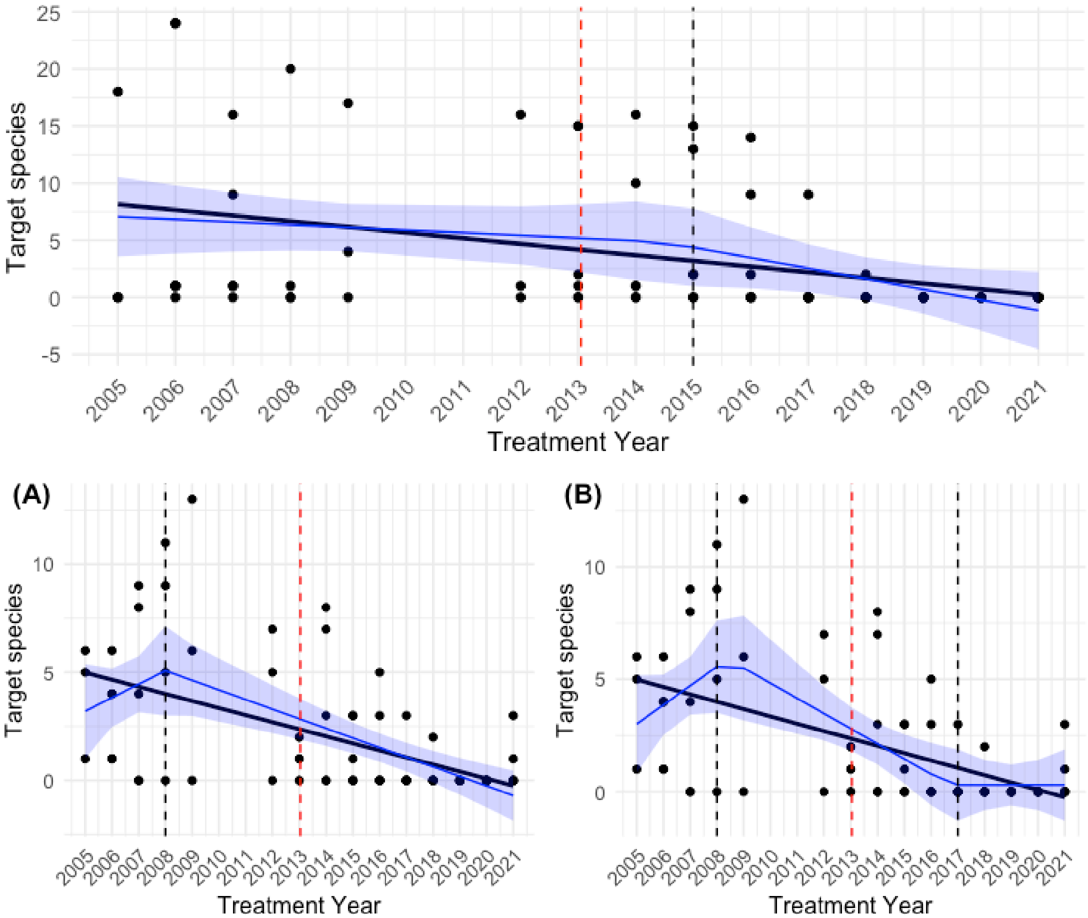


Plate 17: Swamp 1B F1 South Autumn 2021

Additional analysis of two key species identified as having strong trends over time at this swamp have been completed to examine whether the statistically significant breakpoints in these trends temporally align with mining activities. *Epacris obtusifolia* was identified as a species that was common prior to mining in 2013, but barely detected from 2017 onwards. The best fitting model was the linear model, showing a statistically significant decline but with no breakpoints (Graph 32). The next best fitting model is also shown with one breakpoint in 2015. *Mitrasacme polymorpha/ pilosa species complex* was also selected for analysis with the species complex more common before impact, compared to after impact. The best model had a single breakpoint (Graph 32, A), however model selection uncertainty was very high and the next best fitting model is also shown (Graph 32, B). The analysis identifies that there was a statistically significant decline in the number of detection events from 2008 onwards, which pre-dates mining activities.



Best break point analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Break points indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Graph 32: Breakpoint analysis showing best fitting models for *Epacris obtusifolia* (above) and *Mitrasacme polymorpha/ pilosa species complex* (below) at Swamp 1B

3.5.2.5.3 Performance measures summary

Table 34 details the historical TARP triggers for Swamp 1B. A statistically significant difference in TSR was detected in 2021, for the second consecutive period, triggering a Level 1 TARP for the first time. Breakpoint analysis indicates the decline in TSR may align with the commencement of drought, however no recovery is evident in the post-drought period to date. Composition was statistically significantly different to pre-mining data, triggering a Level 1 TARP in 2016 (two consecutive years of impact), a Level 2 TARP in 2017 (three consecutive years impact), a Level 3 TARP in 2018 (four consecutive years impact), an exceeding TARP in 2019 onwards (seven years consecutive impact). TARPs were triggered for these years as the statistically significant difference in species composition was determined to be as a result of a trend in loss of 'wet' species and increase in 'dry' species over the same time period. Although the two species identified in the additional breakpoint analysis suggest factors other than mining may also be influencing swamp floristic change. Nevertheless, TSR is declining statistically significantly in some years (2018, 2020 and 2021) in comparison to the Control swamps, and the species composition changes indicate an overall trend towards species more tolerant of dry soils.

Table 34: Historical TARP triggers for Swamp 1B

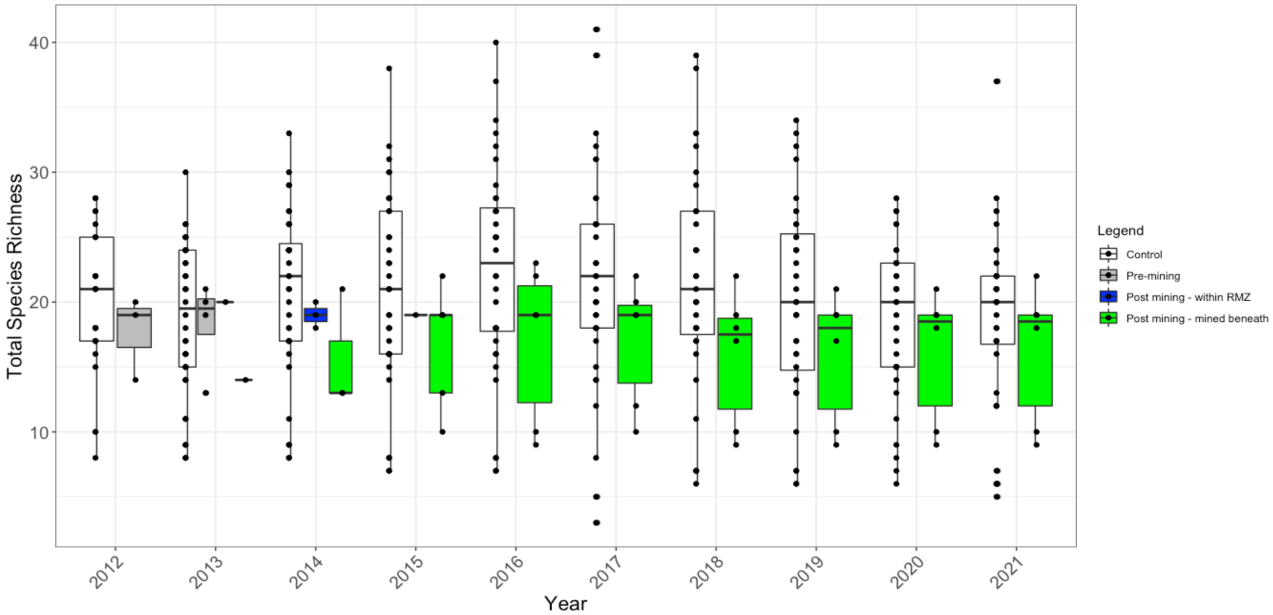
Years	TSR TARP	Composition TARP
2014 (mined beneath)	None	None
2015	None	None
2016	None	Level 1 (two consecutive years): • 2014-2015 • 2015-2016
2017	None	Level 2 (three consecutive years): • 2014-2015 • 2015-2016 • 2016-2017
2018	None	Level 3 (four consecutive years): • 2014-2015 • 2015-2016 • 2016-2017 • 2017-2018
2019	None	Exceeding prediction (five consecutive years): • 2014-2015 • 2015-2016 • 2016-2017 • 2017-2018 • 2018-2019
2020	None	Exceeding prediction (six consecutive years): • 2014-2015 • 2015-2016 • 2016-2017 • 2017-2018 • 2018-2019 • 2019-2020
2021	Level 1 (two consecutive years): • 2019-2020 • 2020-2021	Exceeding prediction (seven consecutive years): • 2014-2015 • 2015-2016 • 2016-2017 • 2017-2018 • 2018-2019 • 2019-2020 • 2020-2021
Total times triggered	**1**	**6**

3.5.2.6 Swamp 5

Monitoring at Swamp 5 began in 2012 with two years of pre mining baseline monitoring, mining within the RMZ commenced in 2013 with Longwall 9 and the swamp was mined beneath in 2014. A total of 48 unique species have been detected over the monitoring period, of which 10% were detected only once.

3.5.2.6.1 TSR

Graph 33 shows a boxplot of TSR data for Swamp 5 contrasted against Control Upland Swamps. The combined data for all Upland Control Swamps were more variable compared with Swamp 5. However, the mean TSR in controls appeared to be relatively stable from 2012 – 2021, experiencing a low degree of overall reduction. Visual assessment of the graph suggests that Swamp 5 has a slightly lower TSR since being mined beneath, but that this degree of reduction may be within the range observed at Control Upland Swamps (Graph 33). Median TSR at Swamp 5 appears to have been relatively stable since 2018.



The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentile), and the whiskers of the boxplot cover 1.5 times the IQR of the data. Boxes shaded white are Control Upland Swamps, boxes shaded grey are Impact Upland Swamps that are Pre-mining, boxes shaded blue are Post-mining - within RMZ, and boxes shaded green are Post-mining - mined beneath. Solid black points are the observations. See Table 1 for mining progress, number and status of Upland Swamps at the year surveyed.

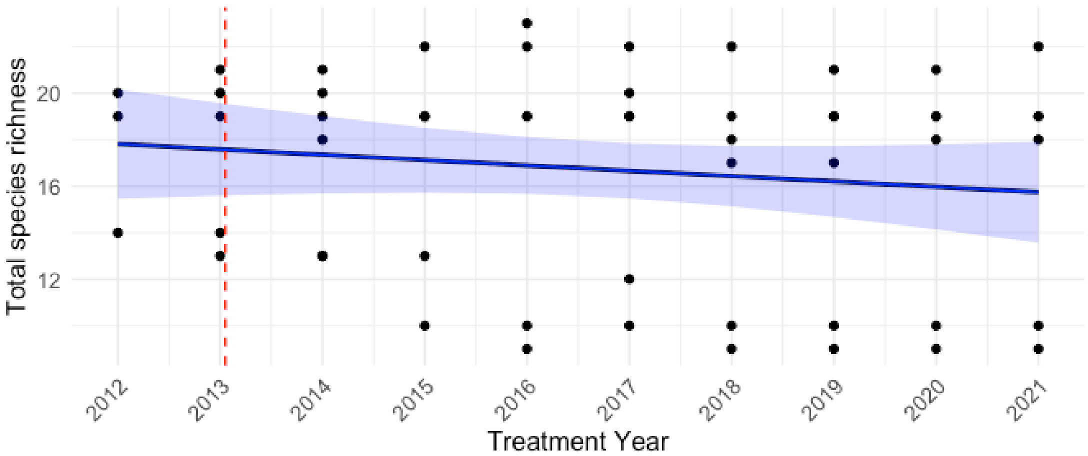
Graph 33: Boxplot of the TSR for each transect, at impact Swamp 5, contrasted against control swamps

No statistically significant difference between TSR at Swamp 5 and control sites (Table 35) have been detected to date, including 2021.

Table 35: Comparison of mean TSR between swamp 5 and control swamps over 2-year periods

Comparison	Test statistic	D.f.	P-value
2014–2015	2.51	1.15	0.215
2015–2016	2.76	2	0.11
2016–2017	4.38	1.15	0.119
2017–2018	4.26	1.47	0.085
2018–2019	2.94	2	0.099
2019–2020	1.77	1.95	0.221
2020–2021	1.49	1	0.376

Post mining at Swamp 5, TSR has been more variable, however no statistically significant breakpoints are identified in analysis and the variation in the data explained by this model was very low (Graph 34).



Best breakpoint analysis model as determined by AIC model section (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Graph 34: Breakpoint analysis showing best fitting models at Impact Upland Swamp 5

3.5.2.6.2 Species composition

The species composition analysis has not identified any statistically significant difference in the pre and post mining data to date (Table 35).

Table 36: Species composition at swamp 5 over 2-year periods

Comparison	P-value (pre-post mining)	Percentage of deviance
2013–2014	0.511	0.597
2014–2015	0.947	0.602
2015–2016	0.876	0.685
2016–2017	0.765	0.722
2017–2018	0.627	0.706
2018–2019	0.824	0.637
2019–2020	0.651	0.571
2020–2021	0.705	0.566

3.5.2.6.3 Performance measure summary

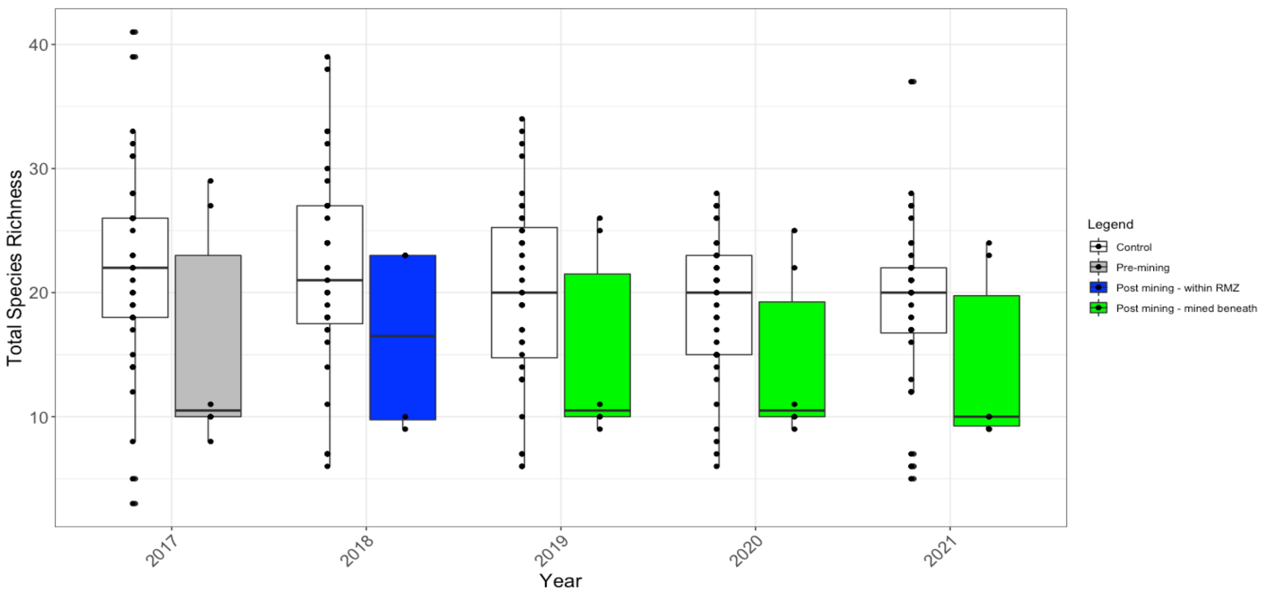
There were no TARPs triggered for Swamp 5 in 2021 or historically. Further, there are no statistically significant trends in the TSR or composition data, which appear to have little to no change when compared to data for Control sites. This may be due to the condition of the Upland Swamp before mining commenced. Swamp 5 is a long, narrow swamp, potentially indicating a marginal/transitional Upland Swamp, with adjoining woodland species likely more prominent.

3.5.2.7 Swamp 23

Monitoring at Swamp 23 began in 2017 with one year of pre-mining baseline monitoring. Mining within the RMZ commenced in 2017 and the swamp was mined beneath by 2019. A total of 47 unique species have been detected at Swamp 23 over the monitoring period, of which 17% were detected only once.

3.5.2.7.1 TSR

Prior to mining, TSR at Swamp 23 was lower than that of the controls, which have also shown a greater degree of inter-year variability than that of Swamp 23 (Graph 35). Overall, there is a slight reduction in TSR observed at Swamp 23 over the course of the monitoring period, this is also seen at the control sites, although median TSR at the control has been relatively stable since 2019.



The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentile), and the whiskers of the boxplot cover 1.5 times the IQR of the data. Boxes shaded white are Control Upland Swamps, boxes shaded grey are Impact swamps that are Pre-mining, boxes shaded blue are Post-mining - within RMZ, and boxes shaded green are Post-mining - mined beneath. Solid black points are the observations. See Table 1 for mining progress, number and status of Upland Swamps at the year surveyed.

Graph 35: Boxplot of the TSR for each transect, at Impact Swamp 23, contrasted against Control Upland Swamps

A statistically significant difference in TSR between Swamp 23 and the control swamps has been detected in each year post-mining, over three consecutive years (Table 37). Due to the limited data series, additional breakpoint analysis will be completed in future iterations of the monitoring program as more data is collected.

Table 37: Comparison of mean TSR between Swamp 23 and control swamps over 2-year periods

Comparison	Test statistic	D.f.	P-value
2018–2019	19.86	1	**0.032**
2019–2020	18.24	1	**0.035**
2020–2021	17.58	1	**0.036**

3.5.2.7.2 Species composition

No statistically significant difference in species composition pre and post mining at Swamp 23 has been detected, including in 2021 (Table 38).

Table 38: Species composition at Swamp 23 over 2-year periods

Comparison	P-value (pre-post mining)	Percentage of deviance
2018–2019	0.729	0.617
2019–2020	0.573	0.627
2020–2021	0.436	0.54

Similar to observations made at Swamp 15B (Section 3.5.1.2, the most commonly recorded species *Gleichenia dicarpa/ microphylla* sp complex (Pouched coral fern) can be used as an indicator of reduced water availability. The senescing Pouched Coral Fern also creates a dense biomass which is difficult for other recruiting species to penetrate, which may initially result in die-back. However, over time as the plants decompose, Pouched Coral Fern may regenerate in these areas as rainfall returns, or new species will likely be recruited in its place, which may change the composition (but not necessarily the health) of the Upland Swamp.

3.5.2.7.3 Performance measure summary

Table 39 details the historical TARP triggers for Swamp 23. There was a Level 1 TSR TARP triggered for Swamp 23 in 2020, this has progressed to a Level 2 TARP in 2021. No statistically significant change in species composition has been detected. This Upland Swamp should continue to be monitored and allow more time since mining to observe if any further changes arise.

Table 39: Historical TARP triggers for Swamp 23

Years	TSR TARP	Composition TARP
2019	None	None
2020	Level 1 (two consecutive years) • 2018-2019 • 2019-2020	None
2021	Level 2 (three consecutive years): • 2018-2019 • 2019-2020 • 2020-2020	None
Total times triggered	**2**	**0**

3.6 Littlejohn's Tree Frog monitoring

The following sections describe the biological and physical data collection results for 2021 in the context of previous years of monitoring and detail the outcomes of statistical analysis to test for trends in Littlejohn's Tree Frog counts associated with mining and habitat characteristics. The detection data for all transects across the program is presented in Annex 4, with statistical outputs tabulated in Annex 5.

An assessment against performance measures for the relevant TARP's is provided in section 3.6.4.2 for Dendrobium Area 3A and 3.6.5.2 for Dendrobium Area 3B.

3.6.1 Monitoring results summary across Dendrobium Area 3

A summary of the Littlejohn's Tree Frog (*Litoria littlejohni*) data for all lifecycle stages (i.e. adult, Tadpole or Eggmass) that were recorded across the entire monitoring program, noting that more sites were added over time, is provided in Table 40. When considered in the context of previous years of monitoring, 2021 recorded lower levels of detection across each lifecycle stage than the previous high rainfall year of 2020 and even the lower rainfall year of 2019.

Table 40: Total Littlejohn's Tree Frog abundance by life stage for all years of monitoring

Year	Number of impact transects	Number of Control transects	Number of pre-mining transects	Tadpoles	Eggmass*	Adults
2006	3	1	1	7	0	79
2007	4	2	2	162	14	104
2008	5	2	2	261	95	41
2009	5	3	2	464	198	54
2010	8	4	2	1036	930	86
2011	8	6	2	362	155	172
2012	8	6	2	283	325	106
2013	11	8	2	950	368	110
2014	11	8	2	956	387	148
2015	11	8	2	1061	644	149
2016	11	8	2	6147	2664	273
2017	11	8	2	1166	481	169
2018	11	8	2	1082	385	129
2019	11	8	2	3290	305	242
2020	11	8	2	4756	140	230
2021	**11**	**8**	2	**2358**	**477***	**61**

**Includes both viable and non-viable Eggmass, as evidence of breeding activity*

A summary of the detection results for the 2021 season are provided in Table 41 below. Littlejohn's Tree Frog were detected in at least one lifecycle stage at all eleven post-mining (mined beneath and within RMZ) impact sites, with the exception of SC10C. At least one lifecycle stage was detected at all control sites monitored in 2021.

When considered as broad groups, the number of Tadpoles and Adults recorded in 2021 were comparable between the impact and controls sites, however Eggmass detection was noticeably lower at the impact sites. This is despite the generally slightly longer distances and greater number of breeding pools on average across the impact transects.

Notably, more non-viable Eggmass were recorded than viable Eggmass across all treatments and the majority, but not all, individual transects. The total number of non-viable Eggmass observed was somewhat higher at the control sites in 2021, with the highest number detected at transect ND1. Approximately 71% of all Eggmass detected across the control sites were recorded as non-viable, whereas approximately 88% were recorded as non-viable across the impact sites.

Table 41: Summary Littlejohn's Tree Frog detection results for 2021

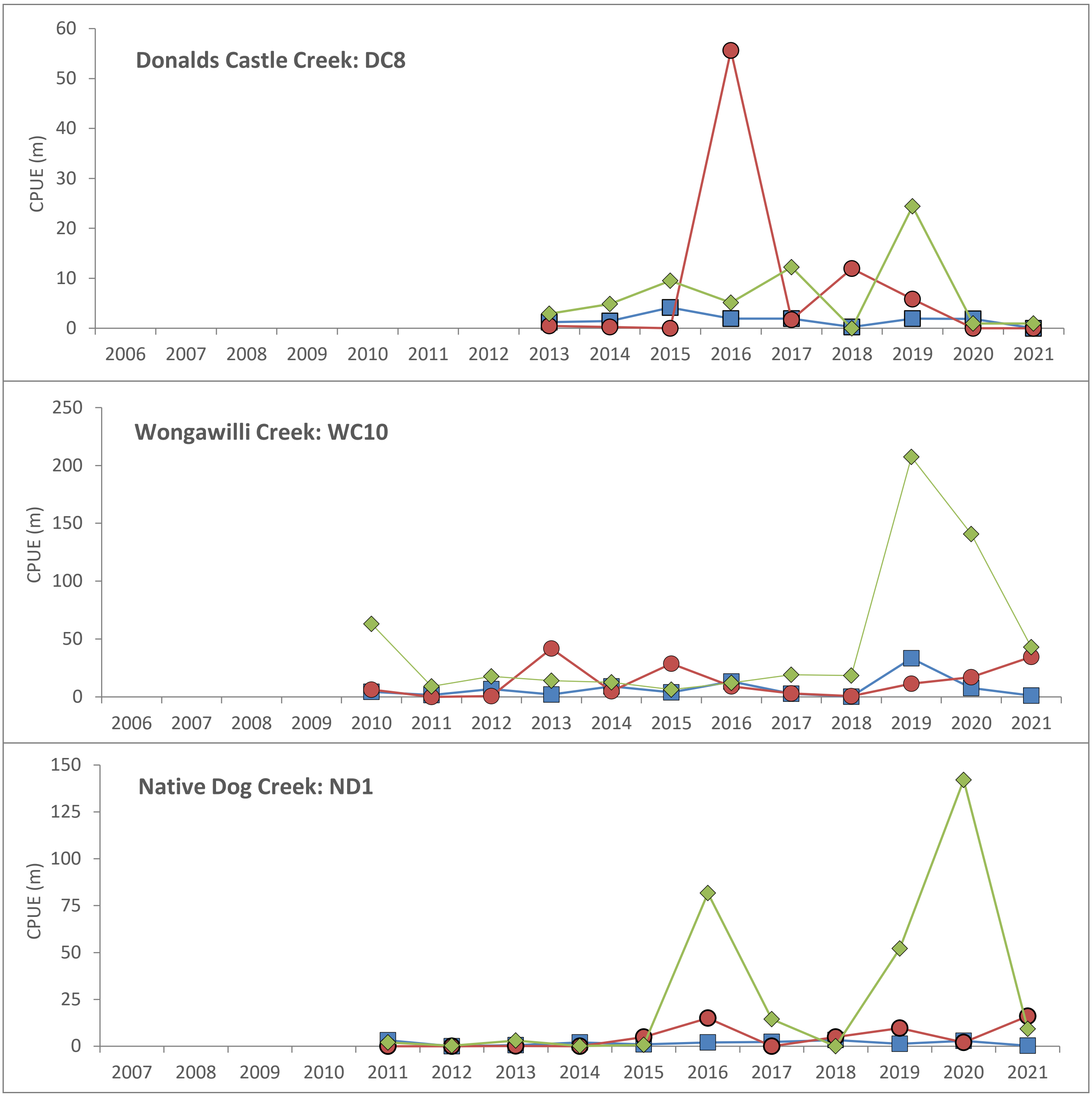
Area	Transect	Total Tadpoles	Total Adults	Total Eggmass*	Total viable Eggmass	Total non-viable Eggmass	Transect length	Number breeding pools**
Control:		**1093**	**19**	**357**	**103**	**254**	**3376**	**126**
3A	SC7(1)	111	57	17	17	40	474	20
3A	SC7(2)	191	1	0	0	1	436	9
3A	SC7A	525	44	1	1	43	453	22
3A	SC8	6	10	0	0	10	315	21
3B	ND1	69	119	5	5	114	742	26
Outside	DC8	4	0	0	0	0	432	3
Outside	WC10	149	120	78	78	42	346	19
Outside	WC11	38	6	2	2	4	176	6
Impact:		**1238**	**36**	**119**	**14**	**105**	**6197**	**189**
3A	6CDL	765	2	2	2	0	89	8
3A	SC10(1)	0	0	0	0	0	539	15
3A	SC10(2)	138	92	4	4	88	950	36
3A	SC10C	0	0	0	0	0	481	12
3A	WC17	63	0	0	0	0	177	7
3B	WC15	0	0	0	0	0	478	16
3B	DC(1)	6	10	0	0	10	642	17
3B	LA4A	2	0	0	0	0	209	3
3B	LA2	0	0	0	0	0	593	23
3B	DC13	169	13	8	8	5	641	17
3B	WC21	95	2	0	0	2	1399	35
Pre-mining		**27**	**6**	**1**	**0**	**1**	**678**	**25**
3B	ND2	8	0	0	0	0	123	7
3B	NDC	19	1	0	0	1	555	18

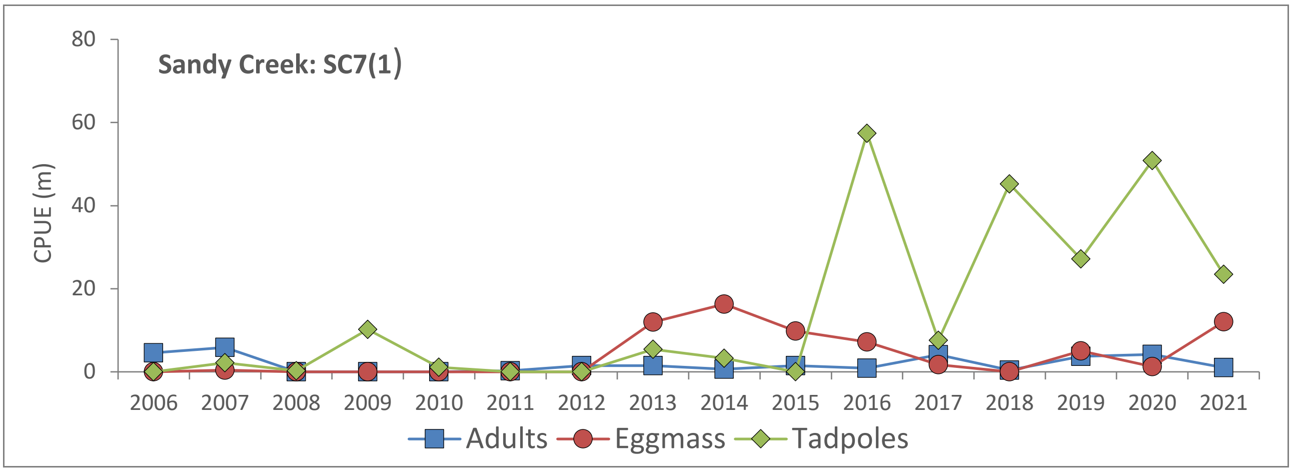
**Includes both viable and non-viable Eggmass.*

***Includes only pools marked in previous pool mapping.*

3.6.2 Patterns of abundance across un-impacted sub-catchment areas

Dendrobium Area 3 occurs across four main sub-catchments. The Donalds Castle Creek and Wongawilli Creek sub-catchments flow northwards out of Area 3 and join before flowing out to the Cordeaux River. Native Dog Creek flows west to Lake Avon, having a relatively smaller sub-catchment area to the others. The Sandy Creek sub-catchment flows north-east into Lake Cordeaux. Each of these sub-catchments are represented by control and impact or pre-mining transects. A summary of the data collected at each of these sub-catchments over time is presented in the following series of graphs (Graph 36). Each sub-catchment is represented by one control, selected based on the highest or most consistent level of detection. This series of graphs is presented in order to establish whether there are any general patterns of change across un-impacted areas of Dendrobium Area 3 to provide context for the presentation and interpretation of data from the impact sites, and comparisons between the impact and control sites.





Graph 36: Littlejohn's Tree Frog detection between 2007 - 2021 at control sites DC8, WC10, ND1 and SC7(1)

Graph 36 demonstrates a high degree of variability across years, lifecycle stages and across sub-catchments. The datasets are characterised by typically low levels of detection with some peaks in individual years. These peaks in detection are generally not consistent across the sub-catchments and do not necessarily follow predictable patterns i.e. peaks in adult detection do not typically align with peaks in Eggmass detection, nor does Tadpole detection appear to peak following relatively high numbers of Eggmass being recorded. Interestingly, while a reduction in detection is apparent across transects and lifecycle stages there is also no uniform response (in terms of scale or timing) to the recent drought evident (2017-2019) with some peaks in detection also occurring during this period.

These graphs presented serve to underline the unpredictability in detection of this species, complex relationship between lifecycle-stages and their likely connection to environmental variables at a population scale. These complex and unpredictable pattens may be suggestive of several factors beyond the scope of this program to investigate, including a propensity in the species for movement across sites, breeding activity occurring over an extended period of the year and possibly differing fine scale environmental conditions, and responses in the species, across the sub-catchments or transects to prevailing conditions. To a limited extent this may also reflect a limitation of single survey approach in the Program. The interpretation of the results detailed in the following sections must be considered in this context and supported by assessment of habitat features as well as frog detection.

3.6.3 Pool characteristics and trends recorded across Dendrobium Area 3

The pool characteristics recorded during the 2021 surveys for Littlejohn's Tree Frog are summarised in Table 42 below. Pool depths are variable across all transects, and within transects. The depth estimates for each pool indicate generally slightly deeper pools at the control sites, with moderate and deeper pools combined representing 28% of all pools in this treatment, compared to 26% at the impact sites. Importantly, the average pool water level estimate indicates much higher average pool water levels at the control sites (82%) when compared to the impact sites (53%). In contrast, the number of pools with observations of flocculant were higher at the impact sites (24%) compared to that of the control sites (2%).

The pre-mining sites have been previously impacted by extraction associated with the Elouera Colliery (as identified in section 2.4). These sites have not been subject to any impacts associated with extraction from Dendrobium Area 3A or 3B, which in 2021 had not entered within the RMZ of these transects. At these transects deeper pools are more dominant with moderate and deeper pools combined representing 60% of all pools in this treatment and all pools across the these transects being full. Transect NDC recorded by far the highest number of flocculant observations, with flocculant also recorded in more than half of the pools at transect ND2 which is a connected tributary to NDC.

Overall, these results indicate potentially somewhat more favourable pool sizes at the control sites, but also that the prevailing environmental conditions during the 2021 surveys (water availability and absence of flocculant) were also generally more favourable for the Littlejohn's Tree Frog at the control sites. While the pre-mining sites represent favourable attributes in terms of pool size composition and water availability, the level of flocculant is greatest at these transects.

Table 42: Pool characteristics recorded during the 2021 field survey

Transect	No. of pools*	Deep >100 cm	Moderate 100-50 cm	Shallow 50-25 cm	Very Shallow <25 cm	Average pool water level (%)	Count of pools with flocculant
Control	**127**	**7**	**28**	**57**	**35**	**82**	**2**
		6%	**22%**	**45%**	**28%**		**2%**
SC7(1)	22	1	2	9	10	97	1
SC7(2)	9		1	3	5	70	
SC7A	21	1	7	9	4	95	
SC8	22	1	3	9	9	74	1
ND1	26	2	8	14	2	71	
DC8	3		3			100	
WC10	19	2	3	11	3	68	
WC11	5		1	2	2	85	
Post-mining	**195**	**27**	**24**	**79**	**65**	**53**	**46**
		14%	**12%**	**41%**	**33%**		**24%**
6CDL	9	2		4	3	36	1
SC10(1)	20	8	1	7	4	100	17
SC10(2)	36	1	5	9	21	99	3
SC10C	12		3	4	5	53	6
WC17	7	1	1	2	3	97	7
WC15	16	1	4	10	1	3	
DC(1)	17	2	3	3	9	71	4
LA4A	4			2	2	29	
LA2	24	4	3	13	4	1	

Transect	No. of pools*	Deep >100 cm	Moderate 100-50 cm	Shallow 50-25 cm	Very Shallow <25 cm	Average pool water level (%)	Count of pools with flocculant
DC13	17		1	7	9	31	
WC21	33	8	3	18	4	36	8
Pre-mining	**25**	**7**	**8**	**8**	**2**	**100**	**22**
		28%	**32%**	**32%**	**8%**		**88%**
ND2	7		2	4	1	100	4
NDC	18	7	6	4	1	100	18

**Includes incidental records of Littlejohn's Tree Frog, not associated with previously marked breeding pools.*

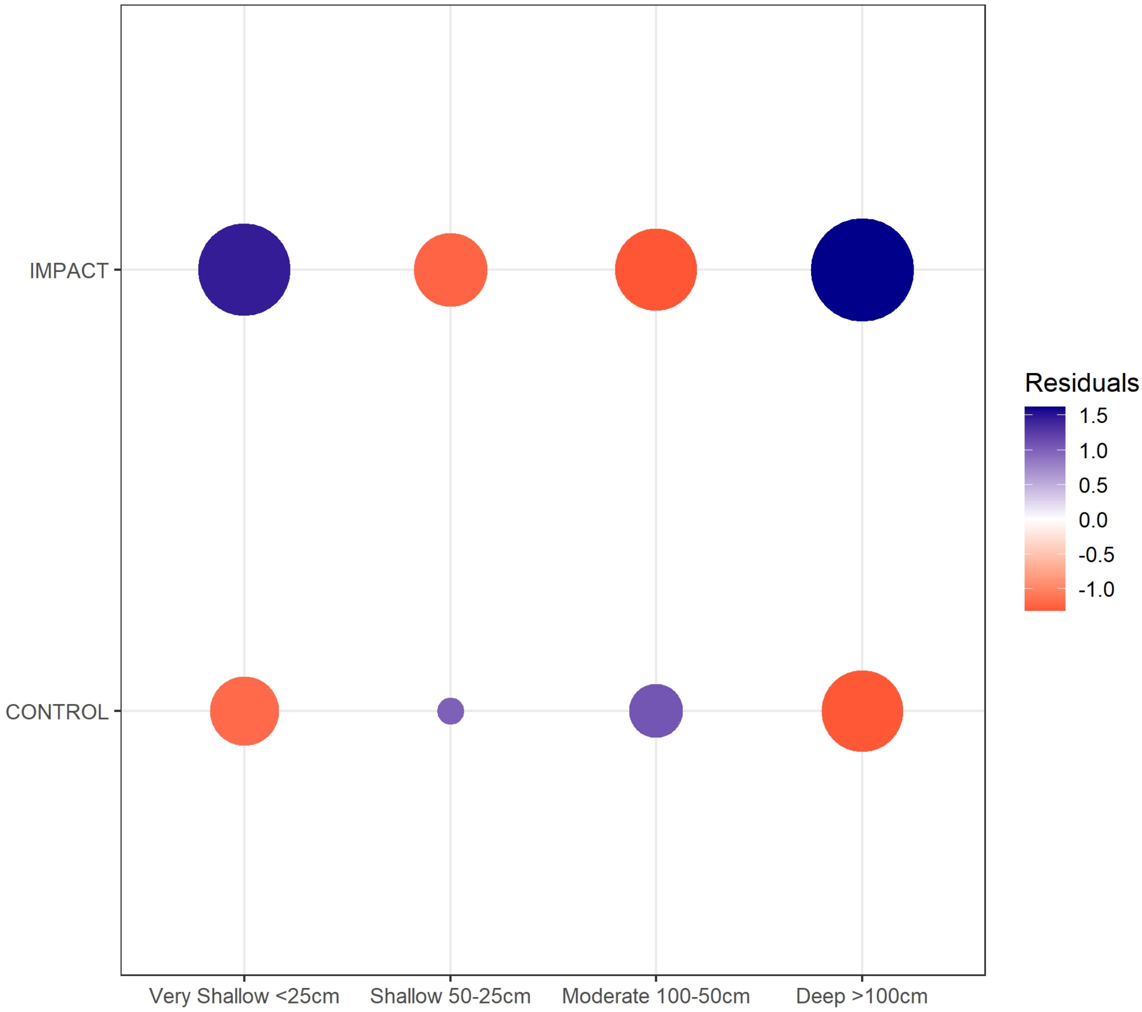
Statistical analyses has been completed to explore the difference between impact and control transect pool characteristics for Dendrobium Area 3A and 3B, to provide further context for the interpretation of the biological frog detection data. Note that these analyses only consider maximum pool depth as a proxy for pool size, to understand potential habitat conditions, this does not take into account the water level within the pool which may be influenced by other factors (e.g. rainfall or mining impact).

These exploratory analyses indicate that there are statistically significant differences between pool characteristics at the area level between Dendrobium Area 3A and 3B when compared to the control sites. Across the Dendrobium Area 3A impact transects there is a greater proportion of very deep and very shallow pools, indicating a potentially greater degree of habitat variation along these transects. Across Dendrobium Area 3B moderate pools were more common at the control transects than at the impact sites, with the impact sites having a greater number of very deep pools.

The findings underscore the importance of three factors in the monitoring approach. First, the importance of pre-mining data in the analysis. Second, consideration of the transect based statistical analysis in the context of potentially more variable habitat conditions at the control sites and more optimal habitat features generally among the control group. Third, the incorporation of multiple assessment methods including habitat/impact observations and semi-quantitate assessment of breeding habitat conditions to support the interpretation of the statistical analysis and consideration of trends in the biological data over time.

3.6.3.1 Dendrobium Area 3A pool characteristics

There were statistically significantly different pool characteristics between Control, Pre-mining (NDC and ND2) and the Impact sites at Dendrobium Area 3A (χ^2 = 13.22, df = 3, p = 0.004). When considering the Dendrobium Area 3A impact transects against the control transects, very shallow and also very deep pools were underrepresented at Control Sites in comparison to the Impact Sites (Graph 37).



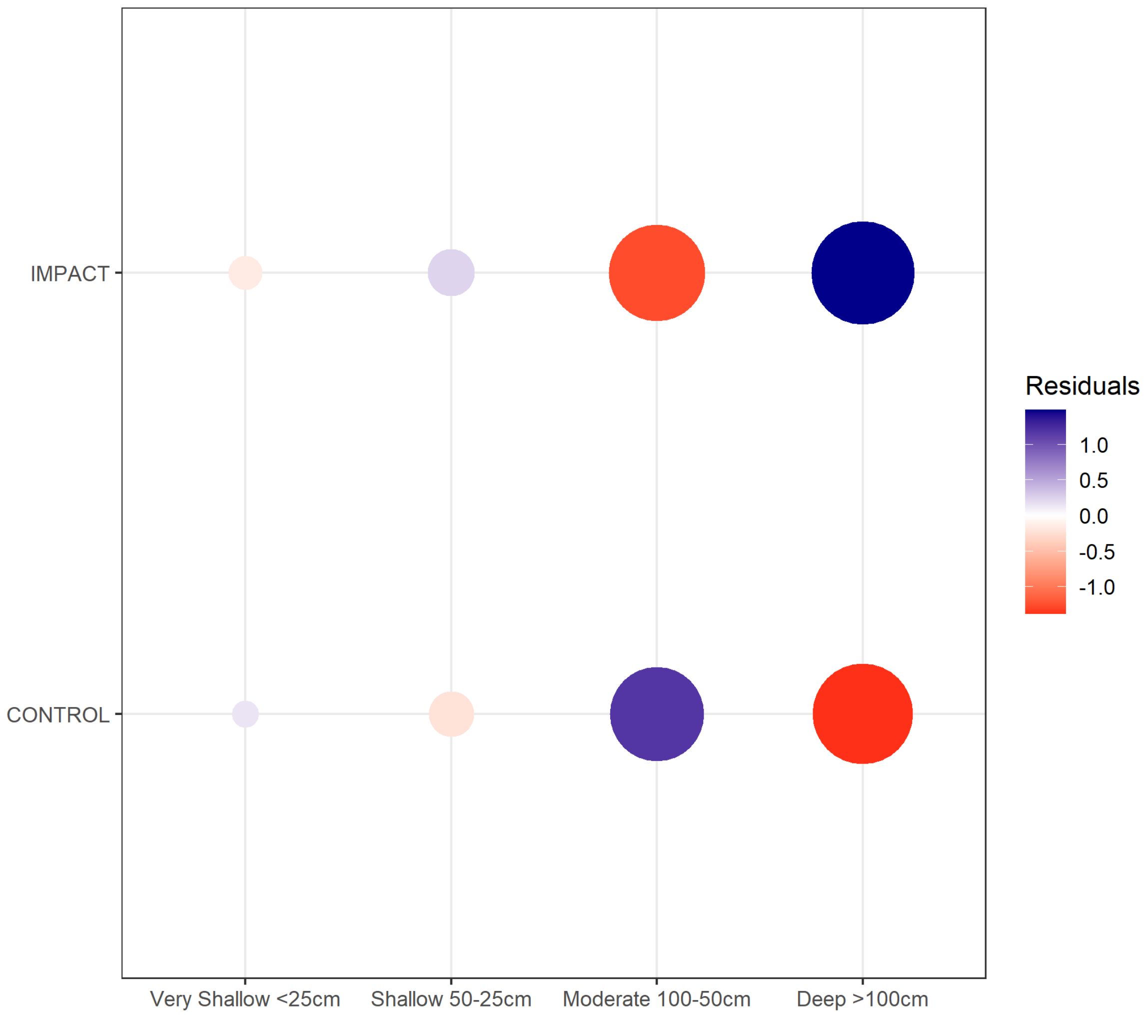
Graph 37: Residual scores from χ^2 test of independence for pools size distribution amongst control (n=127) and impact (n=84) transects.

The colour scale, blue-red indicates overrepresented-underrepresented, while size of the circle indicates the degree. For example, a small red circle means slightly underrepresented, while a large blue circle means strongly overrepresented.

A statistically significant relationship between detection and pool size was identified for Adults (p-value: 0.003), Tadpoles (p-value: 0.027) and Eggmass (p-value: 0.027). Most Adults and Tadpoles were detected in Deep pools, while Eggmasses were more evenly spread.

3.6.3.2 Dendrobium Area 3B pool characteristics

There were also statistically significantly different pool characteristics between Control, Pre-mining (NDC and ND2) and the Impact sites at Dendrobium Area 3B (χ^2= 20.28, df = 6, p-value = 0.002) (Graph 38). When considering the Dendrobium Area 3B impact transects against the control transects, there were more moderate pools at the Control transects and more very deep pools at the Impact transects (Graph 38).



Graph 38: Residual scores from χ^2 test of independence for pools size distribution amongst control (n=127) and impact (n=111) sites.

The colour scale, blue-red indicates Overrepresented-Underrepresented, while size of the circle indicates the degree. For example, a small red circle means slightly underrepresented, while a large blue circle means strongly overrepresented.

A statistically significant relationship between detection and pool size was identified for Adults (p-value: 0.003), Tadpoles (p-value: 0.027) and Eggmass (p-value: 0.027). Most Adults and Tadpoles were detected in Deep pools, while Eggmasses were more evenly spread.

3.6.3.3 Distance to longwalls and flocculant

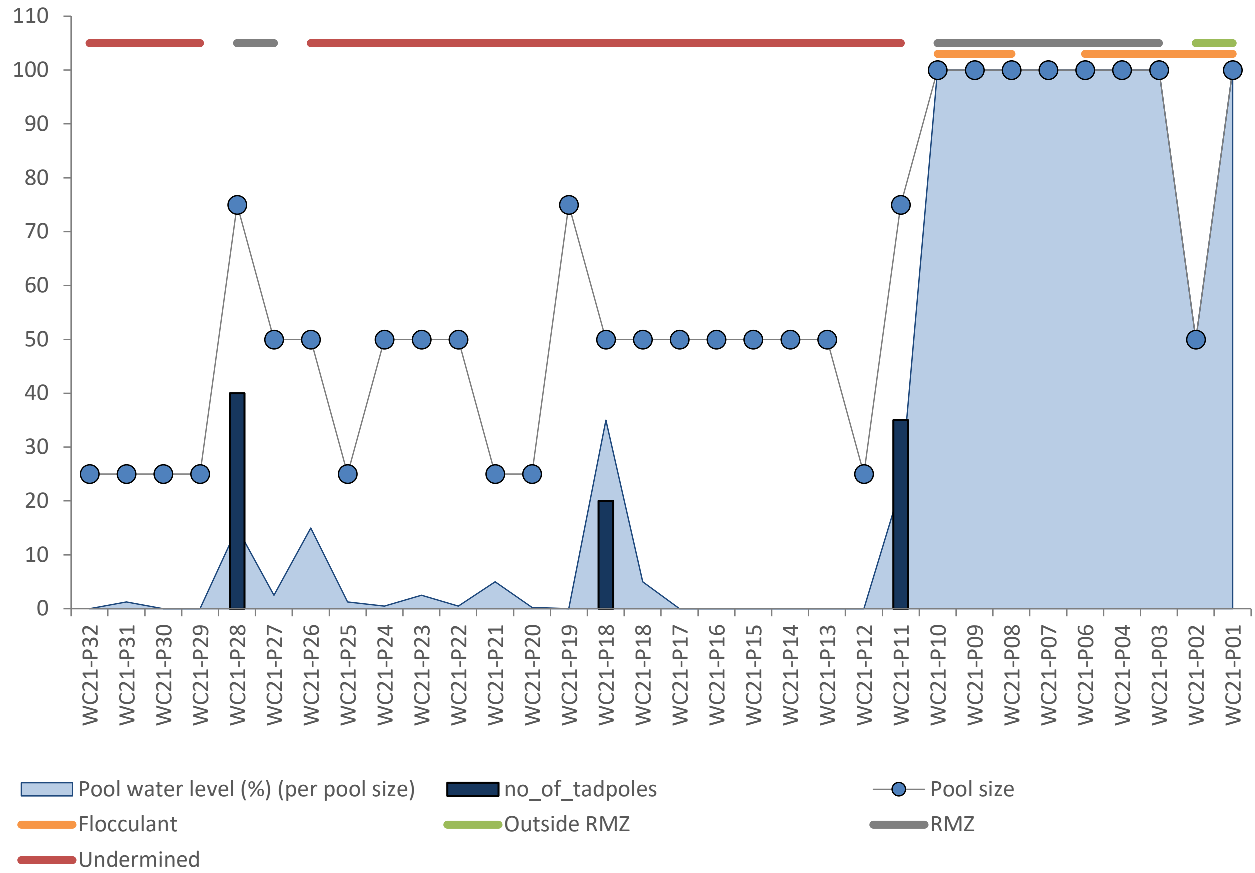
Two avenues for further analysis to better understand trends apparent within the Program are the distance of each longwall and the presence of flocculant. Consideration of the distance to longwall for each pool allows assessment of possible relationships between these factors, separate to the broader control and impact classification applied at the transect level.

These analyses follow observations in the field and in the detection dataset that counts of Littlejohn's Tree Frogs are lower in mined beneath areas, where any impacts to water quantity are likely to be greatest, and also in pools with flocculant present. These trends are visually represented by the 2021 Tadpole detection data from impact transect WC21 (Graph 39). Transect WC21 is 1399 metres in length and features sections that are mined beneath, within RMZ and outside RMZ, with a range of pool sizes, water levels and pools with flocculant.

It can be seen that pools sizes are variable and generally increase from upstream to downstream along the transect. Pool water levels are typically low for the majority of the upstream extent of the transect (to pool 12), which coincides with areas that are mined beneath, although local peaks in pool water level remain in these minded beneath areas. Pool water levels increase notably downstream of the mined beneath section of the transect (i.e. downstream of pool 12), although flocculant is also present in the majority of pools in these section. Tadpoles have been detected in sections of WC21 that are:

- In pools of shallow or moderate depth, with locally high relative water availability.
- Tadpoles were not identified in pools where flocculant was observed, despite the presence of larger pools and highest water levels.

Water levels are consistently higher outside of mined beneath sections in this transect. However, the relationship to Tadpole detection is complex with Tadpoles still detected in mined beneath sections, such as in pool 18 where water availability is locally high and coincides with a moderate sized pool, and in pool 11 (the last mined beneath pool) where water availability is increasing with pool size, but flocculant has not yet occurred. These trends have been statistically tested in the following section.



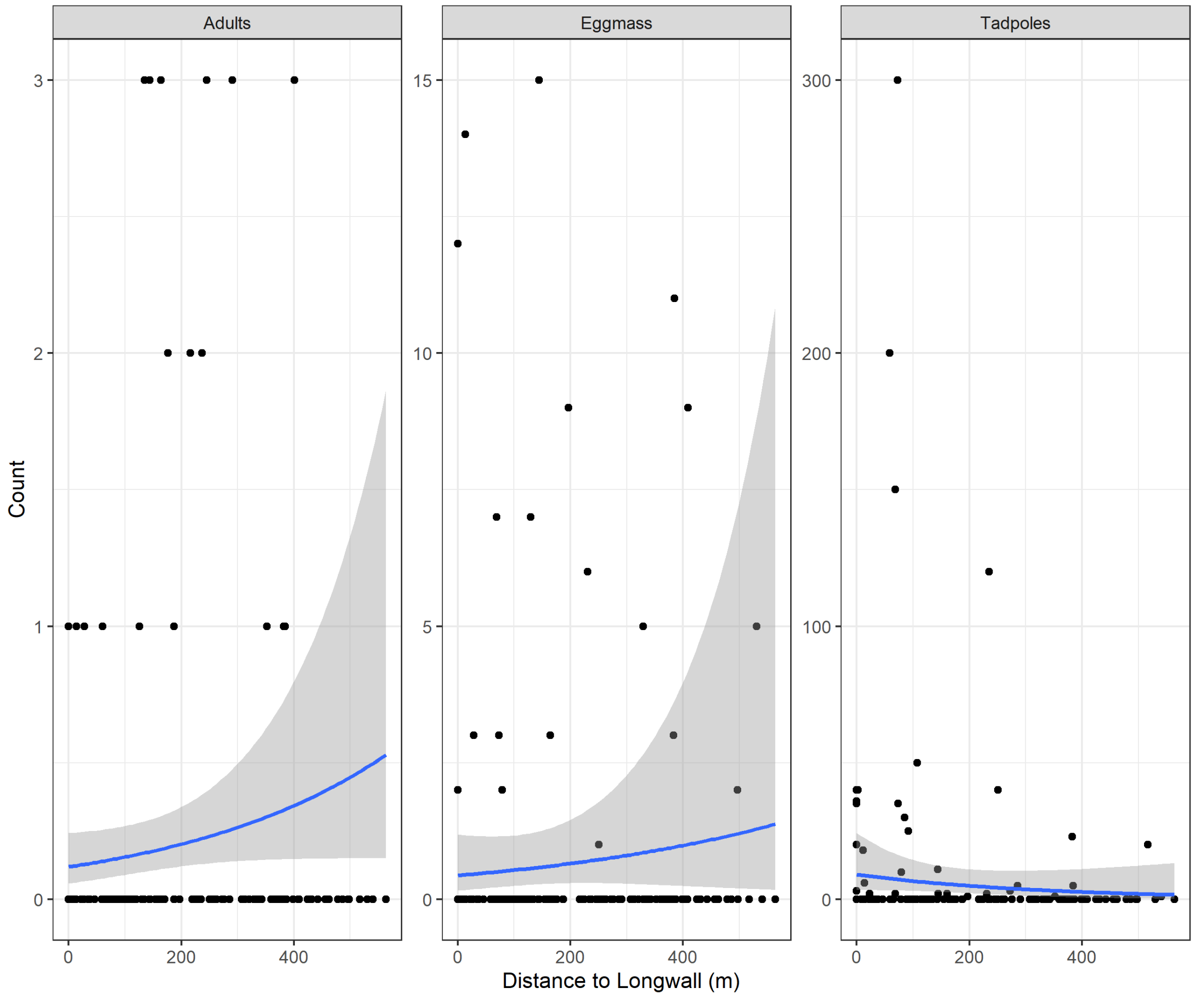
Graph 39: Transect WC21 showing Tadpole detection with pool characteristics, water level, flocculant and mine risk status of each pool.

Note: Upstream (left) to downstream (right). The four pool size categories are shown as very shallow (25), shallow (50), moderate (75), deep (100).

3.6.3.3.1 Distance to longwall

To investigate whether the distance of pools to the closest longwall were statistically significantly related to Littlejohn's Tree Frog detection, data from all impact transects from Dendrobium Area 3A and 3B are pooled together (Control and Pre-mining transects were excluded). The significance of pool distance to longwall could not be statistically tested at the within transect scale due to the high number of zero counts.

Analysis of deviance was undertaken for negative binomial generalised linear models describing Counts of each lifecycle stage as a function of distance to the closest longwall, and pool size. The results did not identify any statistically significant effect of distance to longwall for any lifecycle stage. Some patterns are apparent (Graph 40), with Adults and Eggmass counts appearing to increase slightly with distance to longwall, with Tadpoles to a lesser extent decreasing slightly. Although the level of variation is high, and these patterns do not appear to be strong and are not statistically significant.



Graph 40: Analysis of deviance was undertaken for negative binomial generalised linear models describing Counts of each lifecycle stage as a function of distance to the closest longwall, and pool size

These findings align with those of Klopp-Toker et al. (2021), who also did not identify a statistically significant relationship between the relative abundance of Tadpoles and distance to the closest longwall.

3.6.3.3.2 Flocculant

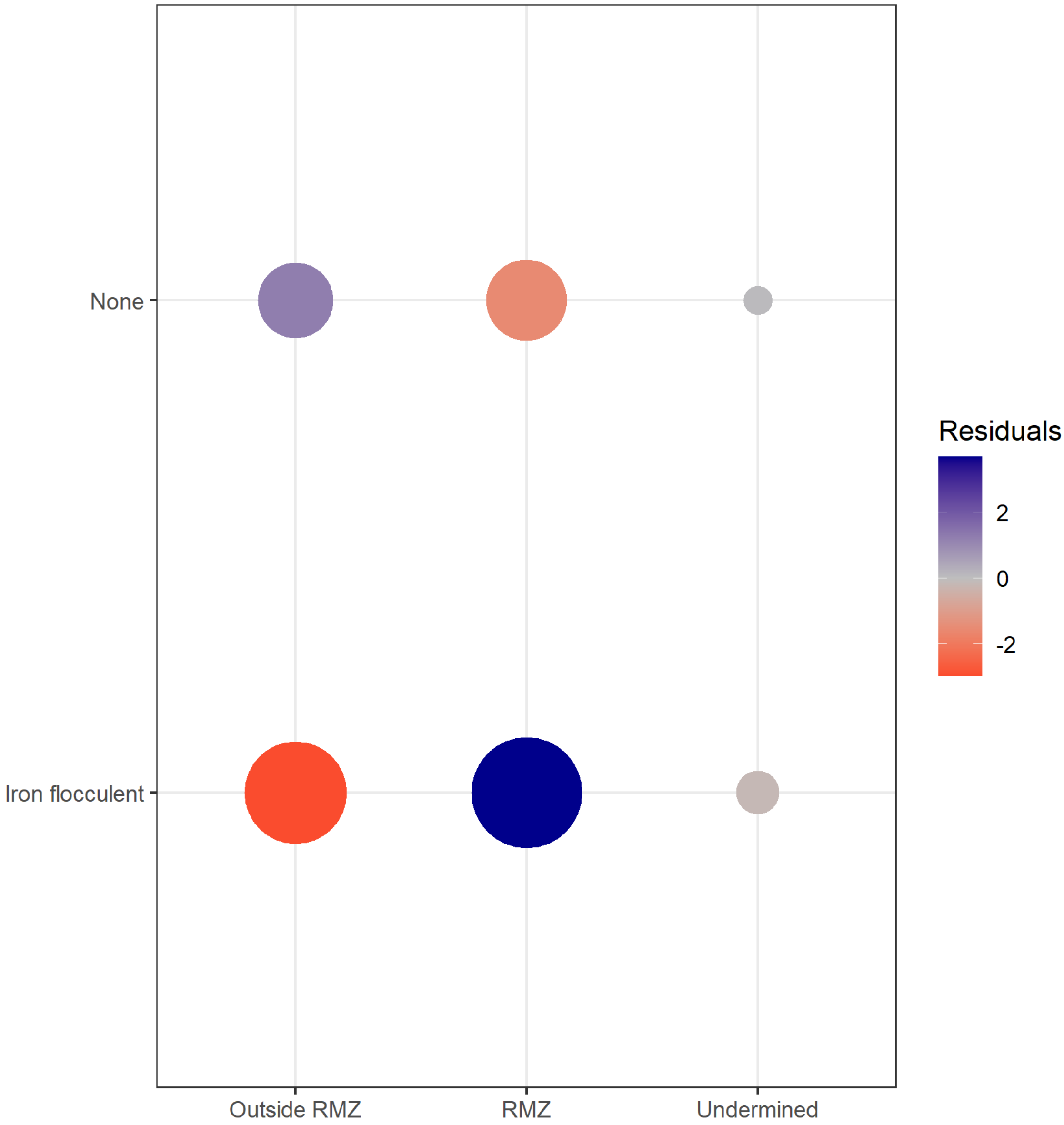
In the Program the presence of iron flocculant has been utilised as an indicator of habitat loss and as a trigger for TARP's, among other factors. Klop-Toker et al. (2021) also observed that Tadpoles were generally absent from pools with iron flocculant, with Tadpole presence and iron flocculant negatively correlated. Indicating these pools are not utilised for breeding and may indicate habitat loss.

Statistical analysis of the 2021 dataset has been undertaken to assess the relationship between iron flocculant and frog detection in the context of the Program. The analyses identified a statistically significant effect of flocculant on the detection of Adults (p-value = 0.005) and Eggmasses (p-value = 0.040), with both lifecycle stages detected in statistically significantly greater numbers where flocculant was absent. A statistically significant effect was not identified for Tadpoles, although the average detection in pools with flocculant (2.3 Tadpoles) is lower than that where flocculant is absent (7.9 Tadpoles). It is also noted that there was variability across the detection dataset and individuals of each lifecycle stage were detected in areas of flocculant to some degree.

The proportion of pools with and without flocculant was also related to mining risk ($\chi^2 = 26.4$, df = 2, $p<0.001$). Proportionally, flocculant was observed in only 5% of pools that have mining outside the RMZ, 41% of pools with mining within the RMZ, and 16% of pools that have been mined under (Table 43). Graph 41 shows how Iron flocculant was overrepresented in stream sections which had mining within the RMZ, and least common in sections outside the RMZ.

Table 43: Observations of flocculant relative to the risk status of the individual pool

Flocculant	Outside RMZ	Within RMZ	Mined under
Present	8	30	10
Absent	139	74	61



Graph 41: Residual scores from χ^2 test of independence for pools with flocculant among pools that are Outside RMZ (n=147), Within RMX (n=104) and Mined under (n=71).

The colour scale, blue-red indicates overrepresented-underrepresented, while size of the circle indicates the degree. For example, a small red circle means slightly underrepresented, while a large blue circle means strongly overrepresented.

These findings suggest that flocculant is more likely to occur at the Impact transects than Control transects and most likely at transects where mining is within the RMZ of the stream. Additionally, that where flocculant does occur, Littlejohn's Tree Frogs are less likely to be present with this likelihood statistically significantly reduced for the Adult and Eggmass lifecycle stages.

3.6.4 Dendrobium Area 3A

Within Dendrobium Area 3A two main creeks and selected tributaries are monitored, with both Control and Impact sections (Figure 5):

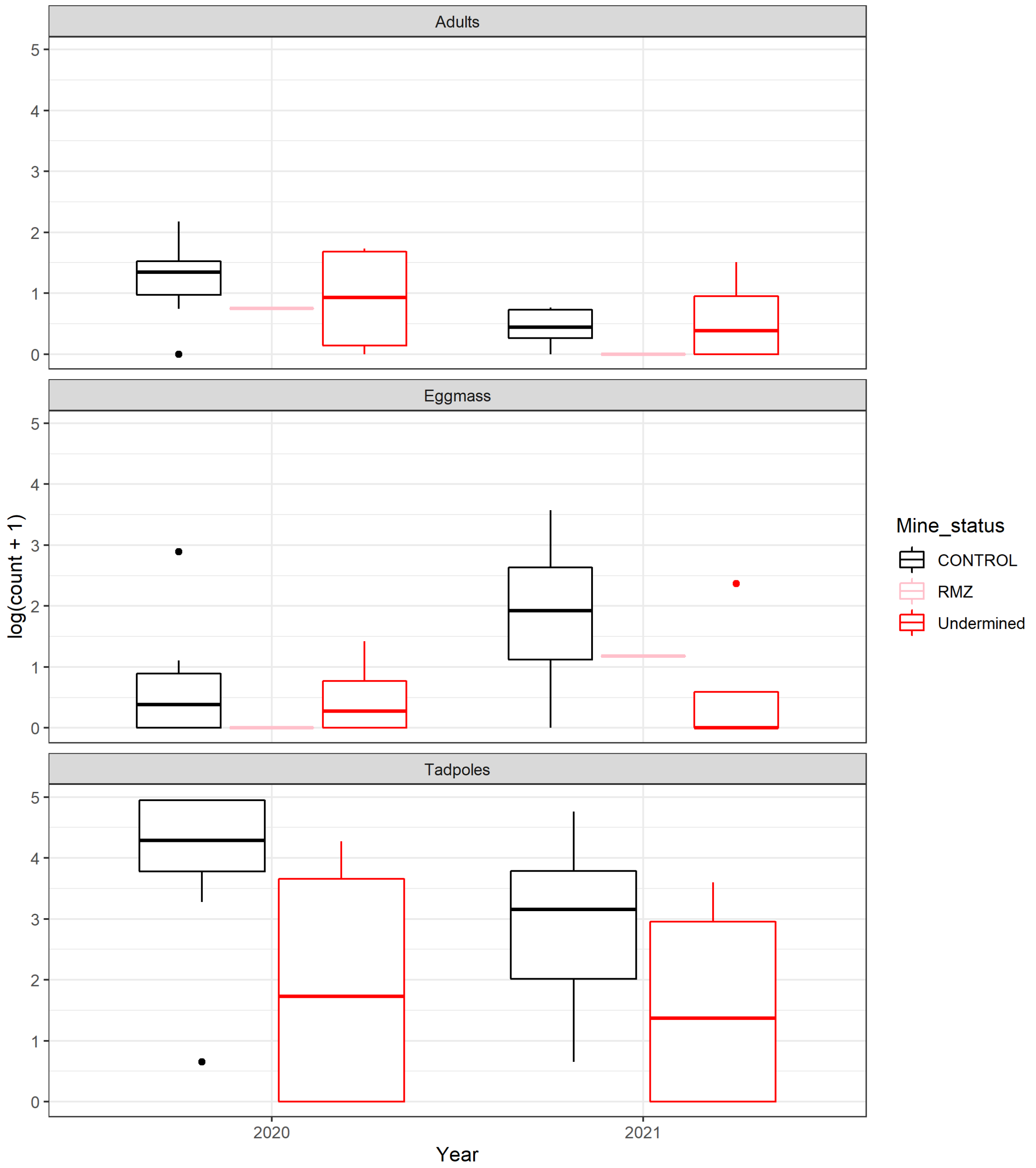
- Sandy Creek first and second order tributaries SC10C, SC10(1), SC10(2), 6CDL, SC7(1), SC7(2), SC7A and SC8
- Wongawilli Creek (third order or higher) and tributaries WC10, WC11 and WC17.

Many of these waterways and transects are interconnected, so it is likely that Littlejohn's Tree Frog move throughout these catchments in response to a number of environmental and seasonal variables which may influence breeding, recruitment and migration.

3.6.4.1 Overall trends

When comparing frog detection results from 2020 to 2021, no statistically significant difference in detection of any lifecycle stage was identified between the overall impact and control groups in 2021.

When considering the results regardless of treatment, there was a statistically significant difference in Adult counts (p-value = 0.005) and Tadpoles (p-value = 0.047), which were both reduced in 2021. Eggmass counts increased at the Control sites in 2021, whereas they were somewhat decreased at the Impact sites, but not to the level of statistical significance (Graph 42).



Graph 42: Boxplots of counts of Adults, Tadpoles, Eggmasses at Dendrobium Area 3A, 2020-2021 (left-right), and between Treatments (Control (n=8), black, Impact (n=5), red).

3.6.4.2 Assessment against performance measures Dendrobium Area 3A

A summary of the results against TARP triggers (Table 4) for Dendrobium Area 3A is presented in Table 44. No changes to TARP Level triggers have occurred in 2021 relative to those in 2020 (Niche 2021).

Table 44: Summary of TARP triggers for Transects in Dendrobium Area 3A

Transect	Results and TARP justification 2021	Additional details
6CDL	**No TARP** triggered	See section 3.6.4.3

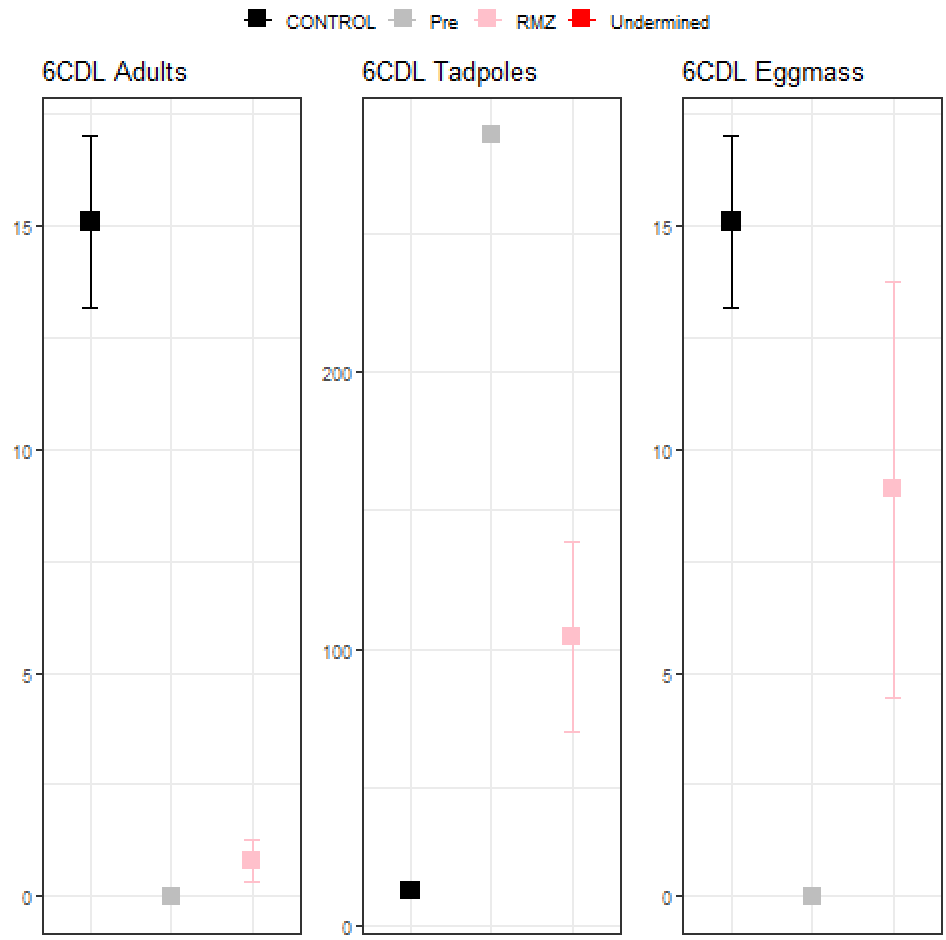
Transect	Results and TARP justification 2021	Additional details
		This tributary has been within the RMZ since 2010, 50 m away from goaf of Longwall 7. No decline in frog detection post mining has been identified.
SC10C	**Level 2 TARP** triggered due to appearance at SC10C (fractured bedrock and iron flocculant) and habitat unlikely to naturally regenerate within the monitoring period. A statistically significant decrease in the detection of Adults has occurred in the post mining period.	See section 3.6.4.4 This tributary is almost completely mined beneath by Longwall 8
SC10(1)	**Level 2 TARP** triggered due to appearance at SC10(1) (fractured bedrock and iron flocculant present at 13 of the 14 pools recorded) and habitat unlikely to naturally regenerate within the monitoring period.	See section 3.6.4.5 Longwall 8 has extended into the RMZ of the tributary across the majority of the transect. Observed indirect impacts (flocculant) were recorded in all but two pools in 2021.
SC10(2)	**No TARP** levels triggered.	See section 3.6.4.6 Longwall 8 has entered into the RMZ of the tributary across much of the transect, with a small section mined under in 2021, although sections outside the RMZ occur within its upstream extent. As in previous years, limited observations of indirect impacts (flocculant) were made at the downstream most end of the transect, but no observable pattern of adverse impacts is observed in the biological data.
WC17	**Level 2 TARP** triggered due to appearance at WC17 (iron flocculant and fractured bedrock since 2017 at WC17) and habitat unlikely to naturally regenerate within the monitoring period.	See section 3.6.4.7 Much of this tributary is mined beneath by Longwalls 7 and 8.

3.6.4.3 6CDL

6CDL had one year of pre-mining data in 2009 and first within the RMZ in 2010, due to the location of the longwalls this tributary is not planned to be mined beneath. It will remain in the RMZ and experience potential indirect impacts from the nearby Longwall 7 which is approximately 40 – 60 m away (Figure 5a).

No Adults, a large number of Tadpoles (n = 765) and two Eggmasses were observed at 6CDL during the 2021 survey.

The statistical test for trends over long-term before and after mining effects at this tributary has not been identified as statistically significant for any lifecycle stage. Any observable changes in populations also happened at the Control sites (Graph 43). Detection levels have not been observed to decline for the Adult or Eggmass lifecycle stages post mining, in fact they have increased. While the detection of the Tadpole lifestage has decreased post-mining, it is above that of the Controls.



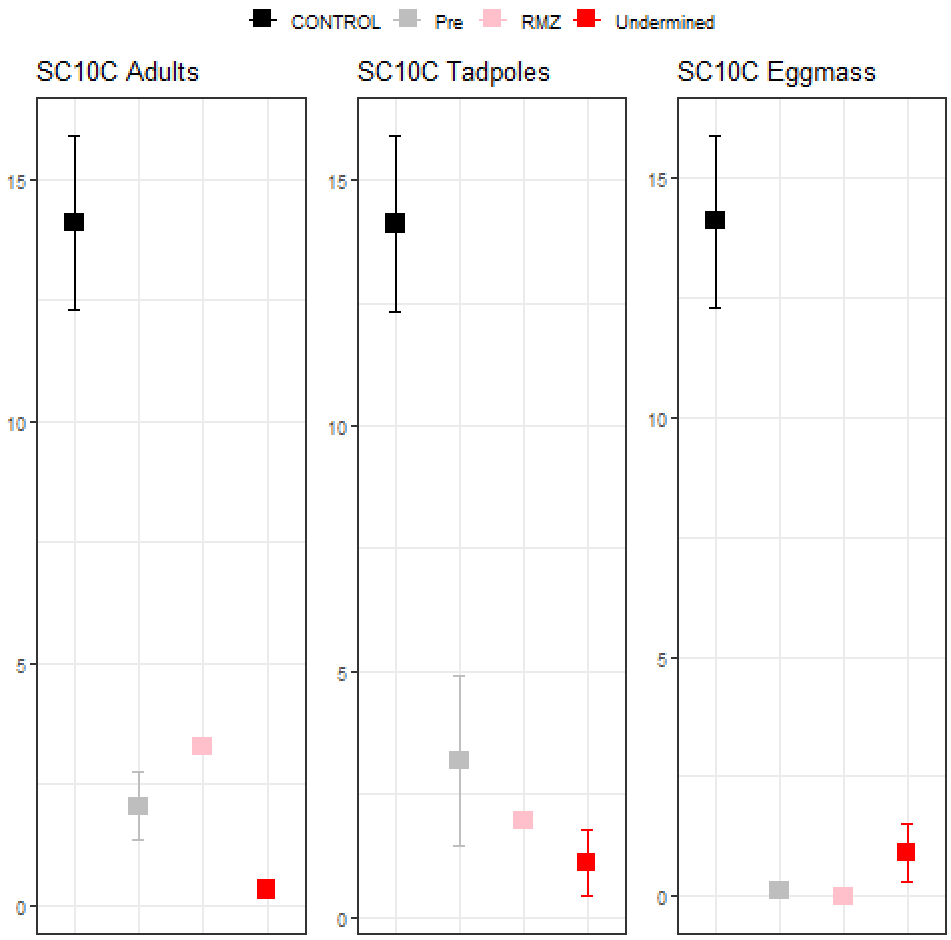
Graph 43: 6CDL mean +- SE count of Adults, Tadpoles, and Eggs at Control sites (n=8) and 6CDL for all years 6CDL has been monitored, See Table 2 for mining progress, number and status of Creeks at the year surveyed.

3.6.4.4 SC10C

Monitoring at SC10C commenced in 2006, with the extraction of Longwall 7 occurring within the transects RMZ in 2011 and Longwall 8 undermining the transect in 2012. No lifecycle stages were recorded in 2021, which also occurred in 2019 and 2017.

A statistically significant difference in detection of Adults was identified between the pre-mining period and mined under periods (p-value <.0001). Transect SC10C also recorded an increase in Adults during the single year of within RMZ monitoring, as did SC10(2). No statistically significant difference between pre and post mining detection was identified. While detection of Tadpoles can be seen to decline between the pre and mined under monitoring periods, detection of Eggmass has increased (Graph 44).

While all counts were statistically significantly higher at Control sites than the Impact site, this occurred both before and after mining.



Graph 44: SC10C mean +- SE count of Adults, Tadpoles, and Eggs at Control sites (n=8) and SC10C for all years SC10C has been monitored. See Table 2 for mining progress, number and status of Creeks at the year surveyed.

Previous monitoring reports indicated fractured bedrock and iron flocculant at this site. On ground observations in 2021 recorded pools with high levels of iron flocculant in the first six pools of the transect (at the downstream end), with all recorded to be overflowing (i.e. 100% capacity). However, the seventh pool (pool four, downstream to upstream) in the transect was observed to be dry with essentially no more water recorded throughout its upstream extent to the end of the transect. This is consistent with observations in 2020 and previous observations (Biosis 2020) with most pools remaining dry.

Habitats are likely to have been somewhat limited pre-mining with shallow pools (seven Very Shallow, four Shallow and one Moderate pool) present across the transect when compared with Control sites. The relatively higher slope of the upstream half of the transect may also reduce the residence time of water in these shallower pools. These factors may be suggestive of a naturally low carrying capacity of the transect.

Within both 2018 and 2019, previous monitoring reports indicate a Level 3 trigger from the DA3A TARP, stating *a decline in the abundance of adult frogs was observed following subsidence impacts detected at SC10C following extraction of Longwall 7 and Longwall 8 during 2011 and 2012 (2 years after the initial mining within the RMZ), and numbers have not recovered* (Biosis 2020). While the 2021 findings align with statement, Niche understands that Level 3 TARPs can no longer be tested in Area 3A (Section 1.5.2).

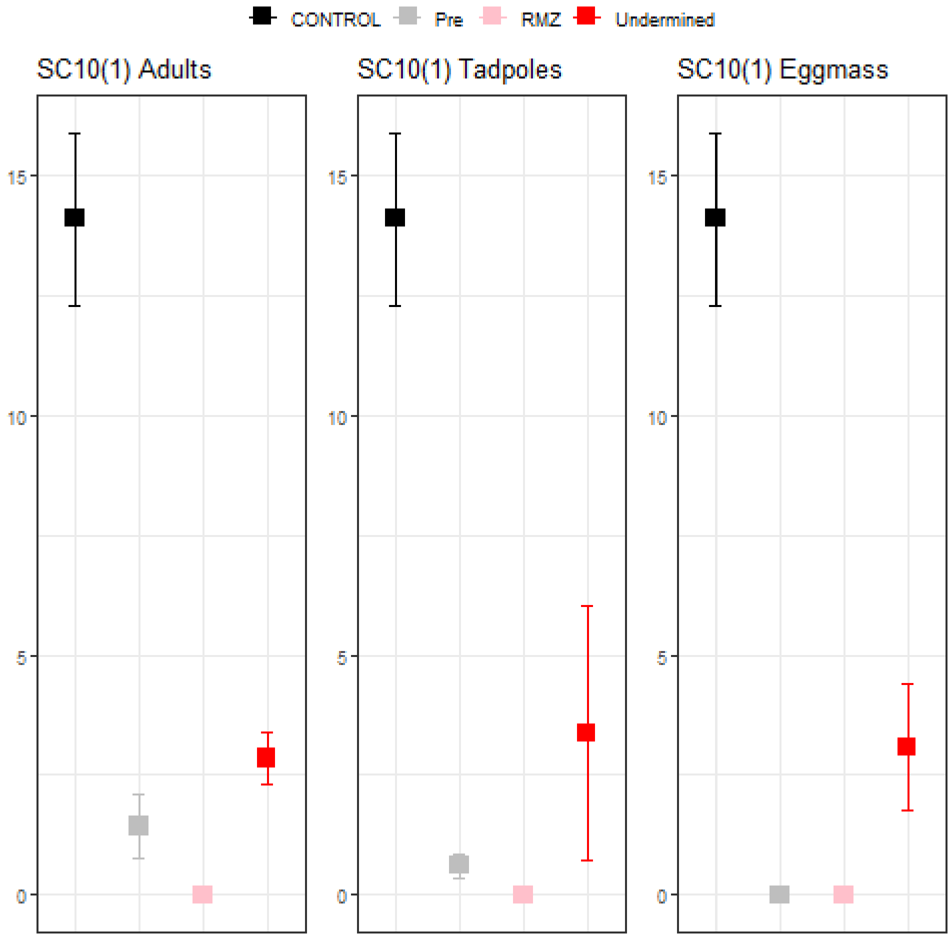
It is determined that SC10C has triggered a Level 2 Landscape Monitoring TARP due to the appearance decline and unlikely to naturally regenerate within the monitoring period, with reductions in habitat conditions along this transect evident in the post-mining period. With a statistically significantly lower level of detection of Adults in the post mining period.

3.6.4.5 SC10(1)

Sandy Creek tributary, SC10(1), was first impacted by Longwall 7 RMZ in 2011 and a small section mined beneath by Longwall 8 in 2012 (Figure 5h,i**)**.

In 2021, 19 Adult Littlejohn's Tree Frogs were recorded, but no Tadpoles or Eggmasses observed. This is despite all pools recording 100% water holding capacity and the presence of a number of moderate and deep pools. Although iron flocculant was observed at 17 of the 20 incidental and monitoring pools identified.

There was no statistically significant effect of mining for any life stage, with detection being higher in the post mining period. While all counts were statistically significantly higher at Control sites than the Impact site (Graph 45), this occurred both before and after mining.



Graph 45: SC10(1) mean +- SE count of Adults, Tadpoles, and Eggs at Control sites (n=8) and SC10(1) for all years SC10(1) has been monitored, See Table 2 for mining progress, number and status of Creeks at the year surveyed.

The previous monitoring reports state:

- *[…] 2017 is the first year that site SC10(1) has triggered the Dendrobium Area 3 Watercourse TARP […] due to build-up of iron flocculant covering all stream surfaces during the 2017 winter survey, and is* *considered likely to reduce productivity, and therefore suitability, of the pools for Tadpoles* (Section 4.3.4 Biosis 2019).

- *There has been a slow decrease in Eggmass and Tadpoles at SC10(1) in the past 3 years [...] SC10(1) is a relatively large stream and is likely to experience the impacts of dry conditions to a lesser extent than other streams, thereby providing refuge habitat during dry periods* (Biosis 2019).

While the statistical test for trends over long-term before and after mining effects at this tributary have not been significant with regards to mining over time, a Level 1 Landscape Monitoring TARP was triggered in 2017 due to iron flocculant observed on the bedrock. Similar observations were made in the 2020 and 2021 surveys. Due to observed changes of decline in tributary appearance (e.g. iron flocculant, debris build up) representing a reduction in available habitat, and as the transect is unlikely to naturally regenerate within the monitoring period, the Level 2 TARP is triggered.

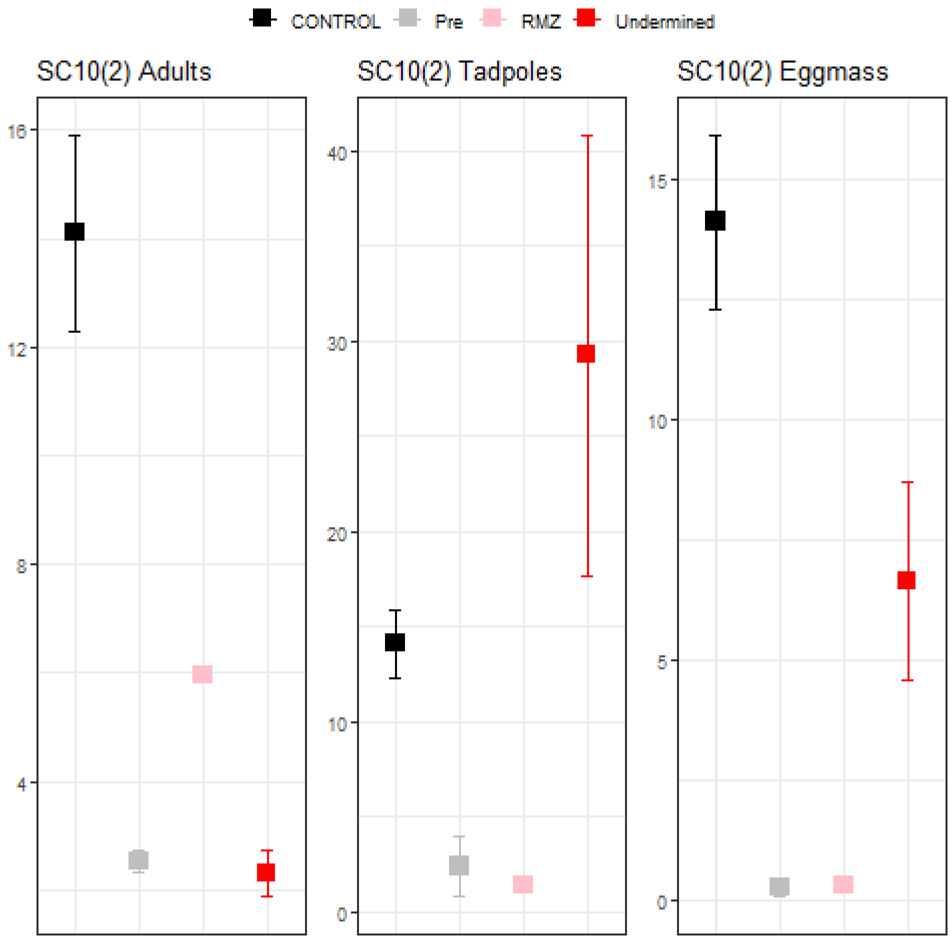
3.6.4.6 SC10(2)

This Sandy Creek tributary has been monitored since 2006. The transect was first impacted by Longwall 7 (within RMZ) in 2011 and a small section mined beneath by Longwall 8 in 2012 (Figure 5h,I,j).

Frog populations observed in 2021 comprised 138 Tadpoles, 11 Adults and 92 Eggmasses. SC10(2) was flowing and pools were typically at 100% capacity on the night of survey. Iron flocculant was recorded at the three most downstream pools only, with the remaining 33 monitoring and incidental pools being clear.

There was a statistically significant difference between the detection of Adults when comparing the within RMZ monitoring period to pre-mining (p-value = 0.01) and also to mined under (p-value = 0.00) period. The Adult counts were found to increase during the within RMZ period (2011 only) before falling to levels just below the pre-mining in the mined under monitoring period (2012 onwards). No other statistically significant difference in pre-post detection was identified for other lifecycle stages.

While all counts were statistically significantly higher at Control sites than the Impact site (Graph 46), this occurred both before and after mining.



Graph 46:SC10(2) mean +- SE count of Adults, Tadpoles, and Eggs at Control (n=8) and the SC10(2) Impact site for all years SC10(2) has been monitored. See Table 2 for mining progress, number and status of Creeks at the year surveyed.

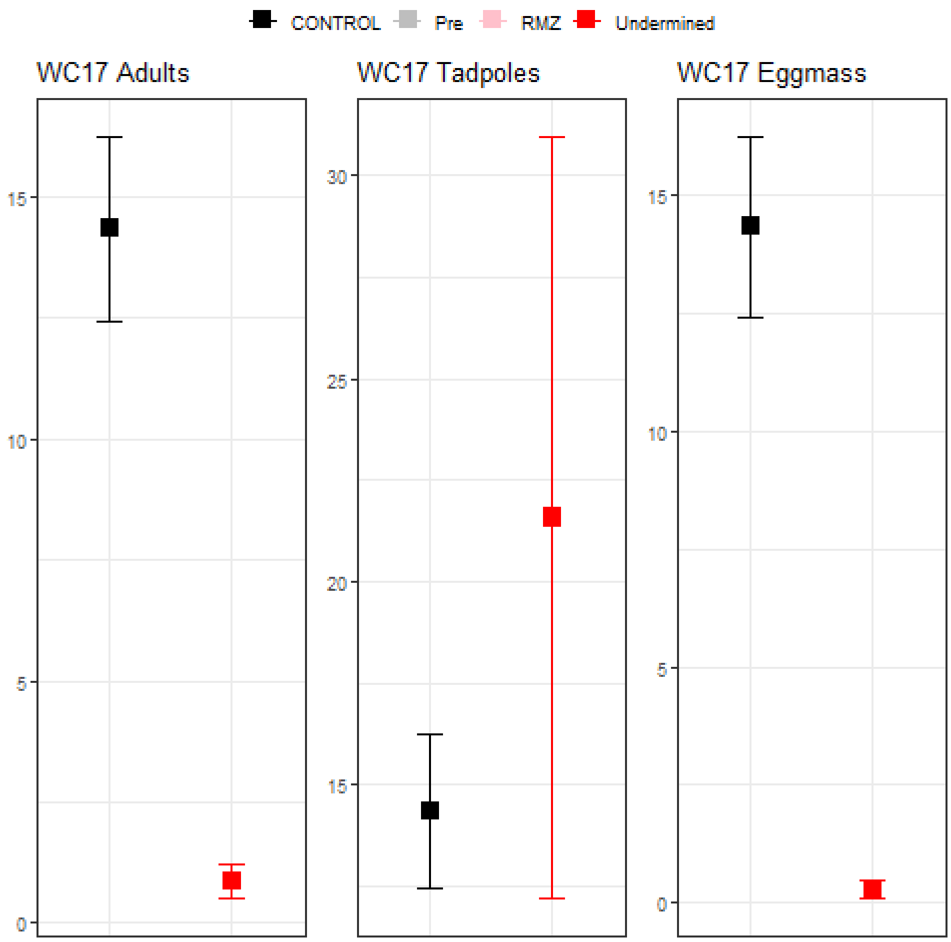
Previous monitoring reported no statistically significant decline in Littlejohn's Tree Frog at SC10(2) since mining began in 2011 (Biosis 2020). While there have been statistically significant differences in Littlejohn's Tree Frog Adult lifecycle stage at this tributary with regards to mining over time in 2021, these findings do not indicate overall reduced counts following mining, rather differences between the high counts in the single year of monitoring when mining was within the RMZ of the tributary. As this is represented by a single year of monitoring, the value may appear artificially high. While the Adult lifecycle stage has been subsequently lower than the within RMZ period this appears to be comparable to baseline levels and is not statistically significant, with both the Tadpole and Eggmass counts above the pre-mining levels. Further, the transect appearance has not changed since the 2017 recovery and no additional iron flocculant was observed in 2021. Therefore, no TARPs have been triggered for this transect in 2021.

3.6.4.7 WC17

No pre-mining monitoring of WC17 was carried out. The initial survey in 2011 recorded relatively high numbers of Littlejohn's Tree Frogs in all life stages (Figure 5q), this tributary has consistently recorded low numbers of Littlejohn's Tree Frog post the year of being mined beneath (also in 2011), with no Littlejohn's Tree Frog recorded in any life stage in the first year of post-mining monitoring (2012), and also in the 3rd, 4th and 7th year of mining.

In 2021 there were Tadpoles recorded (n = 63) within the tributary but no Adults or Eggmass. All seven pools held between 90-100% of their water holding capacity in 2021, in contrast to 2020 when only three pools held water but recorded the highest number of Tadpoles (n = 125) detected. Tadpole numbers have varied statistically significantly post-mining, with sporadic detection of Adults and only two Eggmass recorded post-mining, both in 2013. Although the presence of Tadpoles indicates at least episodic breeding activity. Iron flocculant was recorded in every pool in 2020 and 2021, with visible bedrock cracking recorded in the last two pools of the transect in 2020.

There was a statistically significant effect of Treatment on Adult (p-value <.0001) and Eggmass counts (p-value <.0001), with all counts higher at Control sites than Impact sites (Graph 47). However, there was no statistically significant effect of Treatment on Tadpoles (p = 0.43).



Graph 47: WC17 mean +- SE count of Adults, Tadpoles, and Eggs at Control sites (n=8) and WC17 for all years WC17 has been monitored. See Table 2 for mining progress, number and status of Creeks at the year surveyed.

Note: No pre mining data is available.

Previous monitoring reports indicated the following:

- *In 2017, it was determined that WC17 no longer triggered the Landscape Monitoring – Terrestrial Flora and Fauna TARP triggered in 2016 […] as frog numbers had returned to pre- mining levels. In 2018 Littlejohn's Tree Frog was not detected within the WC17 transect at any life stage, the transect was dry during the survey, with no pools containing water (Biosis 2019).*

There has been a relative increase in Tadpoles counts in 2020, and 2021 compared to recent years. With regards to mining over time, the variance is increasing, but Eggmasses have not been recorded since 2013. Adult counts have reduced from previous post-mining years, from what may be an already reduced level. While the presence of Tadpoles is indicative of some degree of breeding activity, Adult and Eggmass counts reflected in the data are not recovering to pre-mining levels at the transect. The stream appearance has been altered since 2017 with every pool having iron flocculant indicating a reduction in habitat conditions. Due to observed changes of decline in tributary appearance (e.g. iron flocculant, debris build up) and as it is unlikely to naturally regenerate within the monitoring period, the Level 2 TARP is triggered.

3.6.5 Dendrobium Area 3B

Within Area 3B four main creeks or their tributaries are monitored, with both Control, Impact and pre-mining sections (Figure 5):

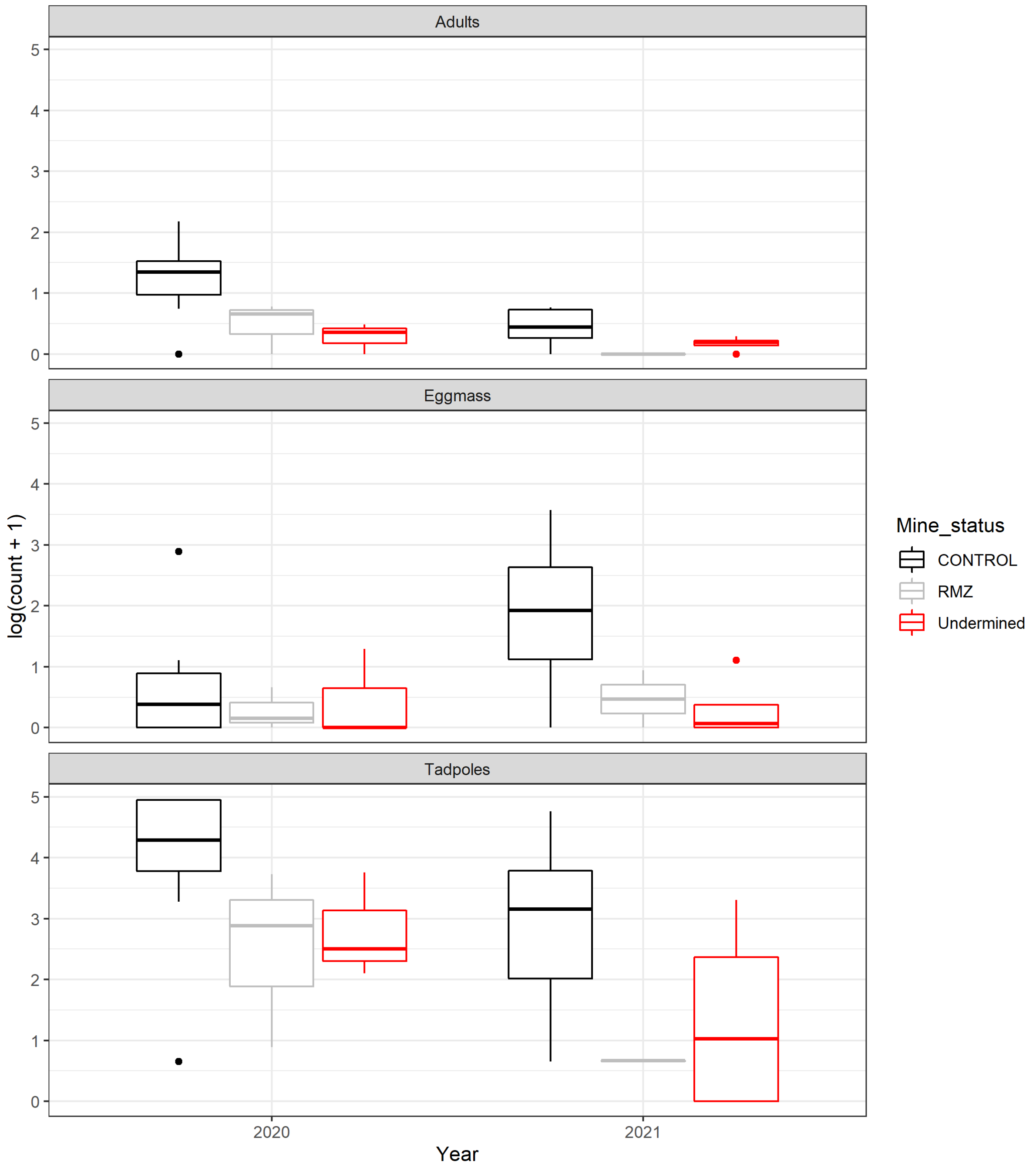
- Wongawilli Creek first and second order tributaries: WC15 and WC21
- Donald's Castle Creek first, second and third order tributaries: DC(1), DC13, DC8
- Native Dog Creek: ND1, ND2 and NDC
- Lake Avon (LA) tributaries: LA4 and LA2.

Waterways within Dendrobium Area 3B are not as interconnected as those within Dendrobium Area 3A. As such, it is possible that Littlejohn's Tree Frog dispersal throughout this area is more limited.

3.6.5.1 Overall trends

When comparing frog detection results from 2020 to 2021, regardless of treatment, there was a statistically significant difference in count of Adults (p-value = 0.008) and Tadpoles (p-value = 0.041), with both being lower in 2021. The number of Eggmasses recorded in 2021 was higher than in 2020, but not statistically significantly.

When considering the overall monitoring dataset in Dendrobium Area 3B, there was a statistically significant effect of Treatment on the counts of Adults (p-value = 0.01) and Tadpoles (p-value = 0. 033). All lifecycle stages had higher counts at Control transects (Graph 48).



Graph 48: Boxplots of counts of Adults, Tadpoles and Eggmasses at Dendrobium Area 3B, 2020-2021 (left), and between mining status.

3.6.5.2 Assessment against performance measures Dendrobium Area 3B

A summary of the results against TARP triggers for Dendrobium Area 3B is presented in Table 45.

Two changes have occurred since 2020 (Niche 2021), transect LA2 has triggered a Level 1 TARP for the first time and transect WC15 has elevated from a Level 1 to a Level 2 TARP following the second consecutive year of reduced habitat conditions being identified.

Table 45: Summary of TARP triggers for transects in Dendrobium Area 3B

Transect Name	Results and TARP justification 2021	Details
DC(1)	**Level 3 TARP** triggered due a reduction in habitat (dry pools for extended times) at DC(1) for more than 2 years following the active subsidence period.	See Section 3.6.5.3 Tributary is within the RMZ and continues outside of the RMZ greater than 400 m from Longwall 9. Impacts to pool levels apparent up to 200 m from mined beneath area.
DC13	**Level 3 TARP** triggered due a continued reduction in habitat (fractured bedrock) at DC13 for more than 2 years following the active subsidence period.	See Section 3.6.5.4 Tributary is mined beneath and within RMZ. Impacts are predominantly observed within the mined beneath section, improving within the RMZ.
LA2	**Level 1 TARP** due to a reduction in habitat (reduction in aquatic habitat, contrary to that observed at the controls) for 1 year following the active subsidence period.	See Section 3.6.5.5 The first year of mined beneath monitoring has recorded the transect transitioning from having all pools at full capacity in 2020 to having only a single pool holding water in 2021. Frog detection results have also declined to levels commensurate to those recorded at the height of the recent drought in 2018.
LA4A	No TARP triggered. Sub-optimal habitats are present along this tributary both pre and post mining with no change in detection identified, or observation of impacts recorded.	See Section 3.6.5.6 Tributary is entirely within RMZ 80-200m from Longwall 13. Some observed impact however the habitats are limited and sub-optimal, with frog detection consistent with pre-mining levels.
WC15	**Level 2 TARP** due a reduction in habitat (dry pools for extended time and bedrock cracking) for 2 years following the active subsidence period.	See Section 3.6.5.7 The transect has both mined beneath sections within RMZ. Impacts are clearly apparent in mined beneath section and become less pronounced within the RMZ.
WC21	**Level 3 TARP** triggered due a continued reduction in habitat (fractured bedrock) at WC21 for more than 2 years following the active subsidence period.	See Section 3.6.5.8 Tributary has sections mined beneath, within RMZ and outside of RMZ. Hydrological impacts are notable in mined beneath sections however pool retention appears to be quite good within sections that are not mined beneath, under above average rainfall conditions. However indirect impacts within the RMZ sections have included the presence of iron flocculant.

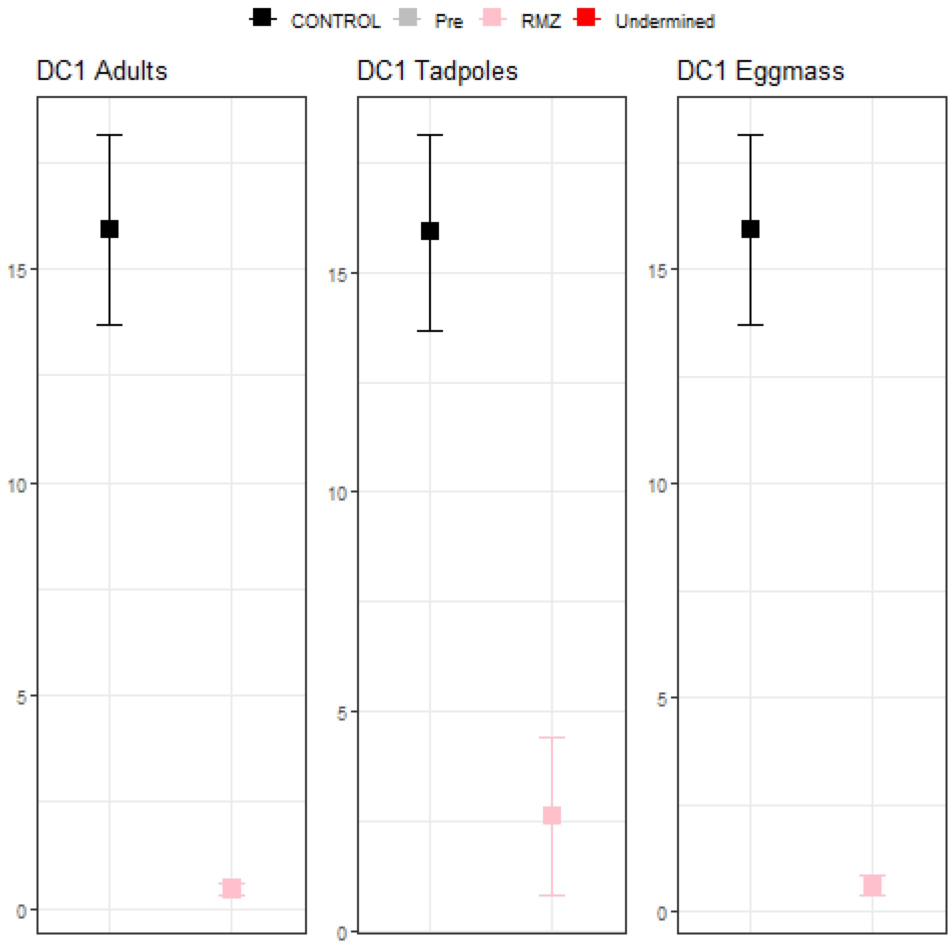
3.6.5.3 DC(1)

Monitoring at DC(1) commenced in 2013, with mining entering the RMZ of the tributary also in 2013. Due to the location of the longwalls, this tributary is not planned to be mined beneath and will remain in the RMZ, however there is potential for indirect impacts from the nearby Longwall 9 (Figure 5d). No pre-mining baseline data was collected for this tributary and therefore implementation of the BACI design is not suitable.

In 2021, no Adults were detected, with 10 Eggmass and six Tadpoles counted. Iron flocculant was observed in four of the 17 pools and while water levels were high from 19 to 30 (typically 100%), levels then diminished rapidly upstream to typically between 0-5% in each pool.

Assessment of available data indicates a statistically significant difference between the Controls and DC(1) across all lifecycle stages, with higher Littlejohn's Tree Frog counts for all life stages at Control sites than at DC(1).

While all counts were statistically significantly higher at Control sites than the Impact site (Graph 49), this occurred both before and after mining.



Graph 49: DC(1) mean +- SE count of Adults, Tadpoles, and Eggs at Control sites (n=8) and DC(1). See Table 2 for mining progress, number and status of Creeks at the year surveyed.

Following the extraction of Longwall 9 in 2013, changed pool water levels at DC(1) were recorded by the Illawarra Coal Environmental Field Team (Biosis 2020) and have continued to date.

The level 1 TARP was triggered in 2017 and 2018 and the Level 2 TARP was triggered in 2019 due to a reduction in habitat for 2 years following the active subsidence period (Biosis 2020). An improvement in this trend was not recorded in 2020 or 2021 and therefore due to a reduction in habitat for greater than 2 years following the active subsidence period the Level 3 TARP was triggered.

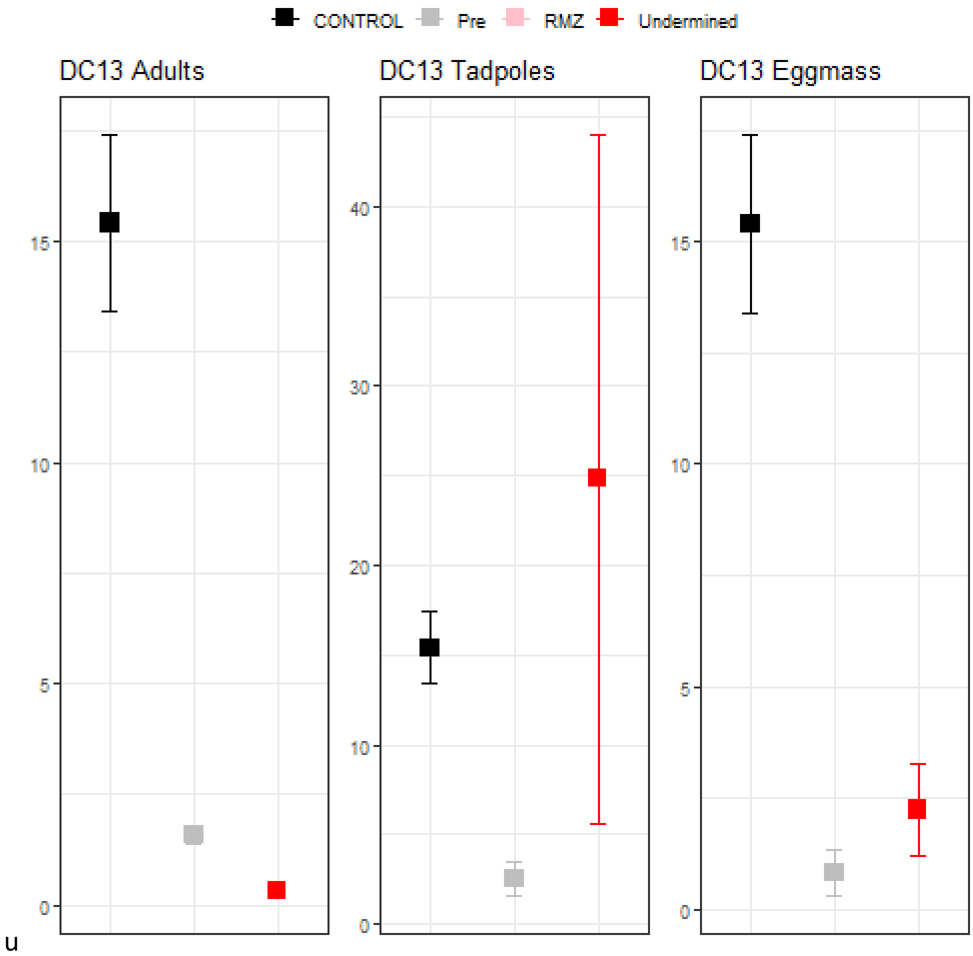
3.6.5.4 DC13

DC13 is located to the west of DC(1) and flows north towards Longwall 9. DC13 has been monitored since 2010, with mining within the RMZ and beneath the transect both occurring in 2013.

In 2021, no Adults were detected, but 169 Tadpoles and 13 Eggmasses were counted. Pool levels were higher at the downstream extent of the transect, away from Longwall 9 (Figure 5b). The majority of Tadpoles and Eggmass were recorded at this downstream end of the transect.

The detection of Adults have been statistically significantly reduced post – mining (p-value <.0001), but not for any other lifecycle stages, with detection of Tadpoles and Eggmass increasing in the post-mining period.

While all counts were statistically significantly different at Control sites than the Impact site (Graph 50), this occurred both before and after mining.



Graph 50: DC13 mean +- SE count of Adults, Tadpoles, and Eggs at Control Sites (n=8) and DC13 Impact site. See Table 2 for mining progress, number and status of Creeks at the year surveyed.

Previous monitoring reports stated:

> "[..] *fracturing of bedrock was observed within the transect. It is determined that Level 3 […] remains triggered and should be re-evaluated in 2019*." (Biosis 2019).
>
> *"[..] many of the identified breeding pools had experienced a significant reduction in water, and were no longer appropriate habitat for Littlejohn's Tree Frogs to survive to metamorphosis.[…]"* (Biosis 2020).

The level 3 TARP was first triggered in 2017 and then again in 2018 due to a reduction in habitat for greater than 2 years following the active subsidence period (Biosis 2020). An improvement in this trend was not recorded in 2020 or 2021 and therefore due to a reduction in habitat for greater than 2 years following the active subsidence period the Level 3 TARP remained triggered.

3.6.5.5 LA2

LA2 is situated above Longwall 17 and has become mined beneath in 2021, following mining within the RMZ by Longwall 16 occurring in 2020 (Figure 5e). Notably in 2021, all identified pools along the transect have been directly mined beneath and as such are most likely to experience potential subsidence impacts.

In 2021, two Adults were recorded with no Eggmass or Tadpoles detected. This is in contrast to the relatively high numbers of all lifecycle stages recorded in 2017, 2019 and 2020. These low levels are comparable to that of the height of the drought in 2018 when the transect was extremely dry with the majority of pools empty (Biosis 2020).

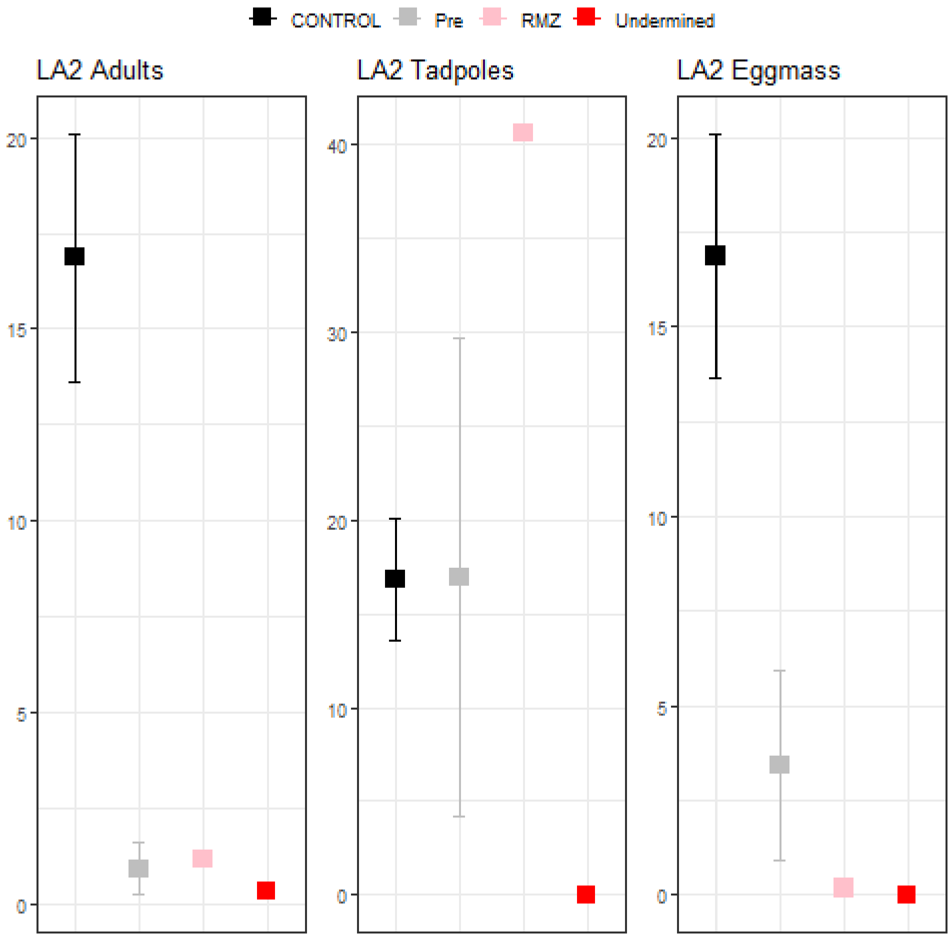
In 2021, only one of the 23 pools held water, and at only 30% of its very shallow capacity. This is despite the high levels of rainfall in 2020 and 2021 and presence of moderate and deep pools along the transect. This represents a marked shift from 2020 when all pools were recorded as being at 100% of their water holding capacity and suggests a loss of water from the transect in 2021 (Table 46).

Table 46: LA2 pool water levels in 2020 and 2021

Pool	Depth	2020 Water level (%)	2021 Water level (%)
LA2-P07	Shallow 50-25cm	100	0
LA2-P08	Shallow 50-25cm	100	0
LA2-P09	Shallow 50-25cm	100	0
LA2-P10	Very Shallow <25cm	100	30
LA2-P11	Shallow 50-25cm	100	0
LA2-P12	Very Shallow <25cm	100	0
LA2-P13	Shallow 50-25cm	100	0
LA2-P14	Shallow 50-25cm	100	0
LA2-P15	Shallow 50-25cm	100	0
LA2-P16	Moderate 100-50cm	100	0
LA2-P17	Moderate 100-50cm	100	0
LA2-P18	Deep >100cm	100	0
LA2-P19	Shallow 50-25cm	100	0
LA2-P20	Very Shallow <25cm	100	0

Pool	Depth	2020 Water level (%)	2021 Water level (%)
LA2-P21	Shallow 50-25cm	100	0
LA2-P22	Very Shallow <25cm	100	0
LA2-P23	Deep >100cm	100	0
LA2-P24	Shallow 50-25cm	100	0
LA2-P25	Deep >100cm	100	0
LA2-P26	Shallow 50-25cm	100	0
LA2-P27	Moderate 100-50cm	100	0
LA2-P28	Deep >100cm	100	0
LA2-P29	Shallow 50-25cm	100	0

A statistically significant effect of mining was not identified for any lifecycle stage in 2021. While all counts were statistically significantly different at Control sites than the Impact site (Graph 51), this occurred both before and after mining.



Graph 51: LA2 mean +- SE count of Adults, Tadpoles, and Eggs at Control Sites (n=8) and LA2. See Table 2 for mining progress, number and status of Creeks at the year surveyed.

The lack of statistically significant difference in the mining treatment in 2021 analysis, despite the very low relative levels of detection and observations of reduced water levels, likely reflects the 2018 year of monitoring at the height of the drought when water levels were naturally reduced to dry conditions pre-mining. This also resulted in reduced detection, providing a comparable year of monitoring in the baseline dataset.

Conditions and detection in the 2018 year of monitoring may suggest that habitats in LA2 are susceptible to water loss/stress, this may in part reflect the degree of sandy substrates present along the tributary and catchment position. Habitats for the species in this tributary may be naturally somewhat cyclical, reflecting the prevailing weather conditions at the time.

These factors notwithstanding, the comparable conditions and detection levels were recorded in 2018 at the height of the drought, whereas 2021 has recorded above average rainfall, also following above average rainfall in 2020. When taken together the declining detection results and assessment of physical conditions suggest a loss of habitat associated with mining when compared to the previous year. As such, a Level 1 TARP is triggered for the first time at this transect, aligning with the interpretation identified in Table 6:

"Reduction in aquatic habitat for 1 year

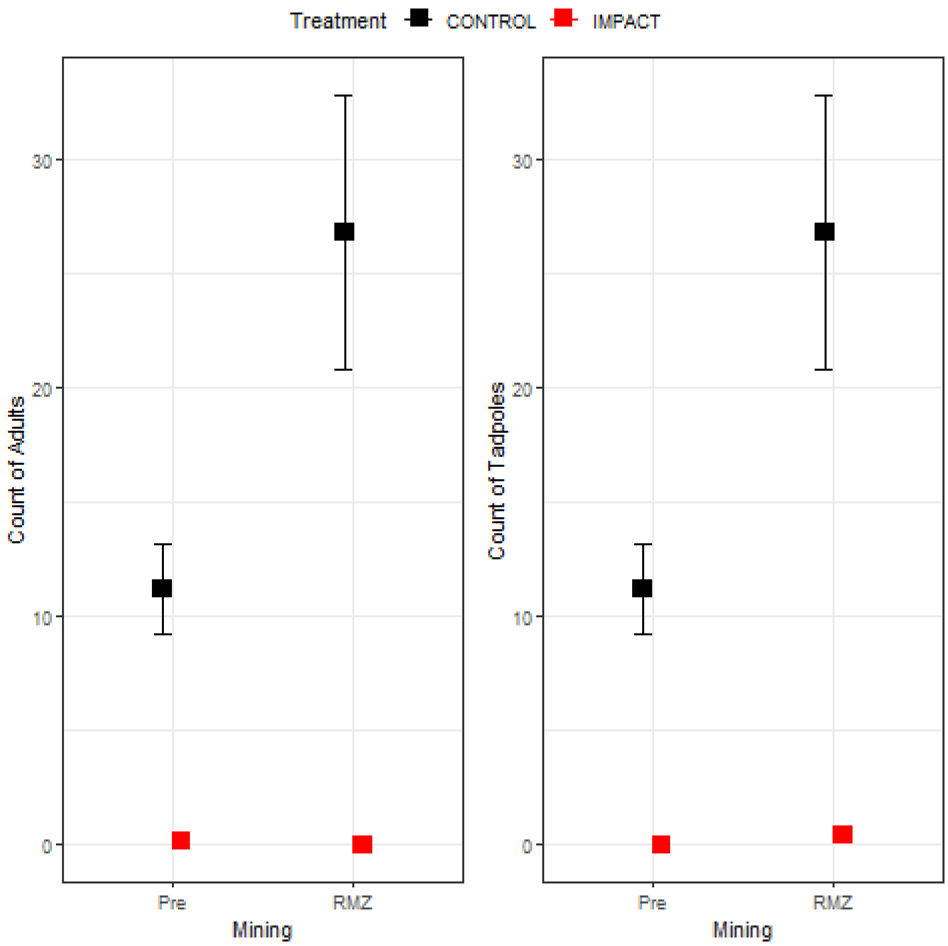
- *Observed and measured changes in pool water levels and/or number of breeding pools available from the previous year without the same pattern at control sites."*

3.6.5.6 LA4A

Due to the location of the Longwalls, tributary LA4A is not planned to be mined beneath and will remain as within RMZ, with the nearby Longwall 12 and 13, mined in 2016.

There are only three pools within this short section of tributary. Across the entire transect, all pools were observed to be almost dry, with some small areas of pooling, in line with previous years. Two Tadpoles were observed, but no other lifecycle stages were detected in 2021. The observations of Tadpoles in 2020 and 2021 represent the first detection of Littlejohn's Tree Frog activity at LA4A since one Adult was counted in 2010. No Eggmass have been detected at LA4 throughout the monitoring.

No statistically significant difference in pre-post mining detection was identified in the Adult or Tadpole detection data (Graph 52). While all counts were statistically significantly higher at Control sites than the Impact site (Graph 52), this occurred both before and after mining.



Graph 52: LA4A mean +- SE count of Adults, Tadpoles at Control sites (n=8) and LA4A. See Table 2 for mining progress, number and status of Creeks at the year surveyed.

The general lack of Littlejohn's Tree Frog records noted for LA4A suggests the tributary supported poor quality habitat before mining began. The key difference at LA4A is that in the pre-mining data Adults are detected sporadically and in very low numbers, and in the within RMZ data Tadpoles are detected sporadically and in very low numbers. Overall, no change in species activity during the monitoring is apparent and as such, no TARPs have been triggered at LA4A.

3.6.5.7 WC15

WC15 stretches across Longwalls 14 and 15 (Figure 5p). Monitoring commenced at WC15 in 2011 and this transect was first impacted by Longwall 14 (within RMZ) in 2018 and then mined beneath in 2019. Cumulatively, Longwall 15 also entered into the RMZ in 2019 and the transect was also mined beneath by Longwall 15 in 2020.

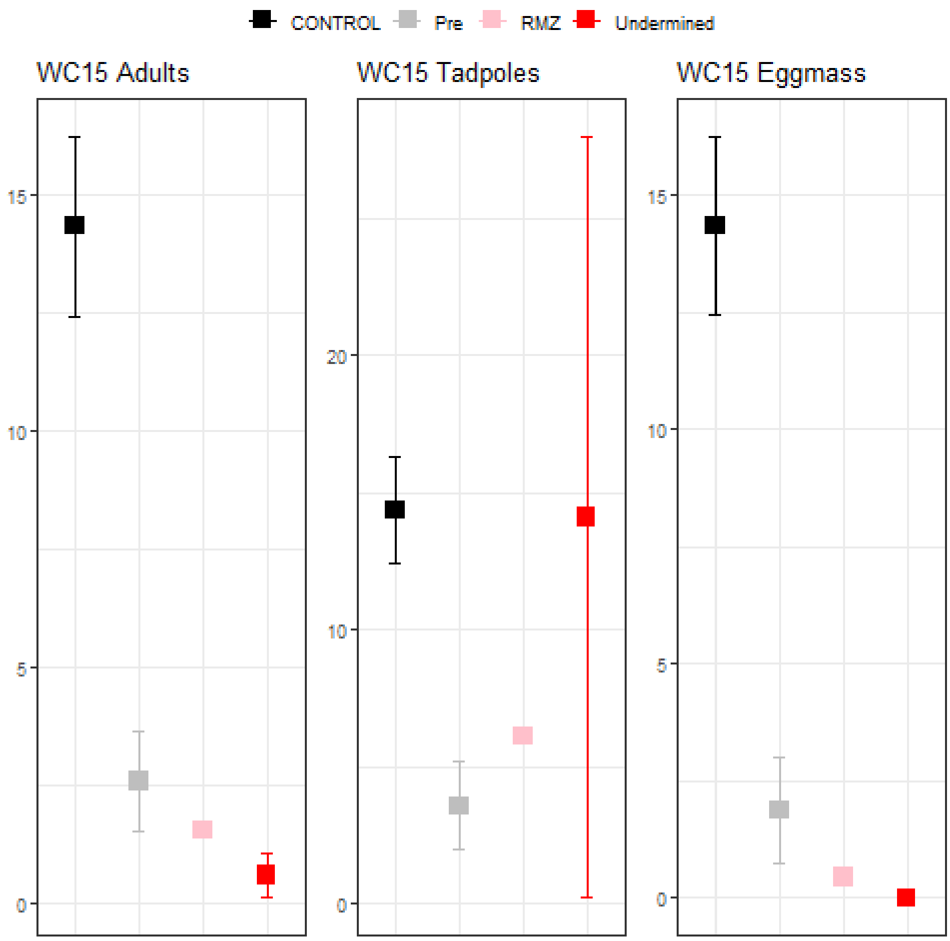
In 2021 there was only water in one out of 16 pools along the transect (at 40% capacity), similar to that observed in 2020, despite the above average rainfall conditions. With visible cracking of bedrock between Pools 18 and 19 in the upper reaches of the tributary (Plate 18 and Plate 19) also observed in 2020.

Plate 18: WC15 bedrock cracking

Plate 19: WC15 sandstone rocks from nearby cracking

One Adult was recorded in 2021, but no other lifecycle stages. Counts of Adults and Eggmass appear to have declined post mining, but Tadpoles increased.

No statistically significant effect of mining on any lifecycle stage was detected in the 2021 analysis, despite the declines in detection observed. While the counts of Adults and Eggmass were statistically significantly different at Control sites than the Impact site (Graph 53), this occurred both before and after mining.



Graph 53: WC15 mean +- SE count of Adults, Tadpoles, and Eggs at Control (n=8) and WC15. See Table 2 for mining progress, number and status of Creeks at the year surveyed.

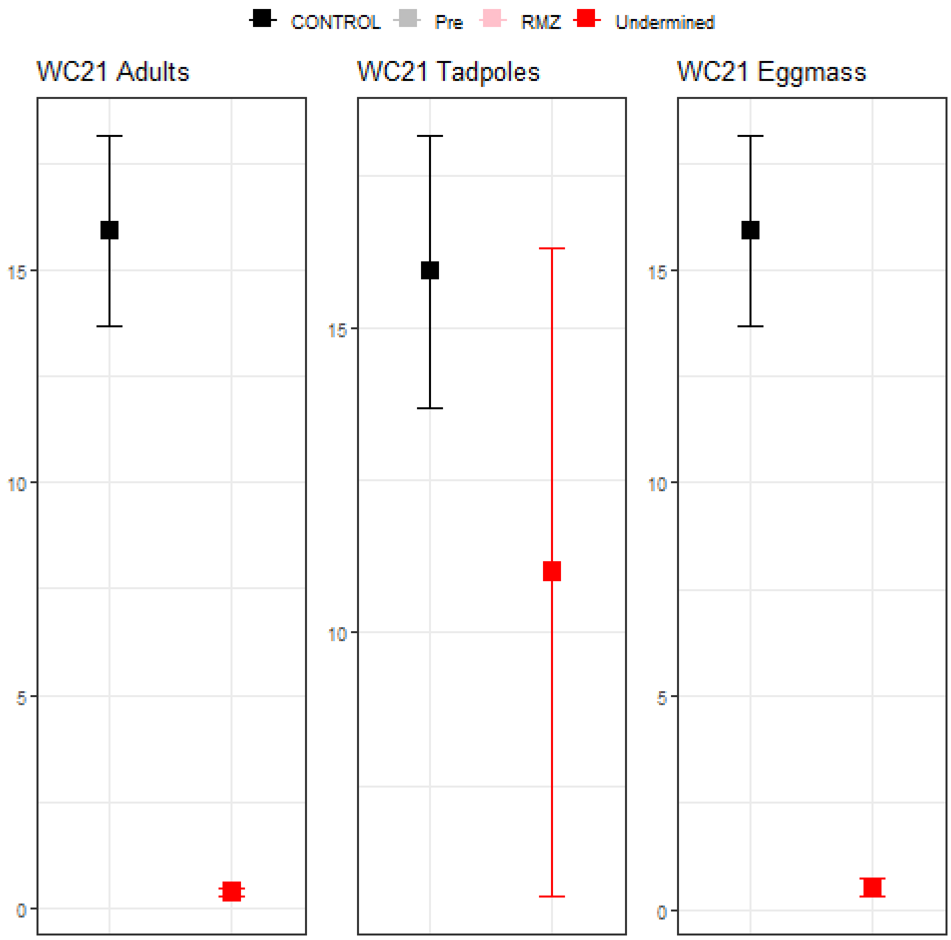
Due to observed bedrock cracking within WC15 and no water in any pools downstream of the cracking, WC15 has triggered a Level 2 TARP due a reduction in habitat (dry pools for extended time) for 2 years following the active subsidence period.

3.6.5.8 WC21

WC21 stretches across three longwalls (Longwall 9, Longwall 10 and Longwall 11). Monitoring commenced at WC21 in 2013, within mining within the RMZ and then beneath the transect (Longwall 9) in 2013. Cumulatively, Longwall 10 also extended into the RMZ of the tributary in 2014, which was then mined beneath in 2014. With Longwall 11 also entering into the RMZ of the tributary in 2015, which was mined beneath by Longwall 11 in the same year. There is no pre-mining baseline data for this tributary, therefore implementation of the BACI design is not suitable.

While the transect includes a number of deep pools with high water levels in 2021, these are located at the downstream end of the transect which also features iron flocculant in this section. Water levels then decrease upstream at the point at which the transect becomes mined beneath and generally remain low.

The counts of Adults and Eggmass were statistically significantly different at Control sites than the Impact site (Graph 54), although there is no pre-data against which to test detection against.



Graph 54: WC21 mean +- SE count of Adults, Tadpoles, and Eggs at Control (n=8) and WC21. See Table 2 for mining progress, number and status of Creeks at the year surveyed.

Previous monitoring reports state:

"Impacts to WC21 were previously recorded by the Illawarra Coal Environmental Field Team between Pool 10 and the end of the transect to Pool 31, following the extraction of Longwall 9, Longwall 10, Longwall 11 and Longwall 12, and these included fracturing of bedrock, cracking, uplift and flow diversion" (Biosis 2020).

[…] reduction in habitat at WC21 has now been recorded for five monitoring periods (four years), thus triggering Level 3 TARP […] 57% of the potential breeding habitat along this stream is experiencing a reduction in water levels (between Pool 11 and Pool 30) including three confirmed breeding pools." (Biosis 2019).

The Level 3 TARP was triggered in 2017, 2018 and 2019 due to a reduction in aquatic habitat for > 2 years (three years in a row). No improvement in this trend was detected in 2020 or 2021, therefore the Level 3 TARP remains triggered.

4. Discussion and recommendations

At the completion of the 2021 ecological monitoring program, 17 years of data has been collected for Dendrobium Area 3A; and 8 years of data collected for the majority of Dendrobium Area 3B (aside from Swamp 11 where monitoring has been undertaken for 15 years).

4.1 Trends across Upland Swamps

Trends across swamps indicate declining TSR post-mining for most (but not all) Impact Upland Swamps. Compositional changes show trends of the loss of wetland flora species, which are either being replaced by species more tolerant of drier soil (suggesting changes toward drier swamp sub-communities) or not being replaced with any new vegetation (suggesting the die-back of swamp vegetation) broadly across monitored Upland Swamps. This is particularly true for those Impact Upland Swamps that have longer post mining impact data available. Although it is reasonable to expect natural species turnover to occur at a swamp, especially after an extended drought period.

Impact Upland Swamps occurring in the RMZ and not directly mined beneath appear to take longer to show impacts at the surface. For example, Swamp 15(A)2 (the only swamp remaining in the RMZ) has taken five years since impact to detect changes in TSR and composition with observed impacts less severe than swamps mined beneath (given changes in groundwater levels are generally not detected until longwalls are within 60 m of a swamp as discussed in Section 3.2, the causal effect here is unclear). In contrast, changes are detected in TSR or composition for swamps directly mined beneath, typically within 1-2 years of impact. This suggests that swamps that are not directly mined beneath are less impacted than those directly mined beneath with compositional changes in vegetation not readily observed for some years.

It should be noted that between 2016 and 2019 was the most significant drought on record for the area, peaking in 2018/2019 (see Graph 1), the effect of which can be seen through contraction in both control and impact swamp size in 2019 and 2020 (as demonstrated by LiDAR analysis). The drying of the Impact Upland Swamps over time since impact may be exacerbated by the effect of the drought, though the correlation between impact of mining and drying of the Impact Upland Swamps is evidenced by the greater magnitude of change experienced at the Impact Upland Swamps compared to Control Upland Swamps over the drought period. Continued monitoring will assist in determining whether any recovery occurs following the above average rainfall period post-drought, and whether this differs in timing or scale when compared to control swamps.

Additional breakpoint analysis has been completed in 2021 for the TSR data and selected species experiencing strong trends within swamps. This analysis has tended to present a more complex picture of temporal trends and their relationship to mining. Many trending declines in TSR and species detection appear to have commenced either pre- or at some years post-mining. Generally speaking, the trends occurring pre-mining have not appeared to be exacerbated by mining, although no recovery or trending increases are seen in the post-mining data at individual swamps, and do not appear to be strongly correlated to rainfall, although this has not been specifically tested. Statistically significant trends or breakpoints that have occurred in the post-mining data are harder to interpret with certainty. In some cases these align with the commencement of drought but do not show a recovery in the post-drought period (2020-2021). Possible explanations may include that there is a lag time generally in vegetative response following acute and extended drought conditions that may take several years to manifest. Impacted swamps may have a lower resilience to drought and therefore may take longer to recover, or the vegetative response will manifest as a different stable state to the pre-drought condition, or recovery potential will be limited. Further monitoring will be required to address these temporal patterns of change. Completing the broken stick analysis for the control swamps during the same period may assist in the interpretation of these trends.

4.1.1 Cumulative impacts

Discussion of cumulative impacts to swamps is an important part of the analysis of impacts, as a small change may never be statistically significant when comparing the data between two consecutive years (as dictated by the TARPs), but might be statistically significant at a different timescale, such as over the entire survey (TAE 2021d). To remedy this, an analysis of cumulative impact in TSR and species composition was undertaken over three, four and five years to enable detection of change over time. Testing across three, four and five years of data provides a larger magnitude and therefore greater ability to detect change over time (i.e. cumulative impacts).

Cumulative impacts have been observed at the following swamps:

- Swamp 15A(2) (TSR and composition) – Cumulative impacts indicate a statistically significant decline in TSR over time since approximately 2017, five years since the swamp was mined beneath. Swamp composition has also been changing statistically significantly over this time period with 'wetter' species becoming less common post impact, suggesting a loss of species that prefer moist soils. A trending decline in swamp extent and in each subcommunity has occurred when compared to 2014.
- Swamp 15B – Cumulative impacts indicate a statistically significant decline in TSR over time since approximately 2013, one year since the swamp was mined beneath. A statistically significant change in composition is observed since 2012. As swamp species appear to be dying out with limited recruitment of new species, the swamp may be experiencing some degree of die-back. A trending decline in swamp extent has occurred since 2014, driven mainly by declines in the Banksia Thicket subcommunity and to a lesser degree the Tea-tree Thicket subcommunity.
- Swamp 11 - Cumulative impacts indicate statistically significant decline in TSR over four years (since 2017) and change in composition since approximately 2016. Trends in swamp extent and subcommunities have been variable but tended to follow that experienced at the control group, although at a greater magnitude of variation.
- Swamp 13 – Cumulative impacts indicate statistically significant decline in TSR over four years (since 2017) and change in composition over three years (since 2018). Swamp extent has tended to show declines slightly greater than those experienced at the control group throughout the monitoring period.
- Swamp 1A – Cumulative impacts over five years show that the TSR is continually reducing over time, since 2013 and is statistically different to that of the control swamps. Species composition data does not identify a statistically significant trend. Trends in swamp extent have been variable but tended to follow that experienced at the control group, although at a slightly greater magnitude of variation, with Tea-tree Thicket declining over the course of the monitoring period.
- Swamp 1B – Cumulative impacts over five years show that the TSR is continually reducing over time (since 2016) and species composition is continually changing since 2013. Overall, the changes to species composition at Swamp 1B indicate a loss of 'species that prefer wet soils, progressively over time, with species preferring drier soils becoming more prevalent after impact. Changes in swamp extent have been variable, where reductions have occurred these have typically been greater in magnitude than that of the control group, with Tea-tree Thicket experiencing the greatest decline.
- Swamp 23 – Cumulative impacts over three years show a statistically significant decline in TSR since 2018. However species composition is not changing statistically significantly over the same time period. Trends in swamp extent and subcommunities have been variable but tended to follow that experienced at the control group, although at a greater magnitude of variation.

4.2 Trends across Littlejohn's Tree Frog populations

Similar trends in detection were observed in Dendrobium Areas 3A and 3B in 2021 when compared to 2020. The counts of Adults and Tadpoles were statistically significantly reduced in 2021, although the number of Eggmasses was (non- statistically significantly) greater in 2021. This difference likely is attributed to the drought-breaking rainfall recorded in 2020, which was greater than the above average rainfall level in 2021.

At the Area level, no statistically significant difference in detection of any lifecycle stage was identified between the overall impact and control groups in 2021, although greater numbers of each lifecycle stage were recorded across the control group.

In both Dendrobium Areas 3A and 3B, most Adults and Tadpoles were detected in deeper pools, while Eggmasses were more evenly spread across the pool size distributions.

4.2.1 Control and Impact transect habitat comparisons

It is considered that as a group the Control transects within the Program generally support higher quality breeding habitat for Littlejohn's Tree Frog, with the Control transects typically featuring overall deeper pools with less variation than the impact sites. Whilst Littlejohn's Tree Frog amplexus and egg deposition may occur within pools of any size, Adult Littlejohn's Tree Frog generally indicate a preference for deeper pools (Niche 2021), which are more likely to support Tadpole metamorphosis due to longer hydroperiods. Klop-Toker et al. (2021) also found that the presence of Tadpoles were positively correlated with the number of pools per transect and pool depth, with Tadpole abundance being positively correlated with pool volume. The results of this year's analysis align with these findings.

The control transects were presumably incorporated into the Program due to the presence of known Littlejohn's Tree Frog habitat and breeding populations. The design of longwall mining layouts is also biased towards lower order streams with smaller pools to avoid larger watercourses and thereby reduce potential impacts to these ecological features. The same bias has not applied to Control site selection. This bias may also be observed in the statistical analysis in 2021, which identified that where pre-mining detection data is available for impact transects, this is typically statistically significantly lower than that of the control group.

Regardless of the observed bias in pools depth (as a readily estimated proxy for pool size), Littlejohn's Tree Frog have been observed consistently from both Control and Impact sites and therefore changes due to longwall mining at Impact sites remain observable and valid comparisons are able to be made between Control and Impact sites. Relatively longer hydroperiods occur in small pools downstream of large swamps (compared with where swamps are absent) due the inherent water retention capacity. Therefore, pool size is not the only factor determining hydroperiod and other factors such as catchment position, stream geomorphology and underlying geology will also play key factors in determining pool hydroperiod.

It is also notable that the prevailing environmental conditions during the 2021 surveys (water availability and absence of flocculant) within habitats were also more favourable for the Littlejohn's Tree Frog at the control sites.

4.2.2 Direct and indirect impacts

Littlejohn's Tree Frog may preferentially select smaller breeding pools associated with upstream swamps due to the limited number of suitable pools in other streams across the mining domain (Klop-Toker 2020). Given observed patterns of limited water retention at Impact sites post-mining, it is likely that mining is having an impact on frog reproduction due to decreased Tadpole survivorship and a reduction in the extent of preferred habitats.

Observed patterns of cracking and limited water retention as well as analysis of swamp piezometric data indicates greater and more obvious hydrological impacts within areas directly mined beneath. Whereas indirect impacts, specifically flocculant, are more typically detected in sections where mining has entered within the RMZ of the stream and water levels are maintained, but in close proximity to mining activity.

Previous monitoring events reported: *Subsidence related impacts, including cracking of bedrock, lowering of water levels and build-up of iron flocculant ….at sites SC10C, SC10(1), WC17, WC21, DC(1) and DC13, with each of these sites triggering either Level 1 (SC10(1), DC(1)) or Level 3 (WC21 and DC13) of the relevant TARP* (Biosis 2020). These effects were also evidenced at these sites, and with the addition of LA2, as a part of the 2021 monitoring year.

In terms of indirect impacts, while each lifecycle stage may be detected in pools with flocculant, statistical analysis has identified that both Adults and Eggmass are statistically significantly less likely to occur in pools with flocculant present. The analysis also identified that the presence of flocculant is most likely to occur in transects where mining has entered into the RMZ of the stream.

Subsidence and hydrological impacts are less detectable with increasing distance from mining and may or may not be observable within the RMZ. Impact transects may contain sections potentially occurring in both mined beneath and RMZ areas, or even outside of the RMZ. Where a TARP has not been triggered for a transect, it is possible that this may be due to the transect having sections in RMZ areas or further from mining. Similarly, impacts may be considered to occur within the RMZ zone where actual impacts are limited due to all or a component of a transect being in an area that has been mined beneath. Where possible these within transect trends will be examined as the program progresses with new data collection protocols.

The distance of the creeks or tributaries from being directly mined beneath and within the RMZ either upstream or downstream appear to have a general trend. Directly mined beneath areas have more observable changes to aquatic habitat with dry pools or limited water retention. This becomes less obvious as the transect moves away from the Longwall. This is evident in transects that contain sections that are mined beneath, within the RMZ and/or sections greater than 400 m from the longwalls (i.e. DC(1) or WC21). However, no statistically significant relationship between the detection of Littlejohn's Tree Frog at a pool and the distance of the pool to the closest longwall was identified in the 2021 dataset.

4.2.3 Non-viable Eggmass

Field observations in 2020 recorded a limited number of Littlejohn's Tree Frog Eggmasses that appeared to be non-viable at both Control and Impact sites. These Eggmasses were in poor condition with white embryo's that contributed to an overall unhealthy appearance, and these were considered unlikely to be viable. In 2021 observations of non-viable Eggmasses were more extensive. This has not been previously recorded within the program (pre-2020). While a certain number of eggs within a clutch may be naturally non-viable at any time (i.e. failed to be fertilised), it is hypothesised that these Eggmasses were subject to drying, became desiccated and were then re-submerged. It was not unusual to find both viable and unviable Eggmass in the same pool. As shown in Plate 20, non-viable Eggmasses with white embryo's can be seen on the centre left branch and at other locations close to the water's surface. On the centre-right branch, as the depth of the branch increases the white embryos decrease and viable Eggmasses then dominate, with Eggmasses approaching early Tadpole stages observable at the end of the branch.

Plate 20: Non-viable and viable Eggmass recorded at WC10.

The non-viable Eggmasses still provide an indication of breeding activity. It is unclear what future effect this relatively high proportion of non-viable Eggmassess recorded across the control and impact transects may have. Non-viable Eggmasses will continue to be monitored in future iterations of the Program to establish whether this is part of any ongoing or developing trend.

4.3 Corrective management actions and offsets

Area 3A CMAs relevant to TARP triggers are outlined in Table 47, Table 4; and Area 3B CMAs relevant to TARP triggers for Upland Swamps are outlined in Table 48 and watercourses in Table 49. Within the latest consent conditions (Longwall 19) it was agreed that the *Strategic Biodiversity Offset* (IMC2016b) met the condition of consent and no further remediation within the Upland Swamps was required due to the level of research and offsetting that has been provided for both the Dendrobium Mine and Bulli Seam Operations Project.

It should be noted that CMAs (e.g. grouting trials) are planned (though not yet executed) for two creeks (DCC and WC21) after water quality and water hydrology impacts were recorded in 2015-2017 (IMC 2017). Offsets were provided for loss of water quality or loss of water flows (subject to Condition 14 of Schedule 3 of the Development Consent) via the transfer of 33 ha of land adjacent to the Cataract River to WaterNSW (IMC 2017). Further, the Strategic Biodiversity Offset (IMC 2016b) includes frog habitat within Maddens

Plains and was considered a suitable offset for impacts on watercourses that have exceeded those predicted in the SMP (IMC 2017).

Table 47: Area 3A Landscape TARP Actions table summary (IMC 2020a)

TARPs	Actions
Area 3A Landscape TARP	
No TARP	• Continue monitoring program • IMC to report in the End of Panel Report
Level 1	• Continue monitoring program • IMC to report in the End of Panel Report
Level 2	• Actions as stated for Level 1 • Review monitoring frequency • Notify relevant technical specialists and seek advice on any Corrective Management Actions (CMA) required • Implement agreed CMAs as approved
Level 3	• Actions as stated for Level 2 • Immediately notify OEH, DoPI, DPI, SCA, other resource managers and relevant technical specialists and seek advice on any CMA required • Site visits with stakeholders if required • Review monitoring program and modify if necessary within 1 month • Implement increased monitoring if required within 2 weeks • Develop site CMA in consultation with key stakeholders within 1 month, (pending stakeholder availability) and seek approvals • Completion of works following approvals • Issue CMA report within 1 month of works completion • Conduct initial follow up monitoring & reporting within 2 months of CMA completion • Review the relevant TARP and Management Plan in consultation with key stakeholders
Exceeding TARP (Swamp 15A only)	• Actions as stated for Level 3 • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation

Table 48: Area 3B Swamp TARP Actions table summary (IMC 2020b)

<table>
<tr><th>TARPs</th><th>Actions</th></tr>
<tr><td colspan="2">Area 3B Swamp TARP</td></tr>
<tr><td>Level 1</td><td rowspan="4">Management strategies
• upfront mine planning
• vegetation monitoring
• water spreading
• seeding/planting
• weeding
• fauna monitoring
• fire management
• grouting of controlling of controlling
Offsets
• Offset required immediately, if no remediation considered practicable. Offset required 5 years following remediation, if it is ineffective. This period can be extended to 10 years, with the agreement of the Secretary.
Other Actions:
• Monitoring period for swamp size is related to capture of LiDARdar data at the end of each longwall ~ 1 year.</td></tr>
<tr><td>Level 2</td></tr>
<tr><td>Level 3</td></tr>
<tr><td>Exceeding TARP (Swamp 15A only)</td></tr>
</table>

TARPs	Actions
Area 3B Swamp TARP	
	• Triggers for groundwater decline result in increased intensity and frequency of vegetation monitoring of vegetation monitoring

Table 49: Area 3B Watercourses TARP Actions table summary (IMC 2020c)

TARPs	Actions
Area 3B Watercourses TARP	
No TARP	N/A
Level 1	• Continue monitoring program • IMC to submit an Impact Report to OEH (DPIE), DoPE (DPIE), T&I, WaterNSW and other relevant resource managers • IMC to report in the End of Panel Report • Summarise action and monitoring in AEMR
Level 2	• Actions as stated for Level 1 • Review monitoring frequency • Notify relevant technical specialists and seek advice on any Corrective Management Actions (CMA) required • Implement agreed CMAs as approved (subject to stakeholder feedback)
Level 3	• Actions as stated for Level 2 • Site visits with OEH (DPIE), DoPE (DPIE), T&I WaterNSW, other resource manager/s (if requested) • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key stakeholders • Develop site CMA (subject to stakeholder feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with OEH (DPIE), DoPE (DPIE), T&I, WaterNSW and other stakeholders • Completion of works following approvals and at a time agreed between BHPBIC (IMC), DoPE (DPIE), T&I and WaterNSW (i.e. may be after mining induced movements and impacts complete), including monitoring and reporting on success.

It is still important to note the impacts and any relevant declines in health for the Upland Swamps or aquatic habitat. For Area 3A, TARPS were triggered in the two Impact Upland Swamps and three tributaries. For Area 3B, TARPS were triggered for five tributaries and five Upland Swamps.

4.4 Recommendations for future monitoring

The 2021 iteration of the monitoring program has adopted a number of recommendations from the previous report (Niche 2021), this represents a continuation of refinement in the monitoring approach with a number of assessment methodologies augmented by additional analyses.

The following recommendations are made in relation to future monitoring carried out as a part of the Program.

4.4.1 Seasonal data collection

As described in Section 2.4, the argument to undertake transect (floristic) data collection only once per year in spring is supported by the fact that no seasonal differences were detected in TSR or in species composition for any swamp. No strong justification to maintain the autumn round of transect data collection was identified and the analysis undertaken suggests that 'spring only' data collection and analysis would not compromise the validity of the Program or fundamentally alter the monitoring results.

It is recommended that future data collection in spring only is considered for the transect (floristic) monitoring, with subsequent data analysis restricted to the spring seasons of data collection.

4.4.2 Statistical analysis

It is recommended that the additional breakpoint analysis undertaken in 2021 should also be applied to the control swamp floristic data to enable direct comparison to trends at impact and control swamps, rather than just within impact swamps. Breakpoint analysis should also incorporate time since bushfire to determine how bushfire impacts may affect changes to TSR and composition at a landscape scale. This will also allow a greater consideration of global trends that are apparent in the monitoring results.

4.4.3 Additional monitoring sites

It is recommended that one additional Control swamp and two additional Control frog transects are added to the Program in 2022, commensurate with the predicted change of Swamp 15A(1), frog transects NDC, ND1 and ND2 to post-mining treatment following longwall progression in this upcoming program year.

4.4.4 LiDAR analysis

Niche have undertaken preliminary investigation into potential additional data products that could be derived from LiDAR data to enhance the analysis workflow. The exploratory analysis found that canopy density values can be calculated with some additional analysis workflow steps. These values give a strong indication of areas of canopy that are thinning over time, potentially suggesting dieback.

Niche recommend a new analysis workflow model be developed and implemented for the 2022 monitoring program round. The new model allows multiple criteria analysis through overlay of canopy height and canopy density LiDAR derived products matched with NDVI moisture index values acquired by South32's new fleet of UAVs to better inform ecosystem functionality of the swamps. The combination of these three datasets allows for subcommunity classification according to a predefined set of rules. This new multiple criteria approach to subcommunity boundary delineation will increase efficiency to complete manual verification of the data and generate greater value from the data that South32 collects as it relates to usage and project outcomes.

Niche also recommend a formalised workflow methodology to verify changes or TARP triggers to swamp extent or ecosystem functionality identified by the LiDAR model, involving the following:

- Add confidence interval when undertaking swamp subcommunity mapping using LiDAR model
- Low confidence areas to be checked in the field during floristic monitoring or with assistance from South32 Environment team.
- Where drying in moisture index (NIR) have been detected, monitoring locations in the field with soil moisture probe and check of ground vegetation condition.

5. Conclusion

Following the 2021 analysis of impacts to Upland Swamps and Creeks against TARPs, an ecological response had been detected at several Impact sites within Dendrobium Areas 3A and 3B where decline in ecological values have been observed.

For Area 3A, TARPS were triggered in the two Impact Upland Swamps and three tributaries. For Area 3B, TARPS were triggered for five tributaries and five Upland Swamps.

Long term declines in ecological condition have been identified through this monitoring program and potential resilience and recovery may be observed after above average rainfall seasons in 2020, 2021 and already in 2022.

The additional assessments of both swamp floristic data and Littlejohn's Tree Frog detection data in 2021 have shed further light on the complex relationships between suitable and optimal habitats, prevailing environmental conditions, and the interplay of these factors with mining effects.

A number of recommendations to improve the monitoring program have been detailed in Section 4.4 to further refine the analysis and in particular to inform ecosystem health assessment from aerial imagery analysis upgrades as technology advances.

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The Analytical Edge Statistical Consulting (TAE) 2022c. Task 2A - Breakpoint analysis of total flora species richness at swamps within the Dendrobium region. Data collected up to and including 2021. 28 March 2022.

The Analytical Edge Statistical Consulting (TAE) 2022d. Task 2A - Breakpoint analysis of total flora species richness at swamps within the Dendrobium region. Data collected up to and including 2021. 28 March 2022.

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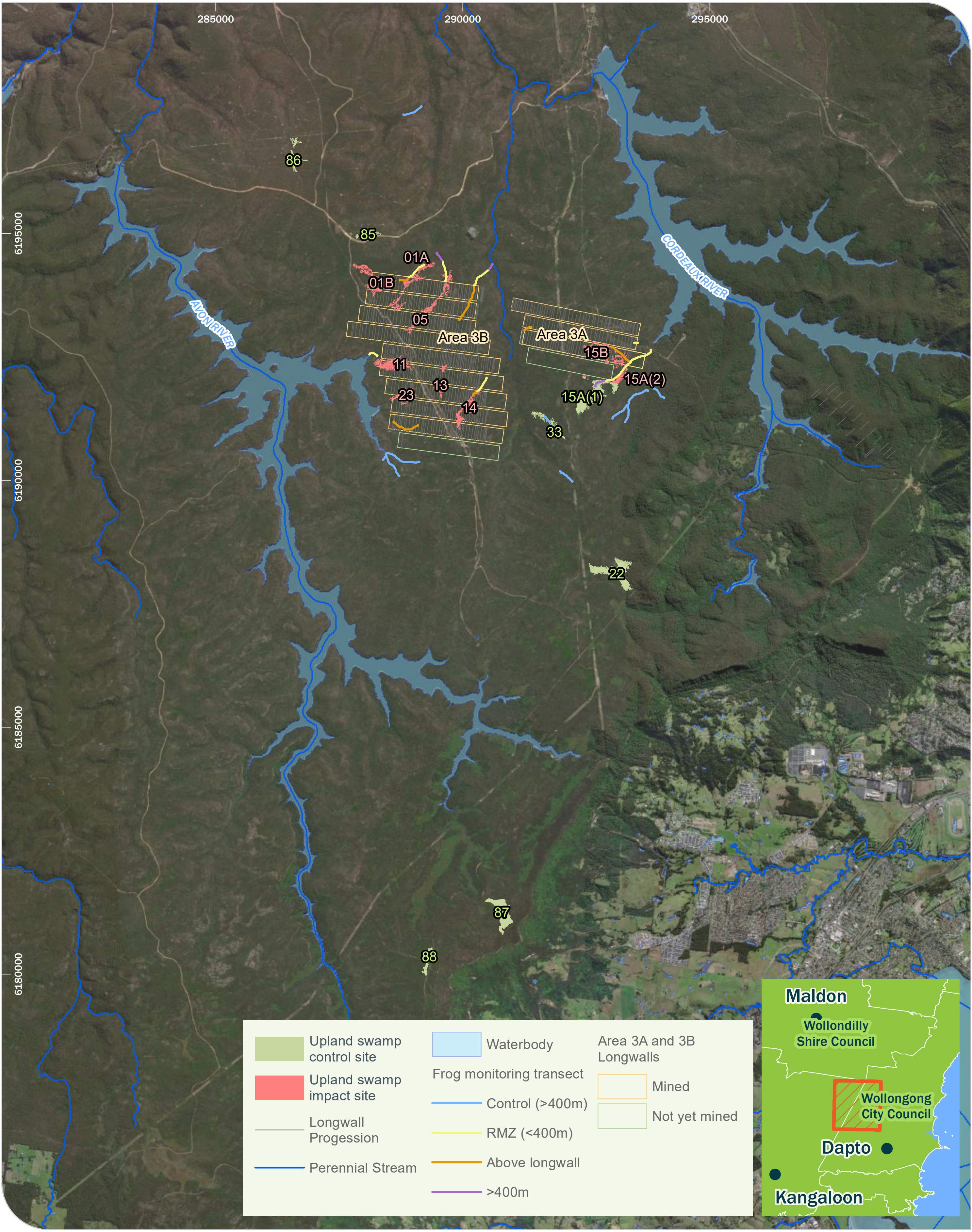
Warton, D. I., S. T. Wright, and Y. Wang 2012. Distance-based multivariate analyses confound location and dispersion effects. *Methods in Ecology and Evolution*, 3(1): 89-101

Watershed HydroGeo 2019. Dendrobium Mine Geographic review of mining effects on Upland Swamps at Dendrobium Mine. Unpublished Report for Illawarra Coal.

Figures



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niche
Environment and Heritage

0 2
km
GDA 1994 MGA Zone 56

Location of the study area

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program
Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 1

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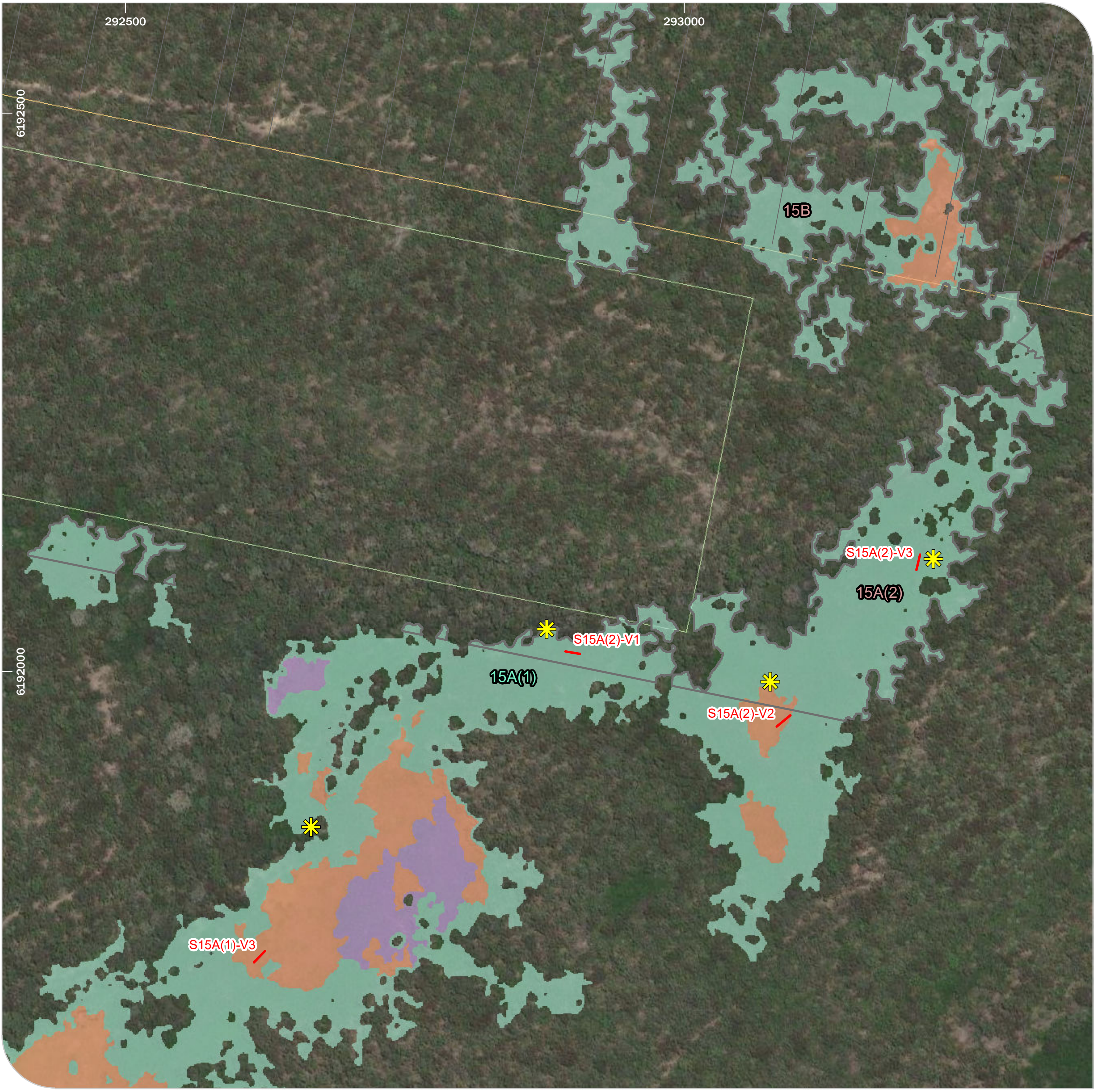

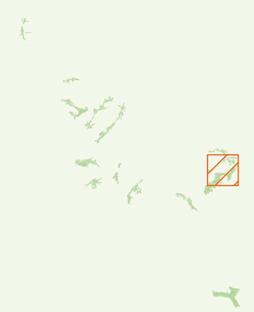

Photo Point

Monitoring Transect

Longwall Progession

Veg sub-community mapping from 2021 LiDAR analysis

Banksia Thicket

Tea Tree Thicket

Sedgeland Heath

Area 3A and 3B Longwalls

Mined

Not yet mined

niche Environment and Heritage

0 100

m

GDA 1994 MGA Zone 56

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Location of flora monitoring impact sites surveyed in Dendrobium Area 3A - 15A(2): Impact

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Figure 2a

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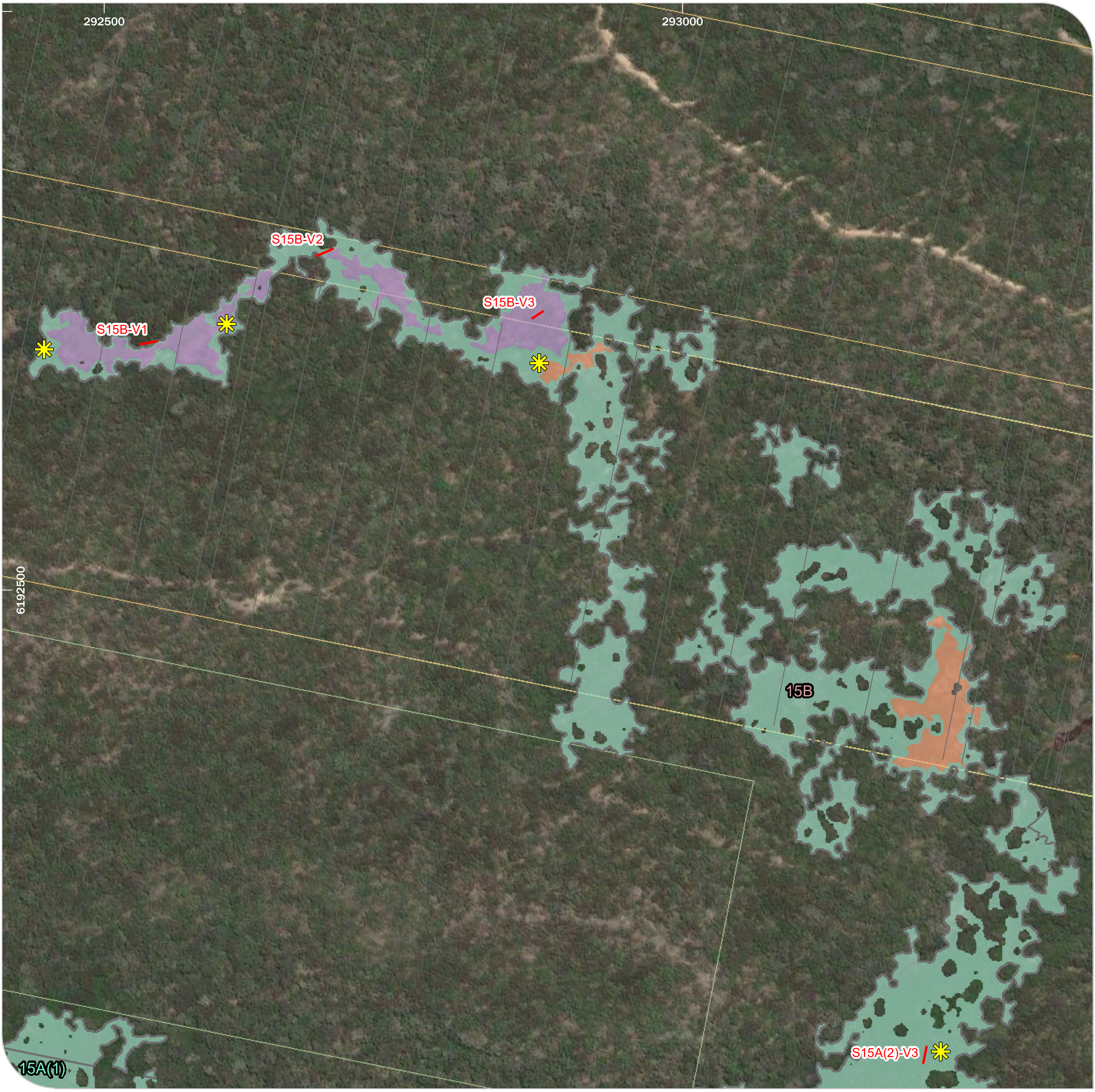

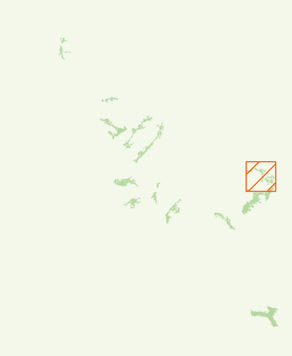

Photo Point

Monitoring Transect

Longwall Progession

Veg sub-community mapping from 2021 LiDAR analysis

Banksia Thicket

Tea Tree Thicket

Sedgeland Heath

Area 3A and 3B Longwalls

Mined

Not yet mined

niche Environment and Heritage

0 50
m
GDA 1994 MGA Zone 56

Location of flora monitoring impact sites surveyed in Dendrobium Area 3A - 15B: Impact

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 2b

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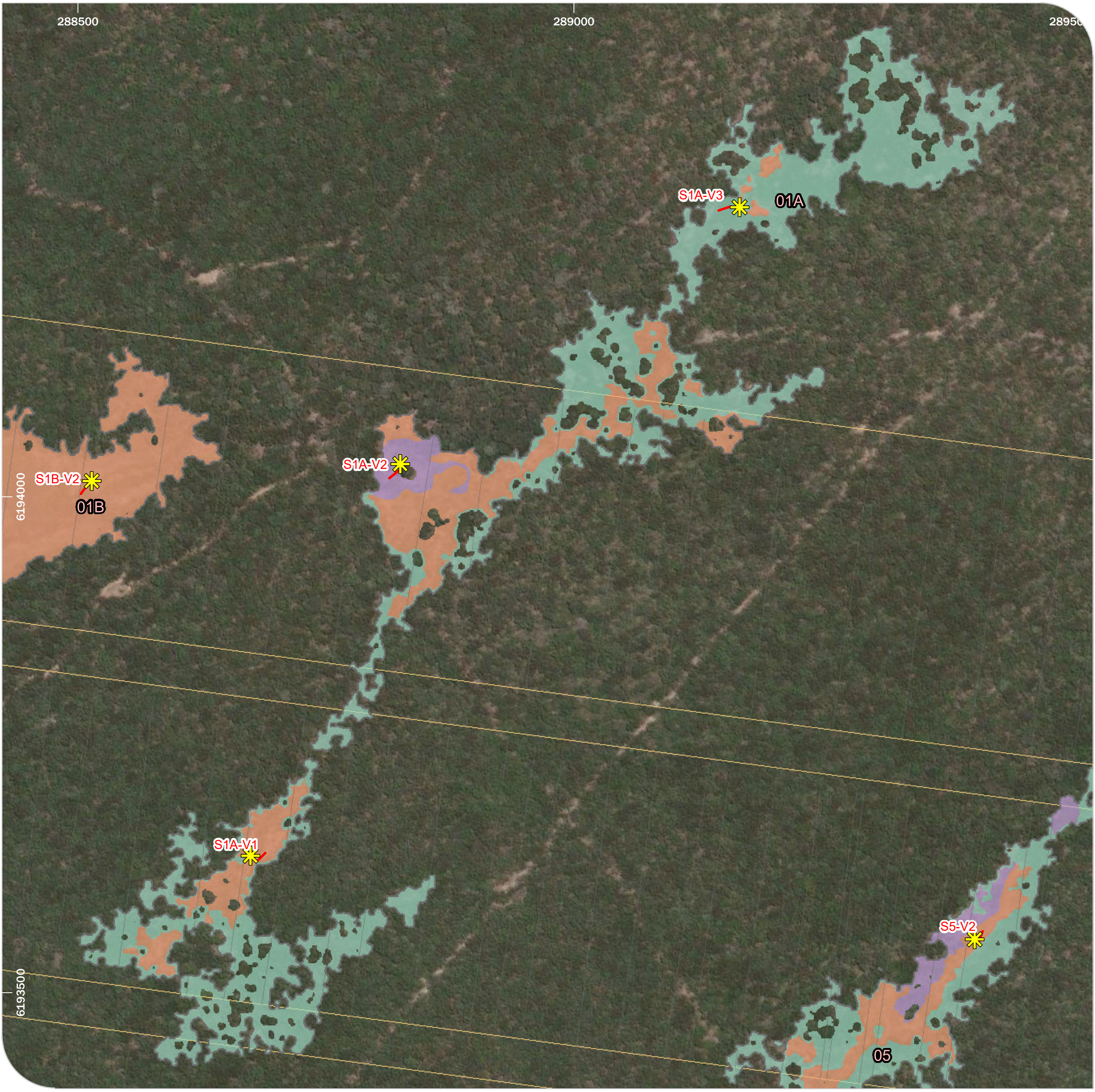

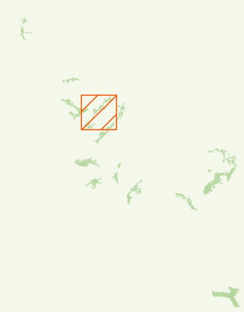

Photo Point

Monitoring Transect

Longwall Progession

Veg sub-community mapping from 2021 LiDAR analysis

Banksia Thicket

Tea Tree Thicket

Sedgeland Heath

Area 3A and 3B Longwalls

Mined

niche Environment and Heritage

0 100

m

GDA 1994 MGA Zone 56

Location of flora monitoring impact sites surveyed in Dendrobium Area 3B - 01A: Impact

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 3a

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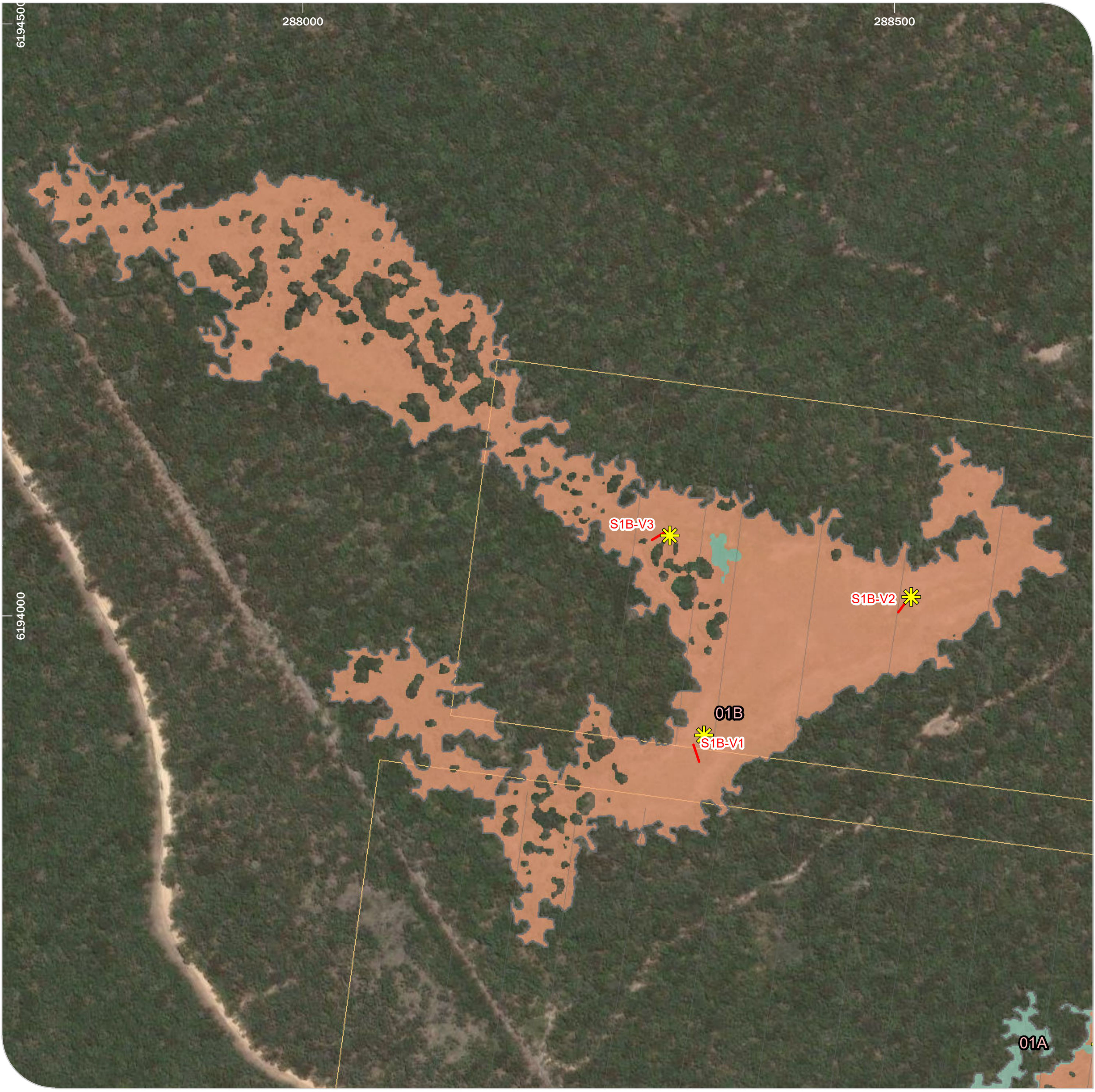


Photo Point

Monitoring Transect

Longwall Progession

Veg sub-community mapping from 2021 LiDAR analysis

Banksia Thicket

Sedgeland Heath

Area 3A and 3B Longwalls

Mined

niche Environment and Heritage

0 100 m

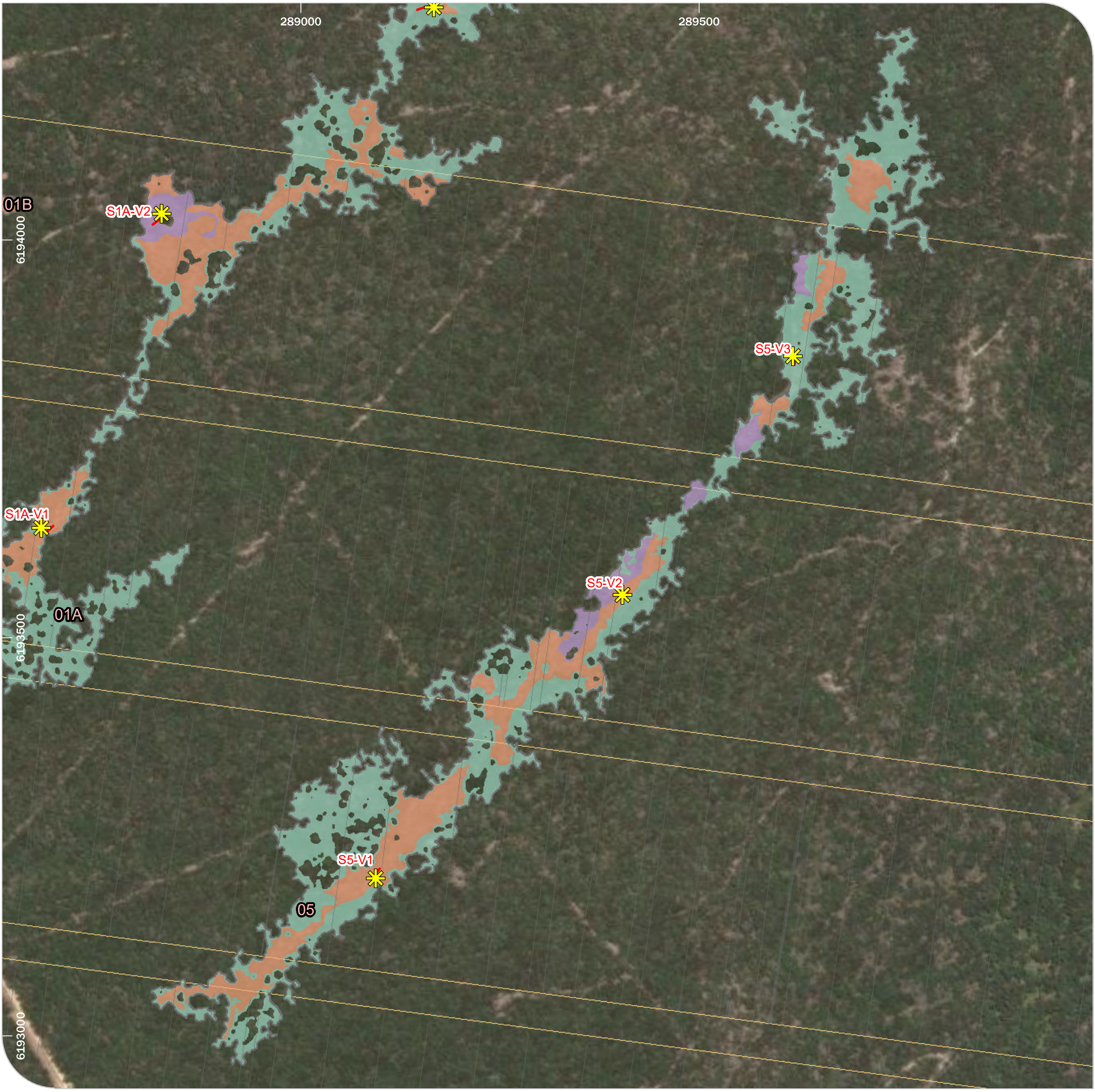
GDA 1994 MGA Zone 56

Location of flora monitoring impact sites surveyed in Dendrobium Area 3B - 01B: Impact

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 3b



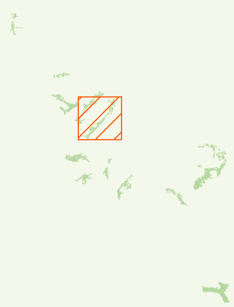


Photo Point

Monitoring Transect

Longwall Progession

Veg sub-community mapping from 2021 LiDAR analysis

Banksia Thicket

Tea Tree Thicket

Sedgeland Heath

Area 3A and 3B Longwalls

Mined

niche Environment and Heritage

0 100
m
GDA 1994 MGA Zone 56

Location of flora monitoring impact sites surveyed in Dendrobium Area 3B - 05: Impact

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 3c

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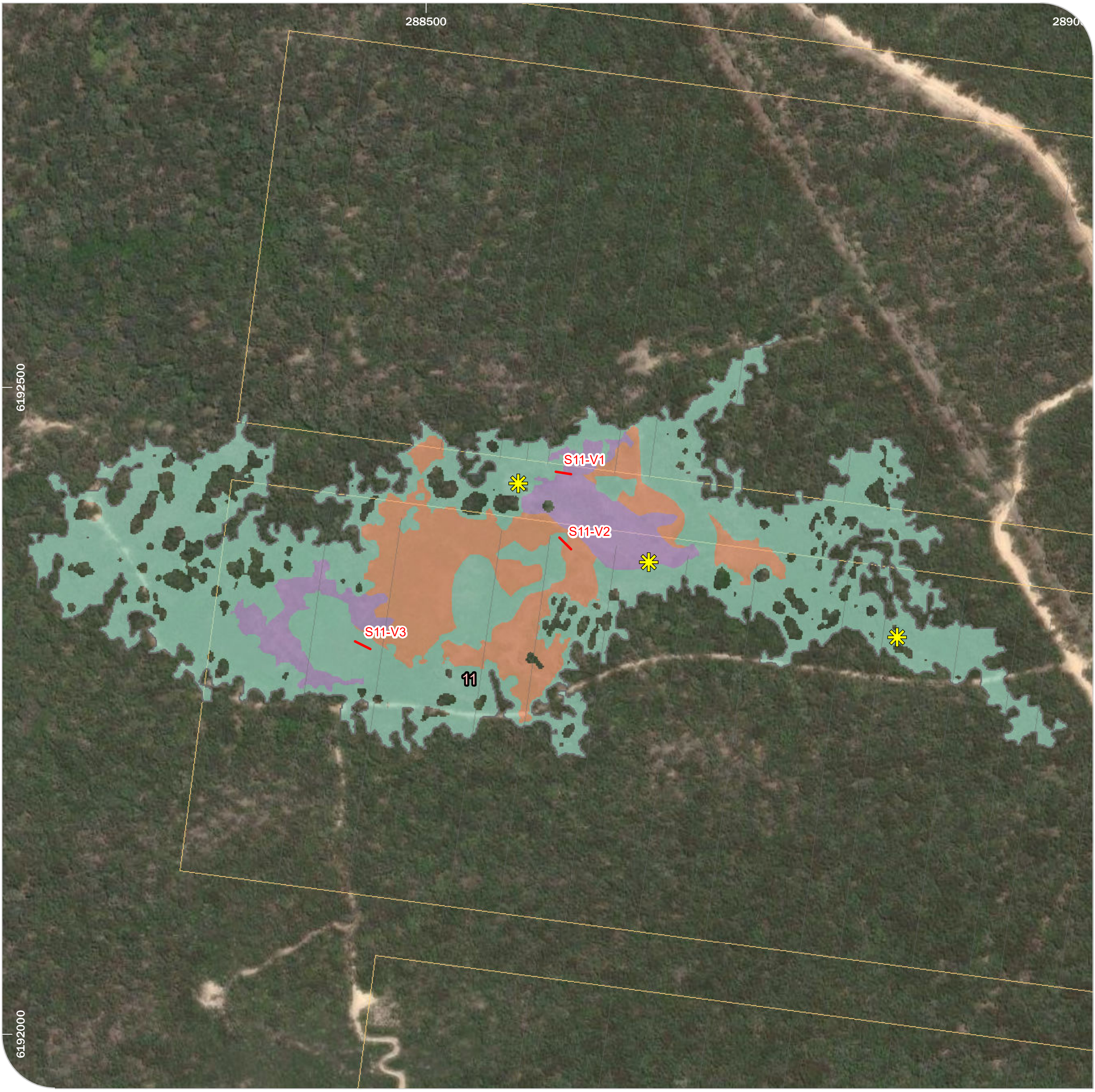

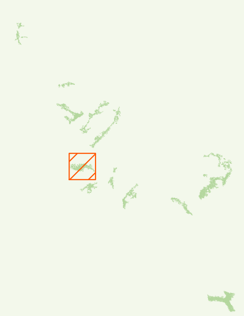

Photo Point

Monitoring Transect

Longwall Progession

Veg sub-community mapping from 2021 LiDAR analysis

Banksia Thicket

Tea Tree Thicket

Sedgeland Heath

Area 3A and 3B Longwalls

Mined

niche Environment and Heritage

0 50
m
GDA 1994 MGA Zone 56

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Location of flora monitoring impact sites surveyed in Dendrobium Area 3B - 11: Impact

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Figure 3d

World Imagery: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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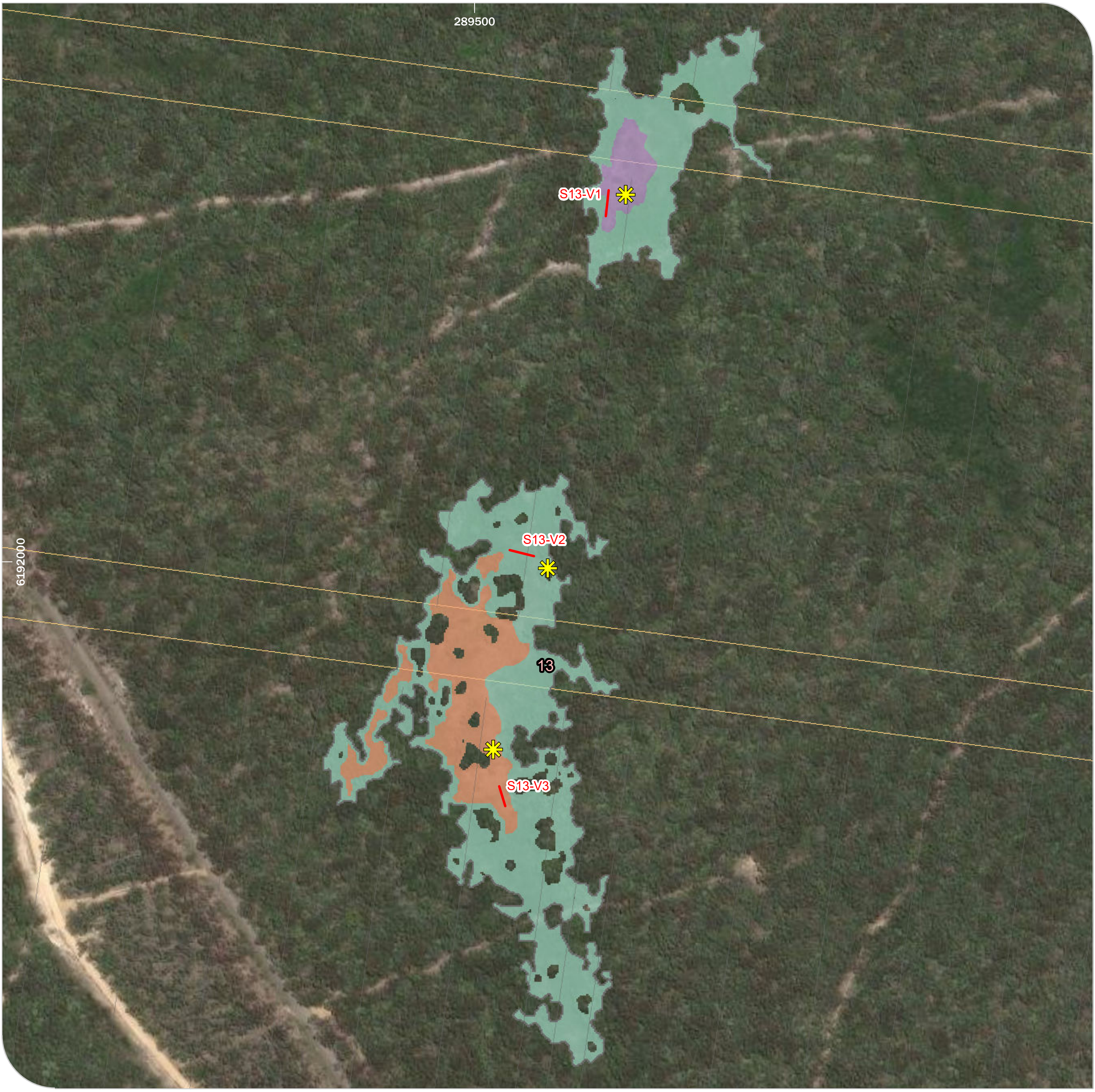

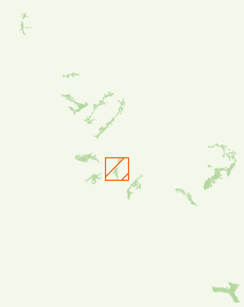

Photo Point

Monitoring Transect

Longwall Progression

Veg sub-community mapping from 2021 LiDAR analysis

Banksia Thicket

Tea Tree Thicket

Sedgeland Heath

Area 3A and 3B Longwalls

Mined

niche Environment and Heritage

0 50
m

GDA 1994 MGA Zone 56

Location of flora monitoring impact sites surveyed in Dendrobium Area 3B - 13: Impact

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 3e

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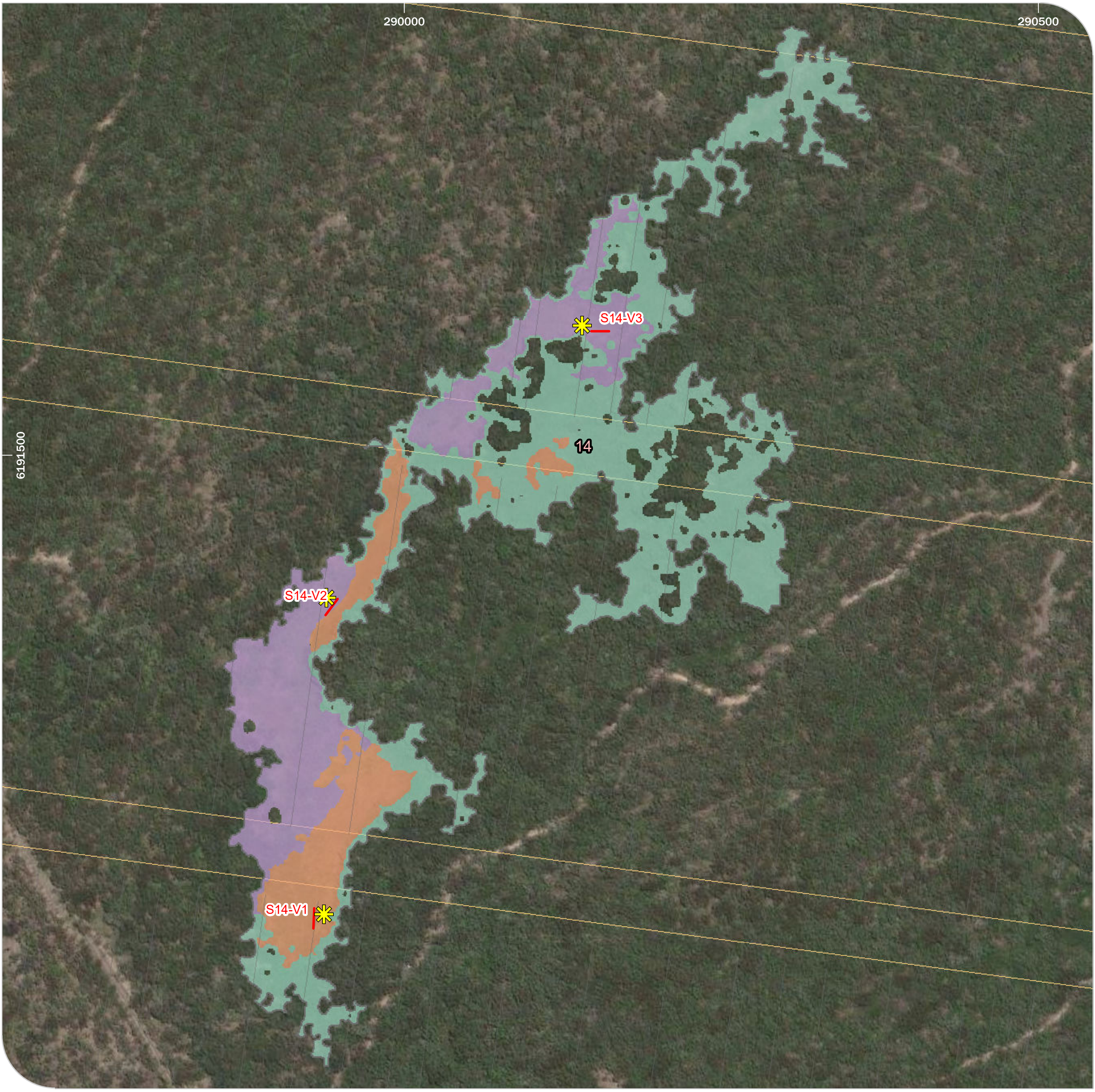


Photo Point

Monitoring Transect

Longwall Progession

Veg sub-community mapping from 2021 LiDAR analysis

Banksia Thicket

Tea Tree Thicket

Sedgeland Heath

Area 3A and 3B Longwalls

Mined

niche Environment and Heritage

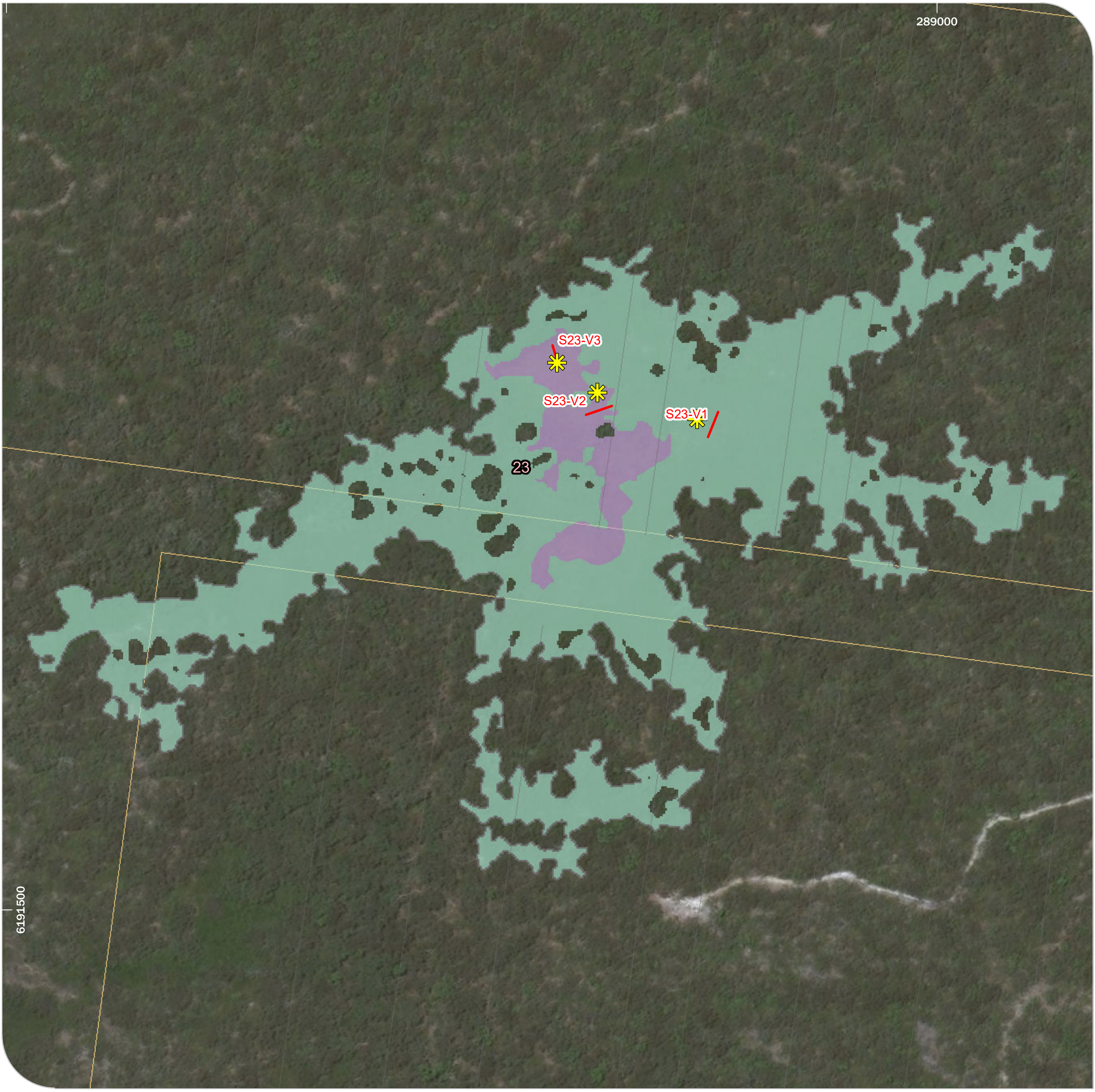
0 50
m
GDA 1994 MGA Zone 56

Location of flora monitoring impact sites surveyed in Dendrobium Area 3B - 14: Impact

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 3f



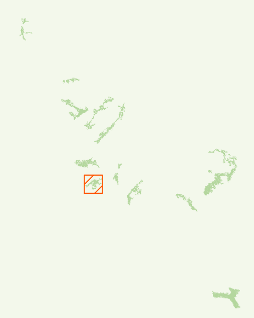


Photo Point

Monitoring Transect

Longwall Progression

Veg sub-community mapping from 2021 LiDAR analysis

Banksia Thicket

Tea Tree Thicket

Area 3A and 3B Longwalls

Mined

niche Environment and Heritage

0 50
m
GDA 1994 MGA Zone 56

Location of flora monitoring impact sites surveyed in Dendrobium Area 3B - 23: Impact

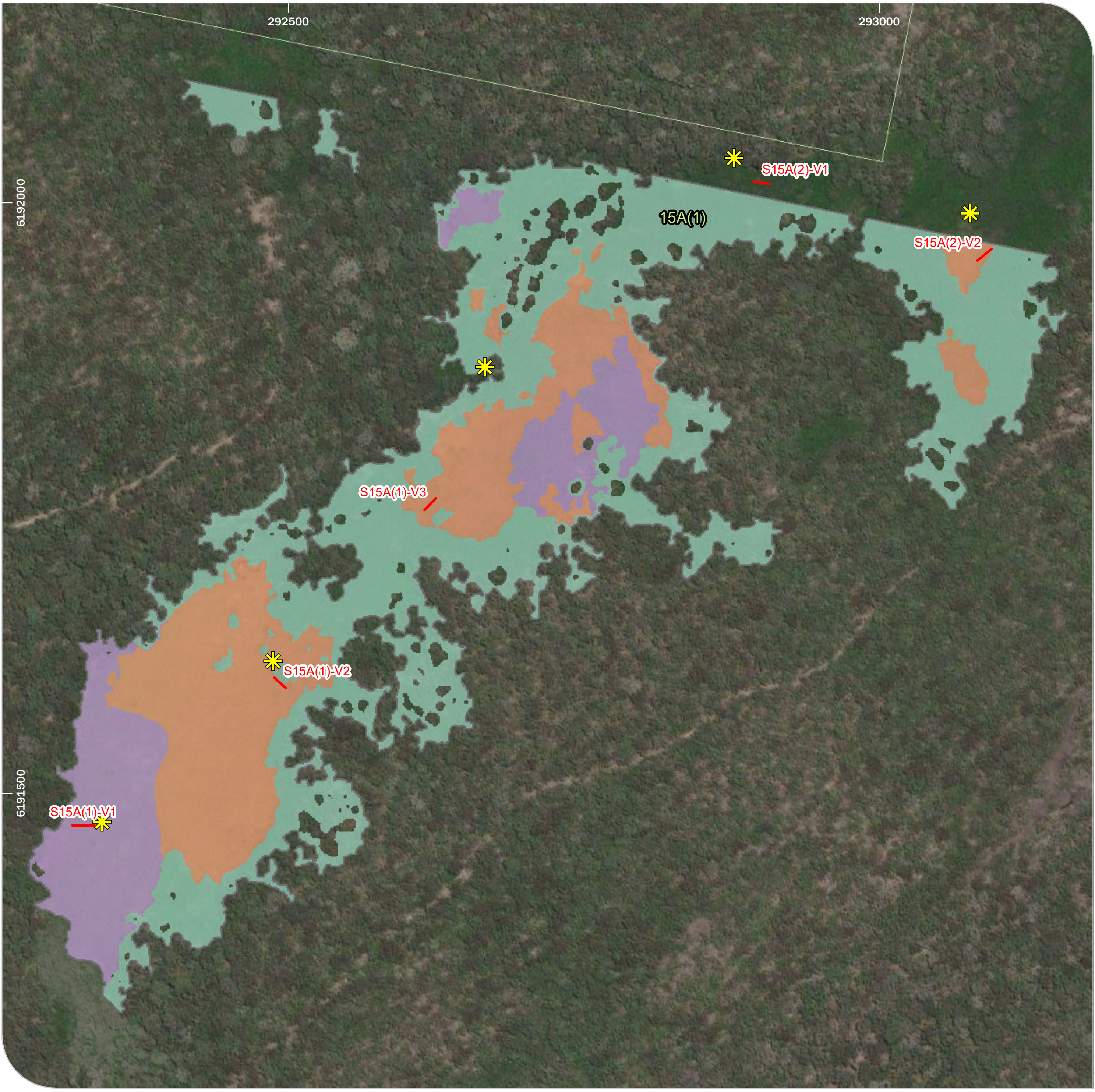
Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 3g

World Imagery: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

v2.0



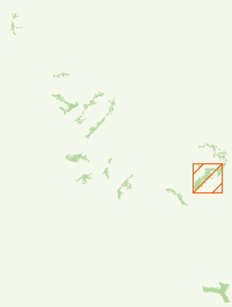


Photo Point

Monitoring Transect

Veg sub-community mapping from 2021 LiDAR analysis

Banksia Thicket

Tea Tree Thicket

Sedgeland Heath

Area 3A and 3B Longwalls

Not yet mined

niche Environment and Heritage

0 100 m

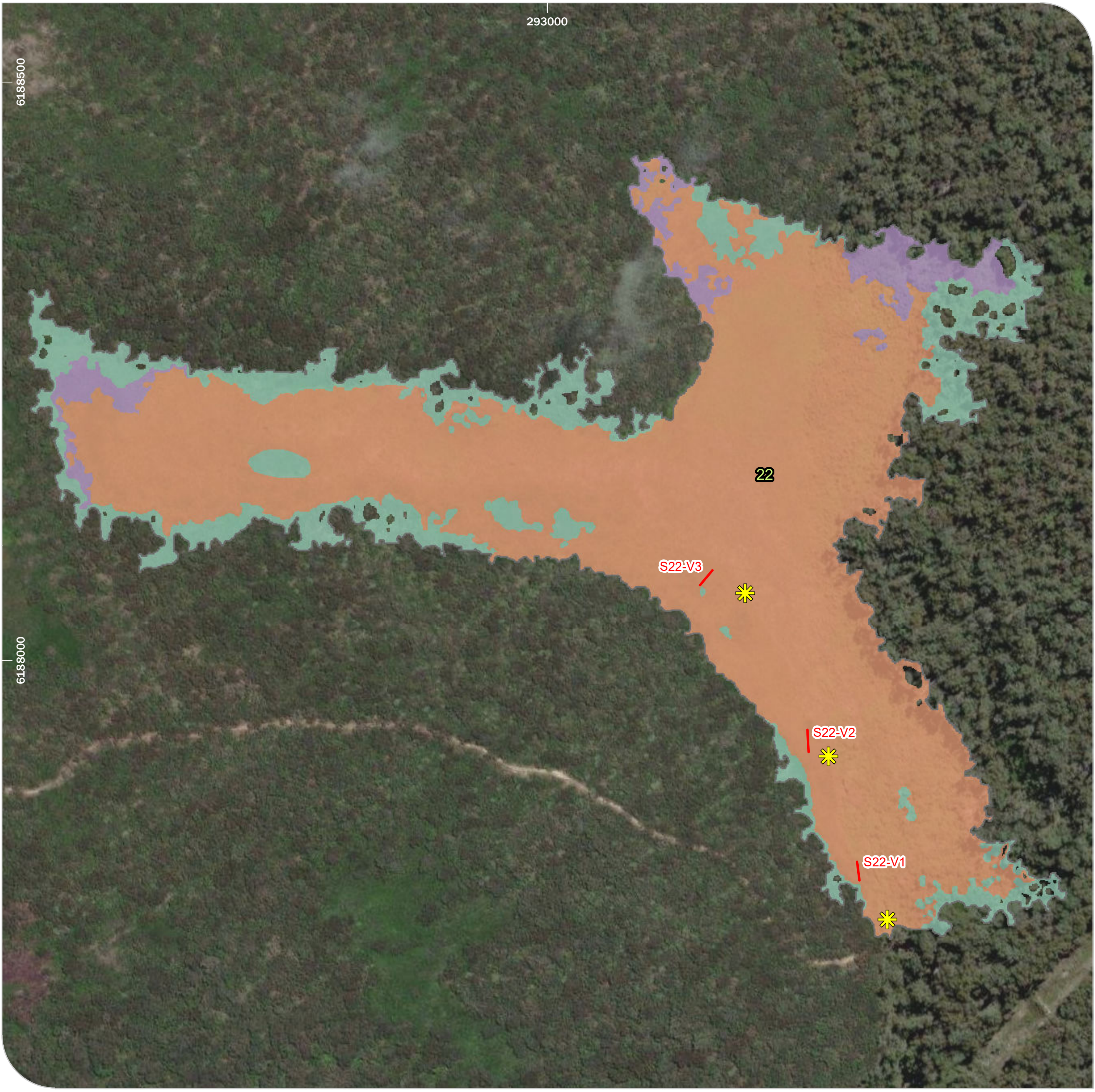
GDA 1994 MGA Zone 56

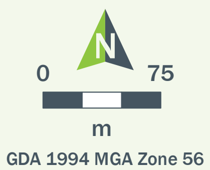
Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Location of flora monitoring control sites surveyed in the 2021 program - 15A(1): Control

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Figure 4a





niche Environment and Heritage

Location of flora monitoring control sites surveyed in the 2021 program - 22: Control

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 4b

World Imagery: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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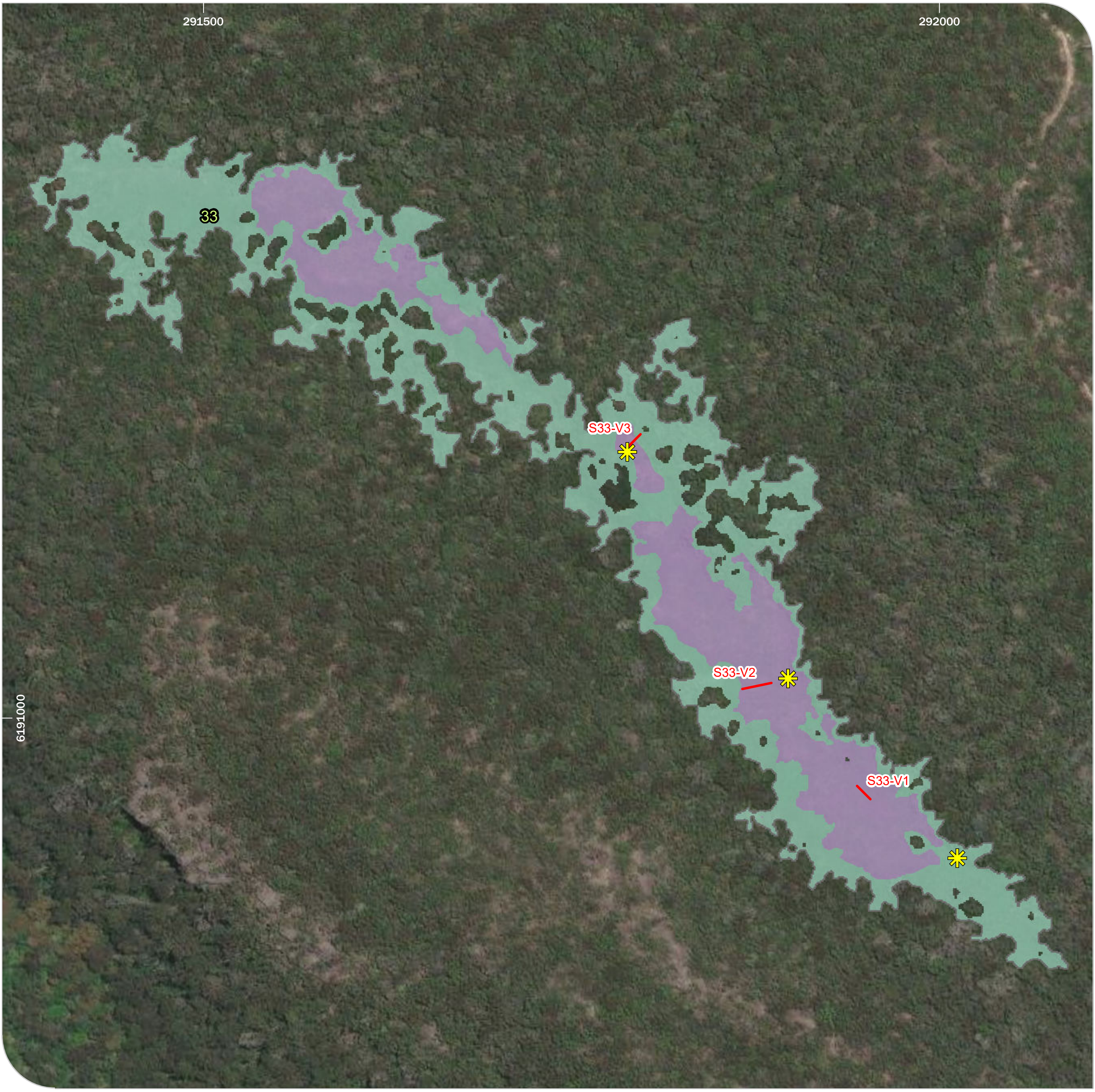

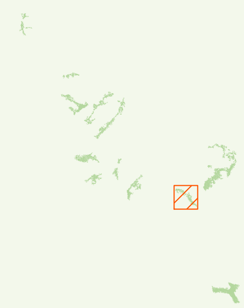

Photo Point

Monitoring Transect

Veg sub-community mapping from 2021 LiDAR analysis

Banksia Thicket

Tea Tree Thicket

niche Environment and Heritage

0 75
m

GDA 1994 MGA Zone 56

Location of flora monitoring control sites surveyed in the 2021 program - 33: Control

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 4c

World Imagery: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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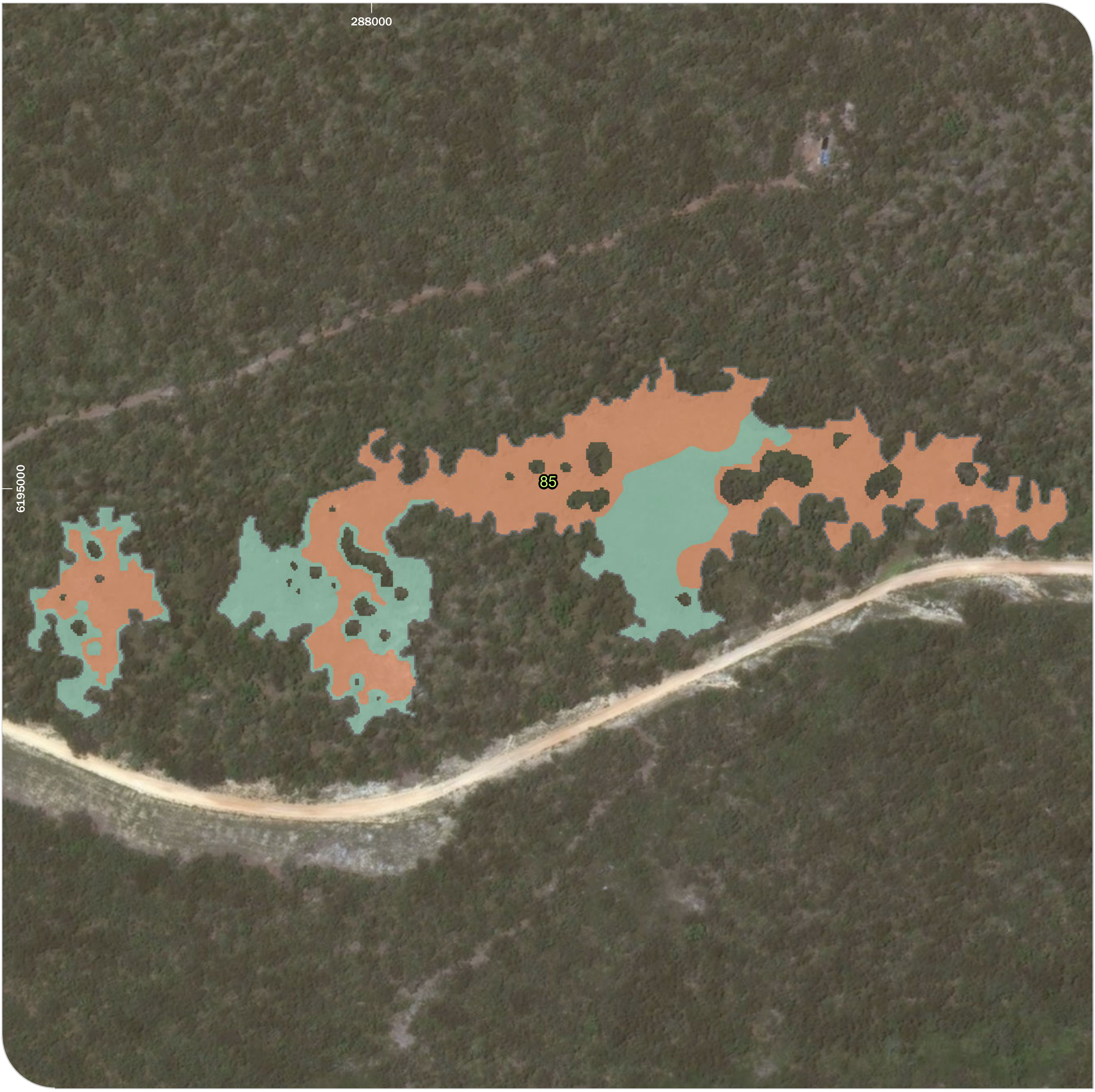

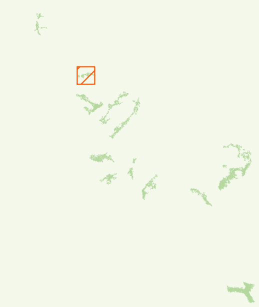

Veg sub-community mapping from 2021 LiDAR analysis

- Banksia Thicket
- Sedgeland Heath

niche Environment and Heritage

0 50
m
GDA 1994 MGA Zone 56

Location of flora monitoring control sites surveyed in the 2021 program - 85: Control
Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 4d

World Imagery: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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v2.0

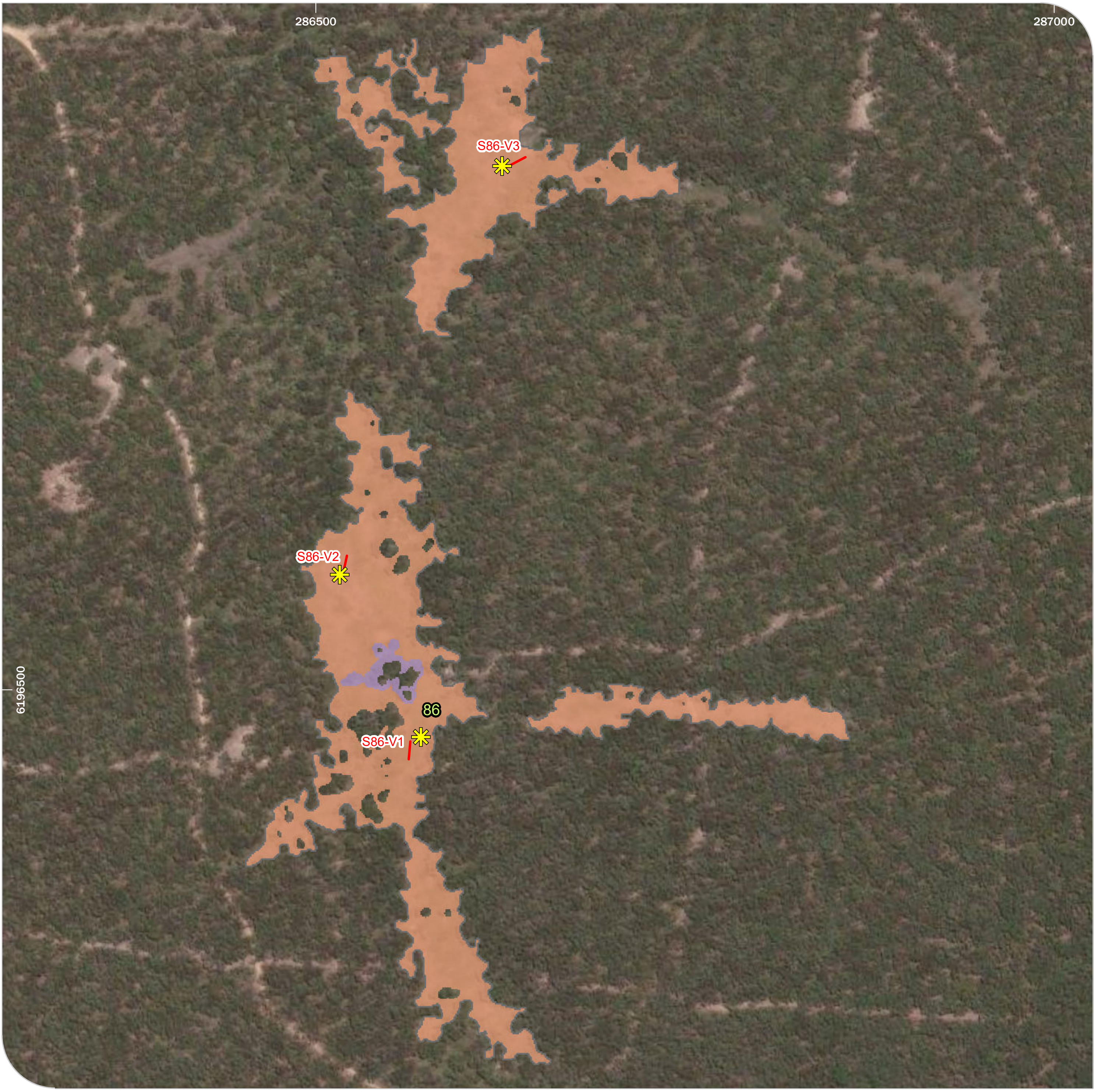


Photo Point

Monitoring Transect

Veg sub-community mapping from 2021 LiDAR analysis

Tea Tree Thicket

Sedgeland Heath

niche Environment and Heritage

0 75
m
GDA 1994 MGA Zone 56

Location of flora monitoring control sites surveyed in the 2021 program - 86: Control

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program
Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 4e

Longwall Progression

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

Very Shallow <25cm

Shallow 50-25cm

Deep >100cm

Threatened frog monitoring impact transect

RMZ (<400m)

Area 3A and 3B Longwalls

Mined

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM

niche Environment and Heritage

0 20 m

GDA 1994 MGA Zone 56

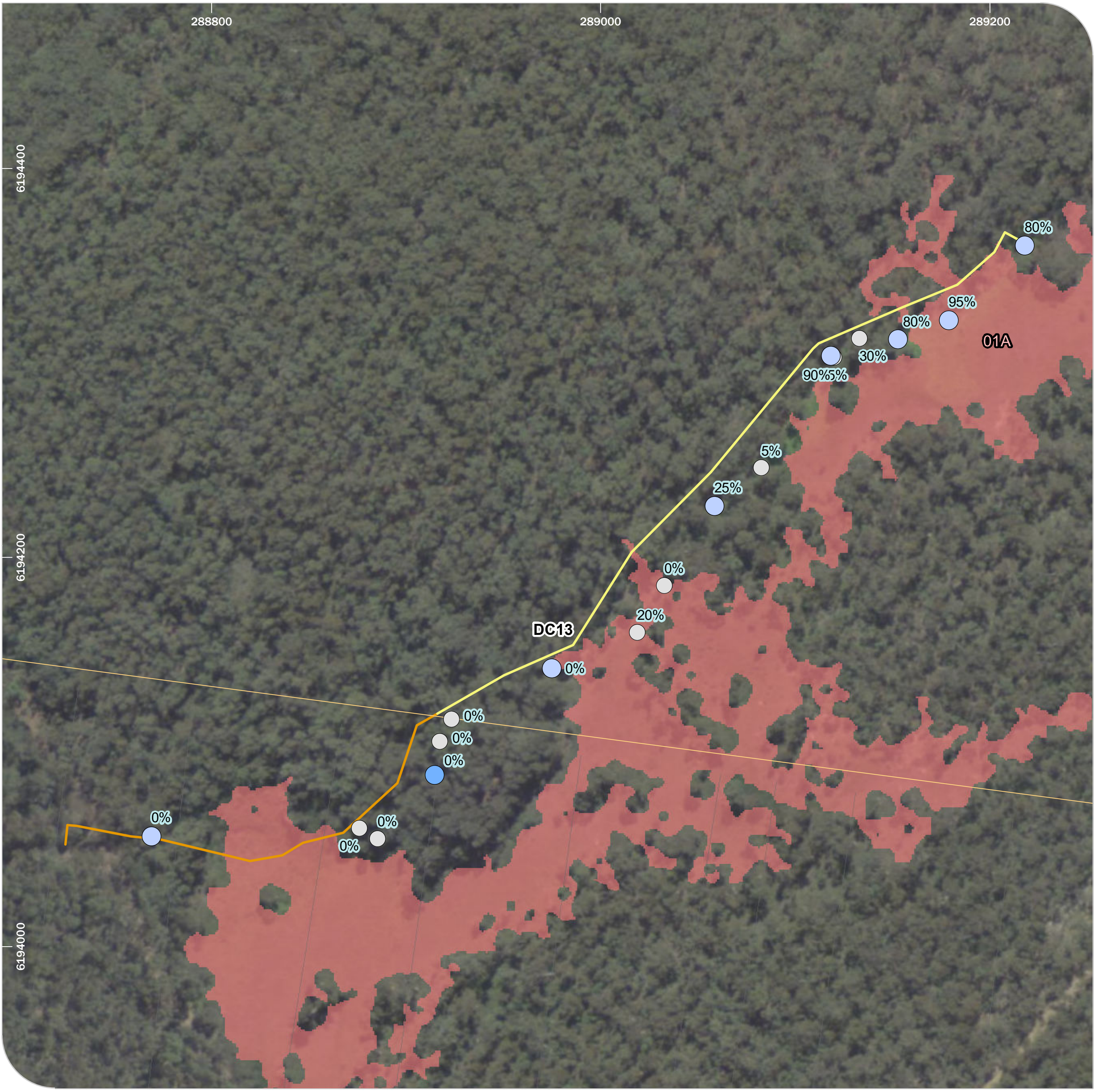
Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

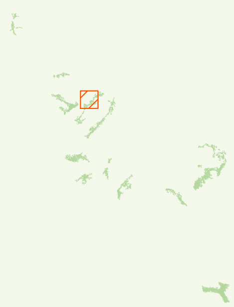
Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Figure 5a

v2.0





Longwall Progession

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

Very Shallow <25cm

Shallow 50-25cm

Moderate 100-50cm

Threatened frog monitoring impact transect

RMZ (<400m)

Above longwall

Veg sub-community mapping from 2021 LiDAR analysis

Upland swamp impact site

Area 3A and 3B Longwalls

Mined

niche Environment and Heritage

0 60

m

GDA 1994 MGA Zone 56

Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 5b

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

Moderate 100-50cm

Threatened frog monitoring impact transect

Control (>400m)

niche Environment and Heritage

0 50 m

GDA 1994 MGA Zone 56

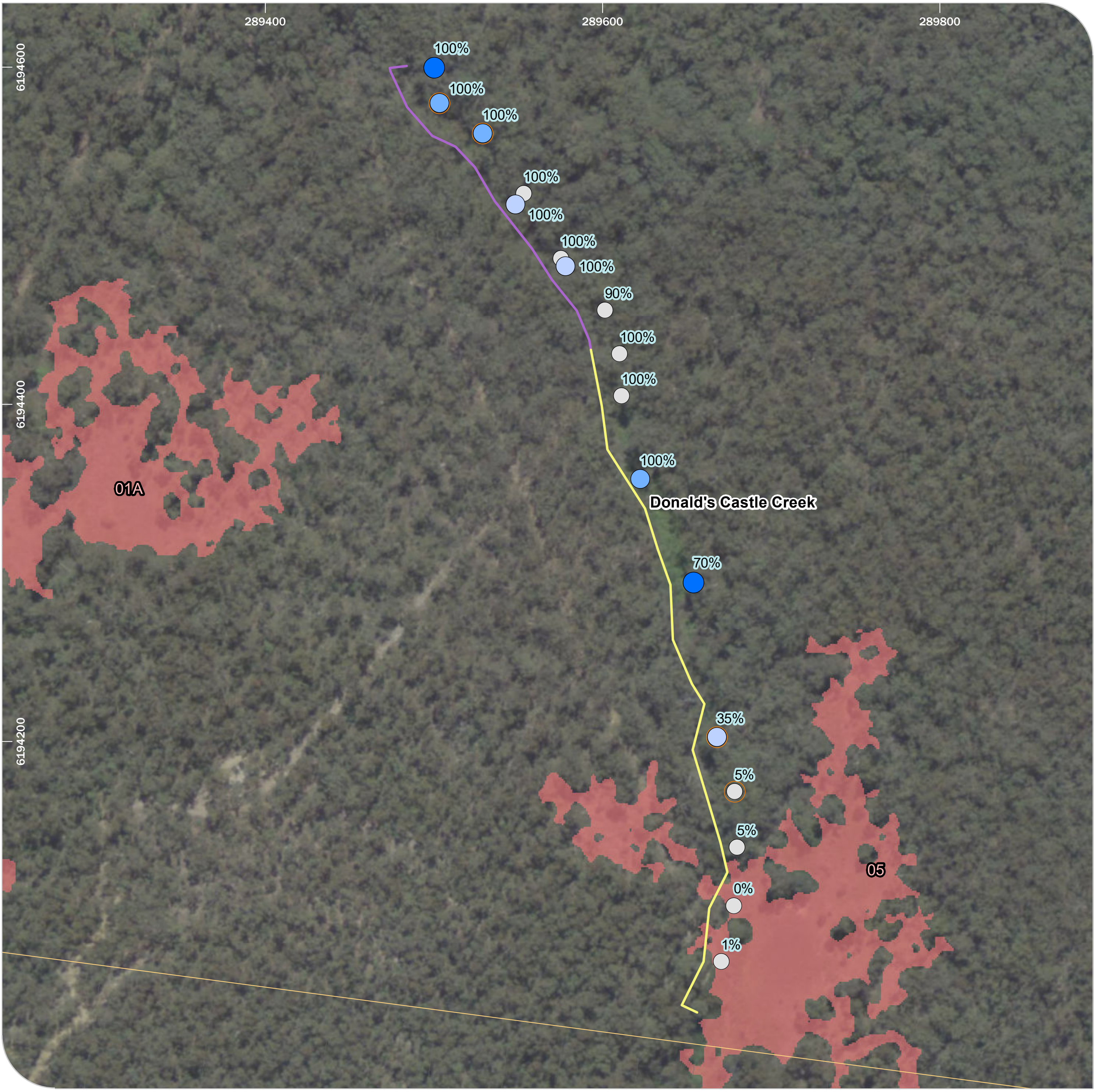
Location of threatened frog monitoring transects used in the 2021 program

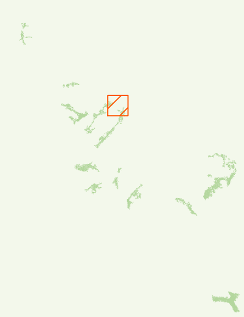
Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 5c

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM





Longwall Progression

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

- Very Shallow <25cm
- Shallow 50-25cm
- Moderate 100-50cm
- Deep >100cm
- Iron flocculent

Threatened frog monitoring impact transect

- RMZ (<400m)
- >400m

Veg sub-community mapping from 2021 LiDAR analysis

- Upland swamp impact site

Area 3A and 3B Longwalls

- Mined

niche
Environment and Heritage

0 70
m
GDA 1994 MGA Zone 56

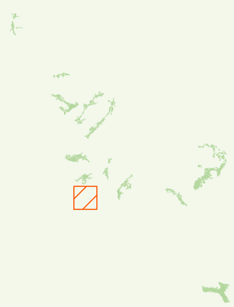
Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Figure 5d

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM



Longwall Progession

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

Very Shallow <25cm

Shallow 50-25cm

Moderate 100-50cm

Deep >100cm

Threatened frog monitoring impact transect

Above longwall

Area 3A and 3B Longwalls

Mined

Not yet mined

niche Environment and Heritage

0 80

m

GDA 1994 MGA Zone 56

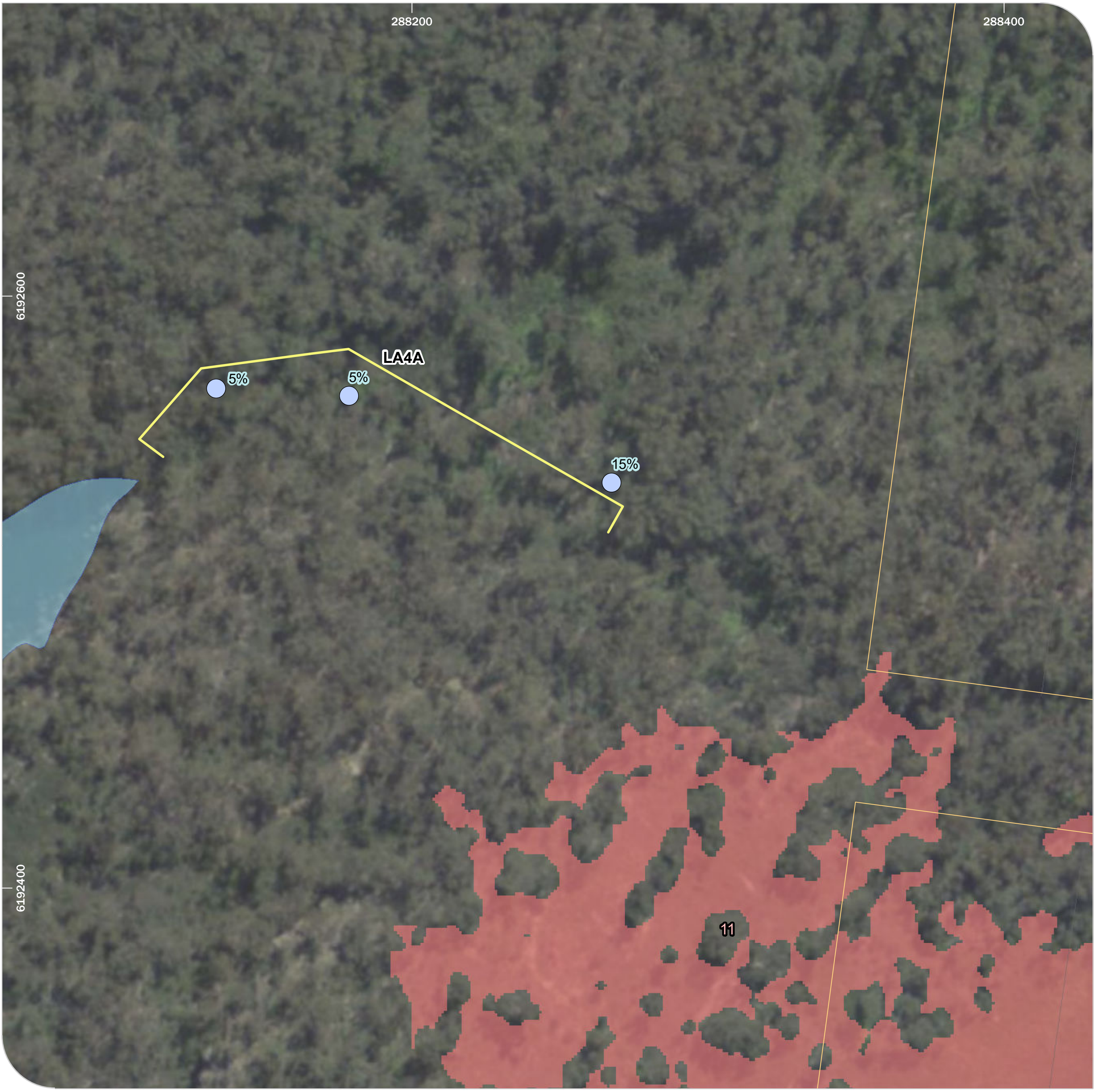
Location of threatened frog monitoring transects used in the 2021 program

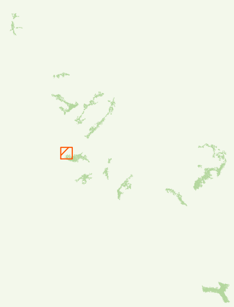
Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 5e

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM





Longwall Progression

Waterbody

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

Shallow 50-25cm

Threatened frog monitoring impact transect

RMZ (<400m)

Veg sub-community mapping from 2021 LiDAR analysis

Upland swamp impact site

Area 3A and 3B Longwalls

Mined

niche Environment and Heritage

0 40

m

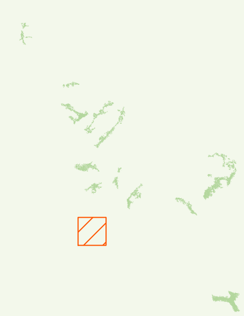
GDA 1994 MGA Zone 56

Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 5f



Waterbody

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

Very Shallow <25cm

Shallow 50-25cm

Moderate 100-50cm

Deep >100cm

Iron flocculent

Threatened frog monitoring impact transect

Control (>400m)

Area 3A and 3B Longwalls

Not yet mined

niche Environment and Heritage

0 100 m

GDA 1994 MGA Zone 56

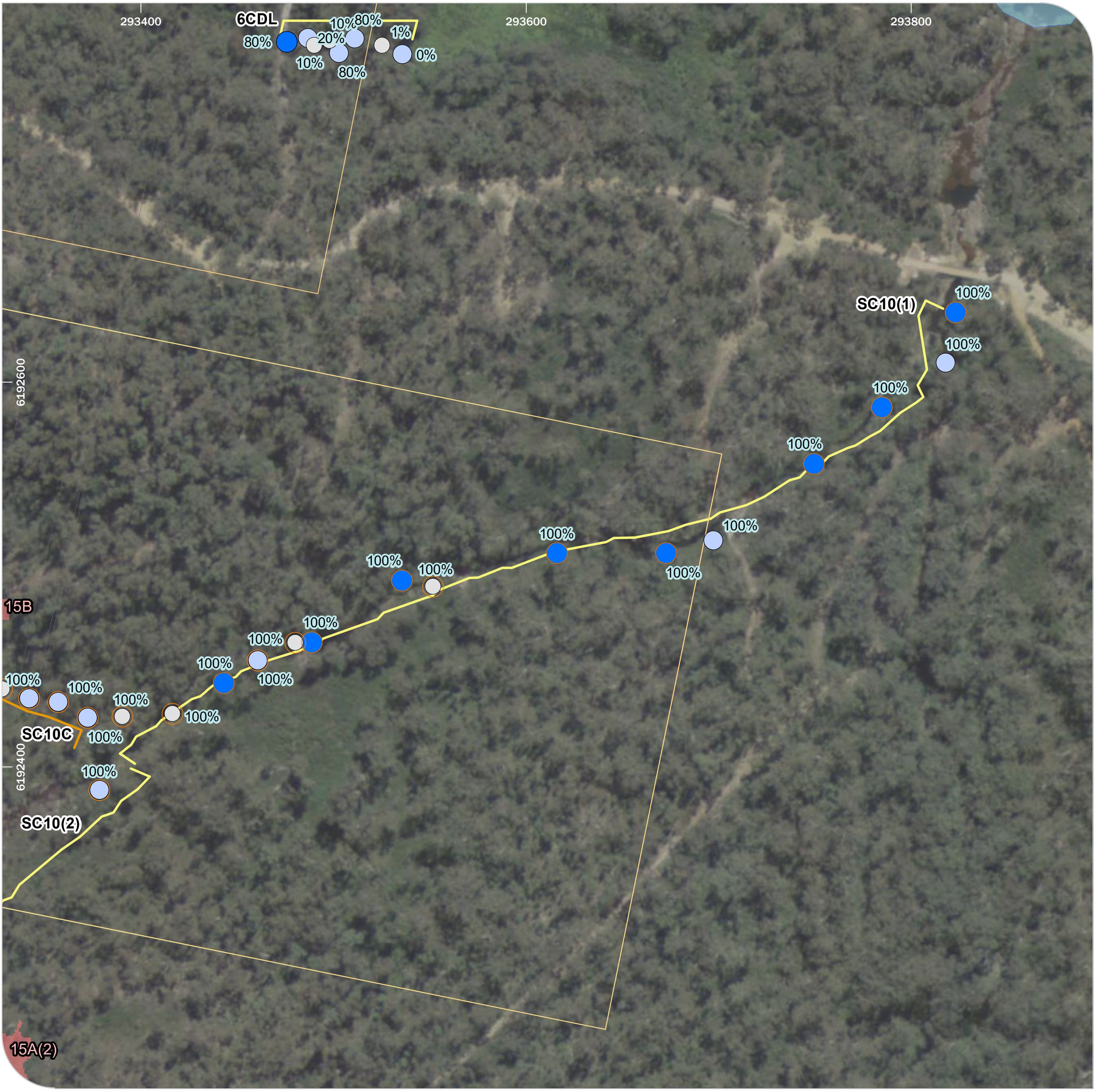
Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Figure 5g

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM



Longwall Progession

Waterbody

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

Very Shallow <25cm

Shallow 50-25cm

Deep >100cm

Iron flocculent

Threatened frog monitoring impact transect

RMZ (<400m)

Above longwall

Veg sub-community mapping from 2021 LiDAR analysis

Upland swamp impact site

Area 3A and 3B Longwalls

Mined

Not yet mined

niche Environment and Heritage

N

0 60

m

GDA 1994 MGA Zone 56

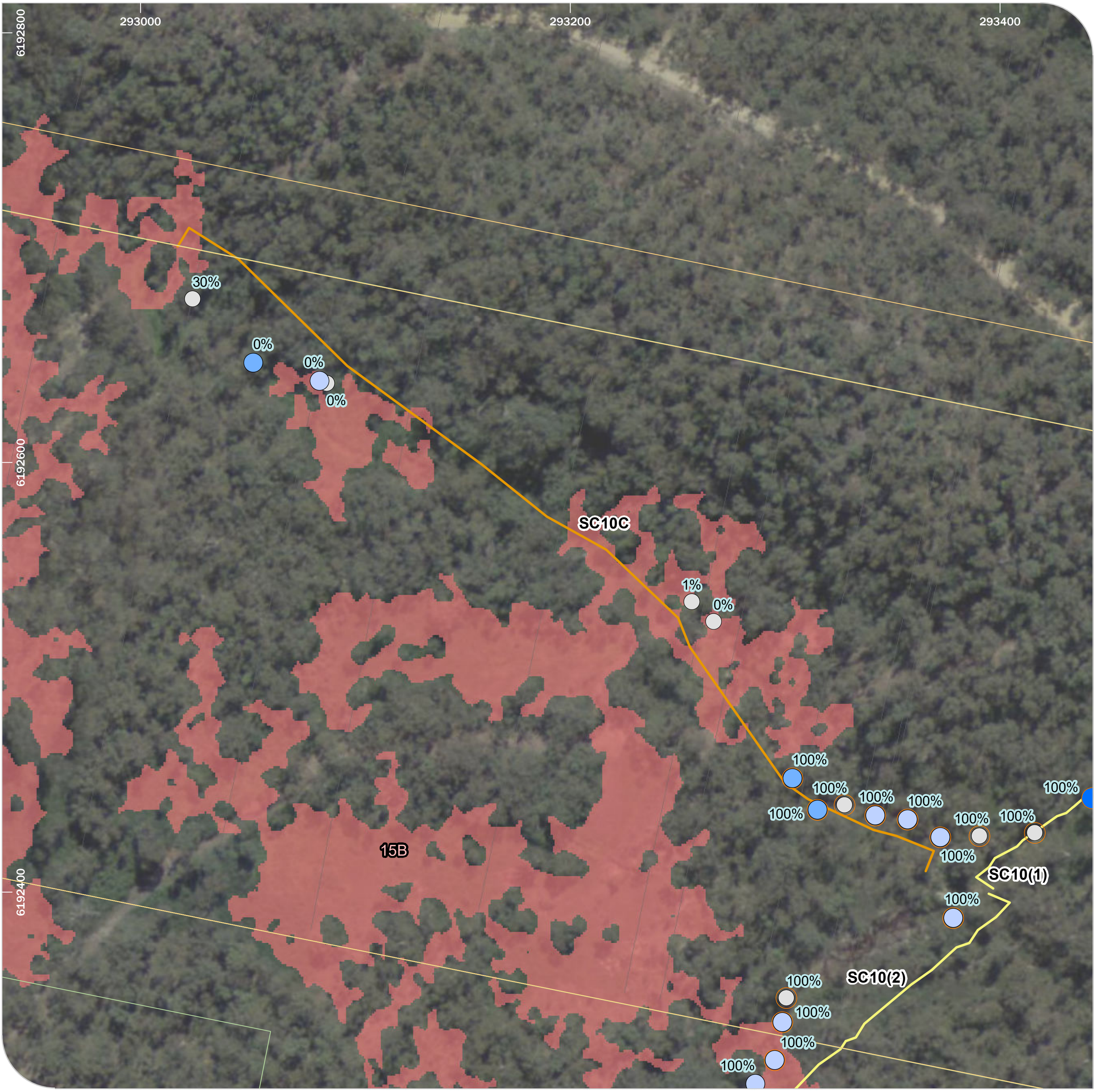
Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

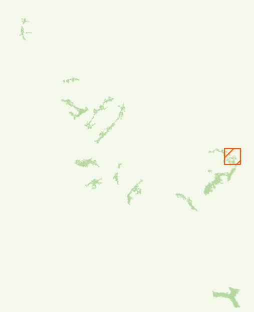
Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Figure 5h

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM





Longwall Progression

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

Very Shallow <25cm

Shallow 50-25cm

Moderate 100-50cm

Deep >100cm

Iron flocculent

Threatened frog monitoring impact transect

RMZ (<400m)

Above longwall

Veg sub-community mapping from 2021 LiDAR analysis

Upland swamp impact site

Area 3A and 3B Longwalls

Mined

Not yet mined

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM

niche Environment and Heritage

N

0 60

m

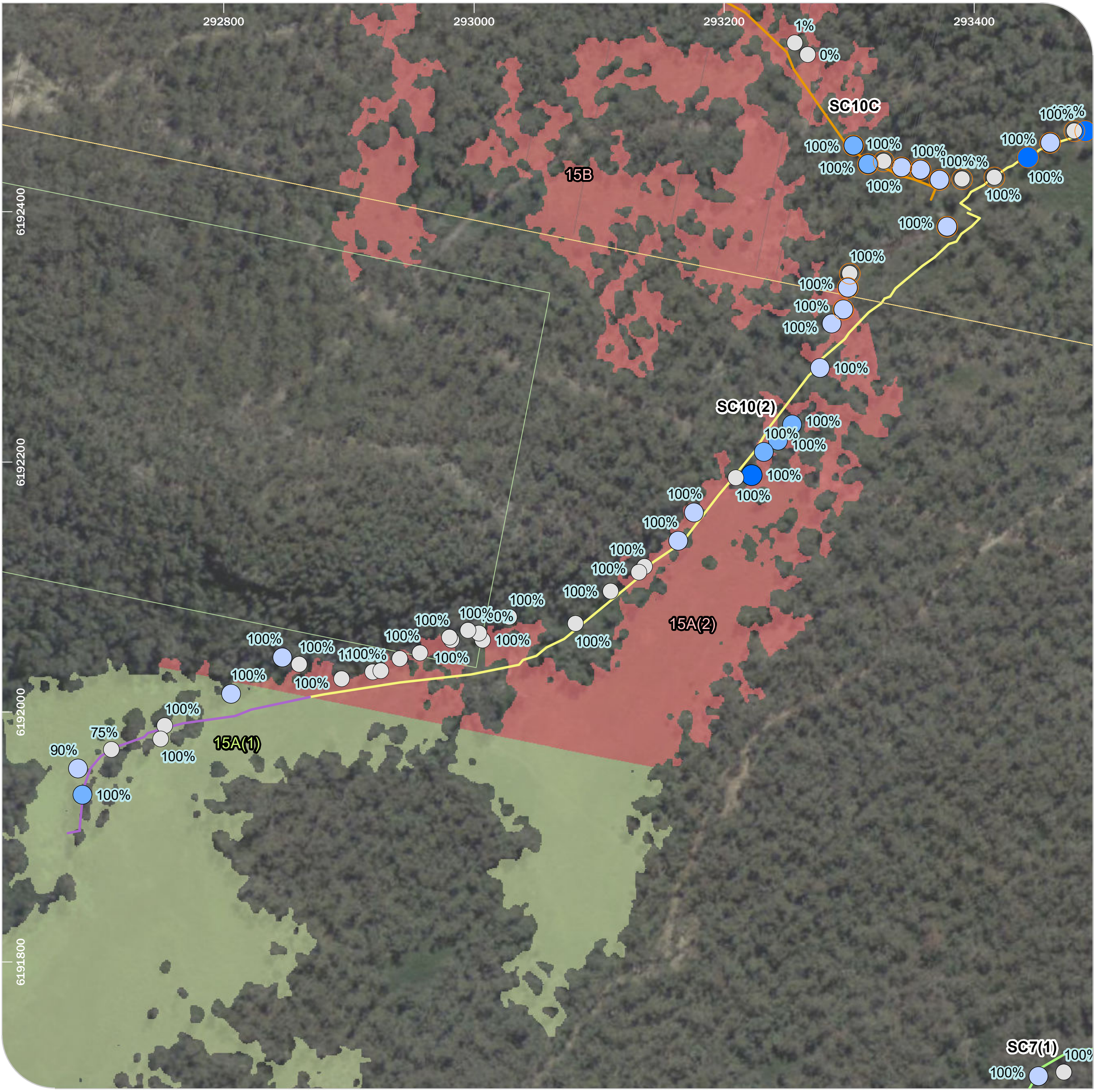
GDA 1994 MGA Zone 56

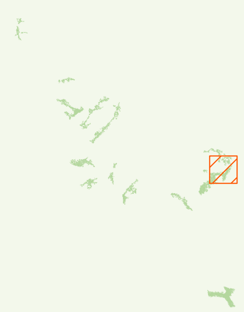
Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Figure 5i





Longwall Progession

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

- Very Shallow <25cm
- Shallow 50-25cm
- Moderate 100-50cm
- Deep >100cm
- Iron flocculent

Threatened frog monitoring impact transect

- Control (>400m)
- RMZ (<400m)
- Above longwall
- >400m

Veg sub-community mapping from 2021 LiDAR analysis

- Upland swamp control site
- Upland swamp impact site

Area 3A and 3B Longwalls

- Mined
- Not yet mined

niche Environment and Heritage

0 100 m

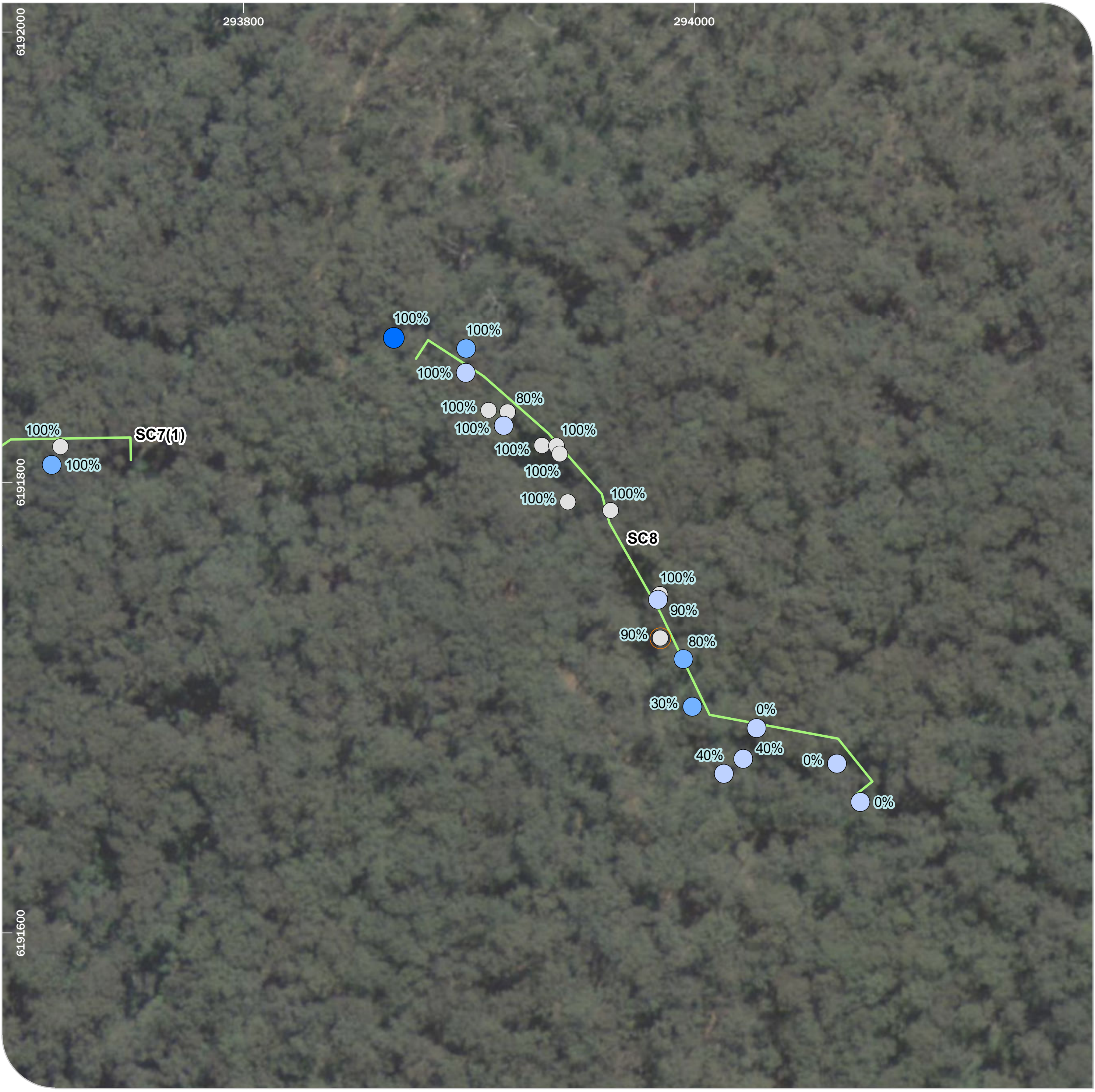
GDA 1994 MGA Zone 56

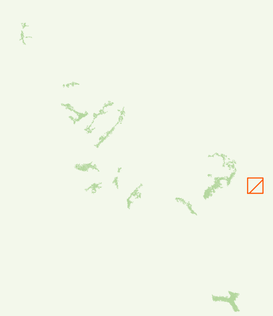
Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 5j





Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

- Very Shallow <25cm
- Shallow 50-25cm
- Moderate 100-50cm
- Deep >100cm
- Iron flocculent

Threatened frog monitoring impact transect

- Control (>400m)

niche Environment and Heritage

0 50 m

GDA 1994 MGA Zone 56

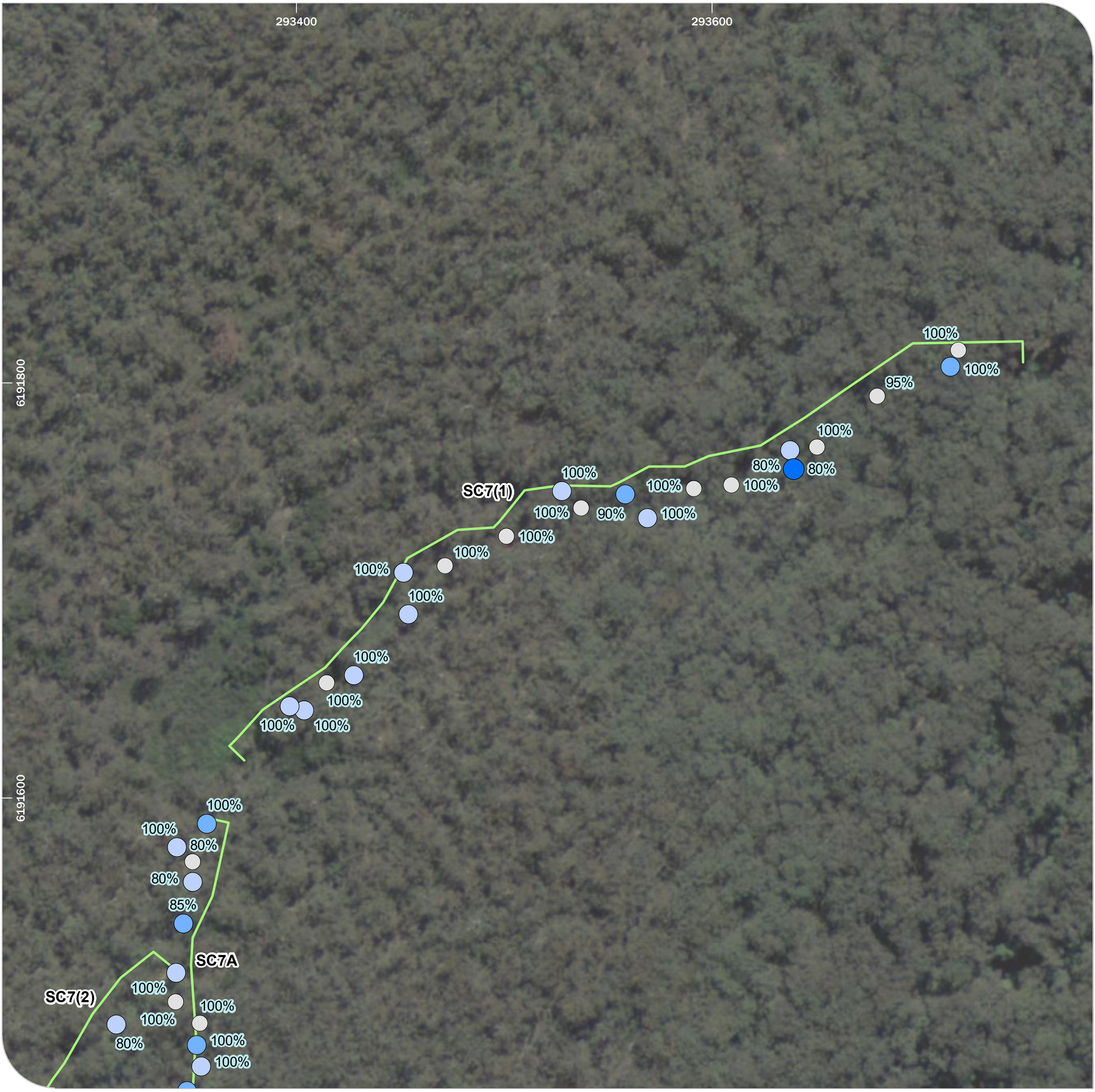
Location of threatened frog monitoring transects used in the 2021 program

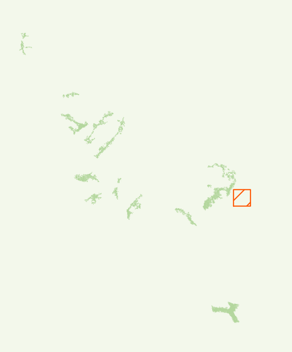
Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 5k

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM





Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

- Very Shallow <25cm
- Shallow 50-25cm
- Moderate 100-50cm
- Deep >100cm

Threatened frog monitoring impact transect

- Control (>400m)

niche Environment and Heritage

0 60 m

GDA 1994 MGA Zone 56

Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 5l

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM

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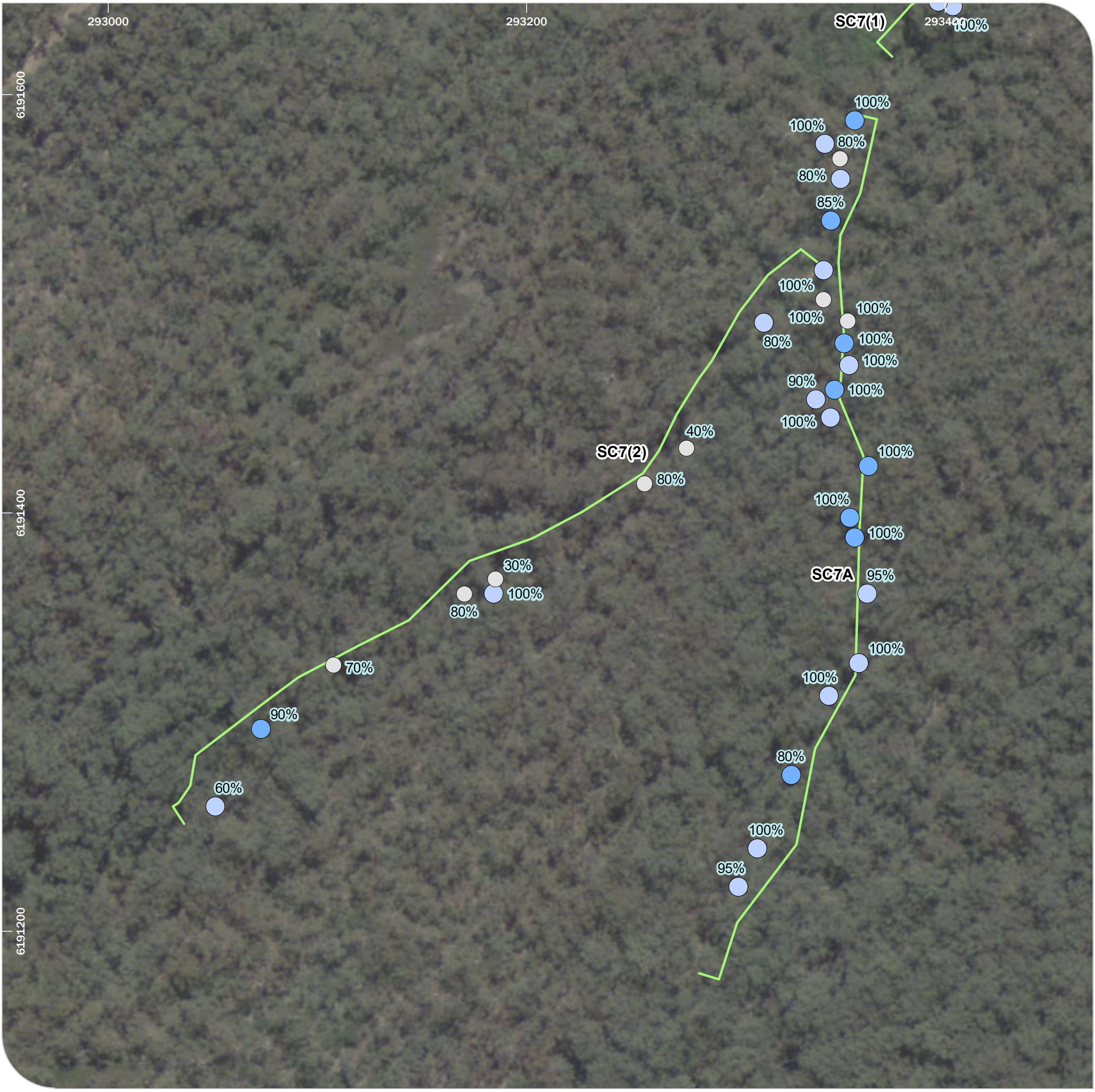


Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

- Very Shallow <25cm
- Shallow 50-25cm
- Moderate 100-50cm

Threatened frog monitoring impact transect

- Control (>400m)

Environment and Heritage

0 60
m
GDA 1994 MGA Zone 56

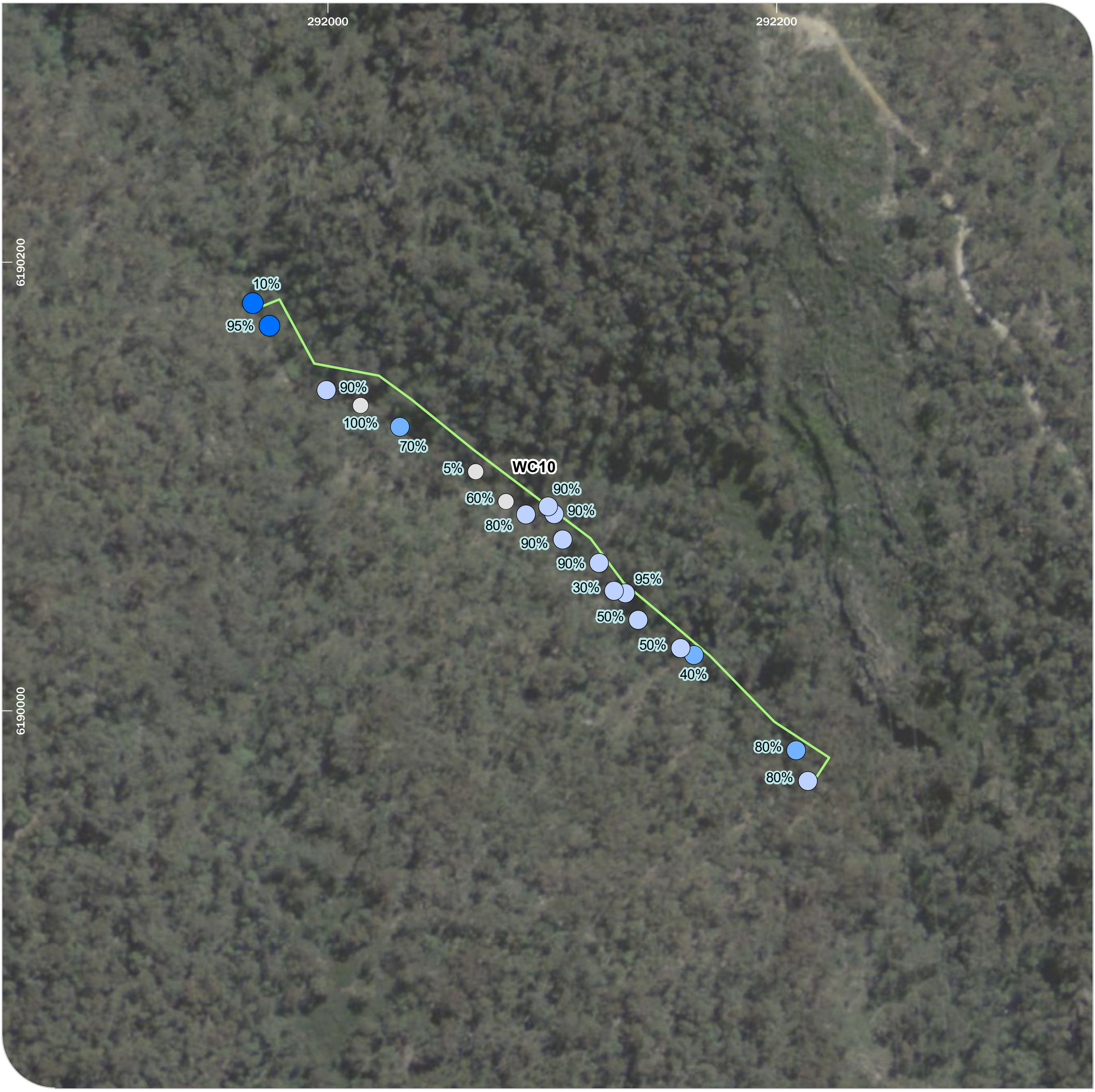
Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 5m

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM



Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

- Very Shallow <25cm
- Shallow 50-25cm
- Moderate 100-50cm
- Deep >100cm

Threatened frog monitoring impact transect

- Control (>400m)

niche Environment and Heritage

0 50
m
GDA 1994 MGA Zone 56

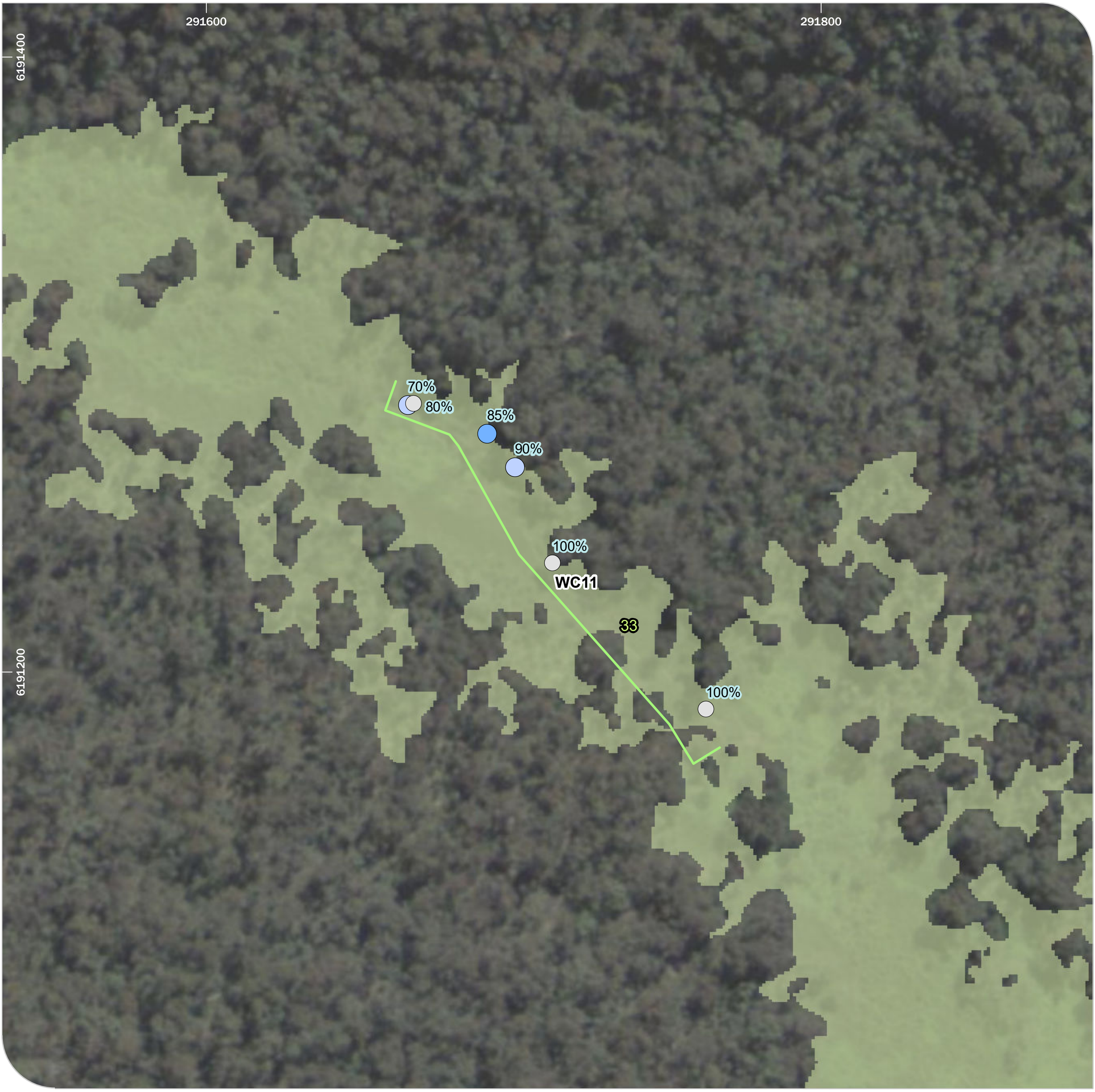
Location of threatened frog monitoring transects used in the 2021 program

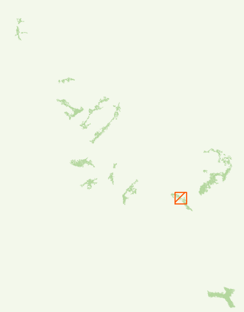
Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 5n

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM





Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

- Very Shallow <25cm
- Shallow 50-25cm
- Moderate 100-50cm

Threatened frog monitoring impact transect

- Control (>400m)

Veg sub-community mapping from 2021 LiDAR analysis

- Upland swamp control site

niche Environment and Heritage

0 40 m

GDA 1994 MGA Zone 56

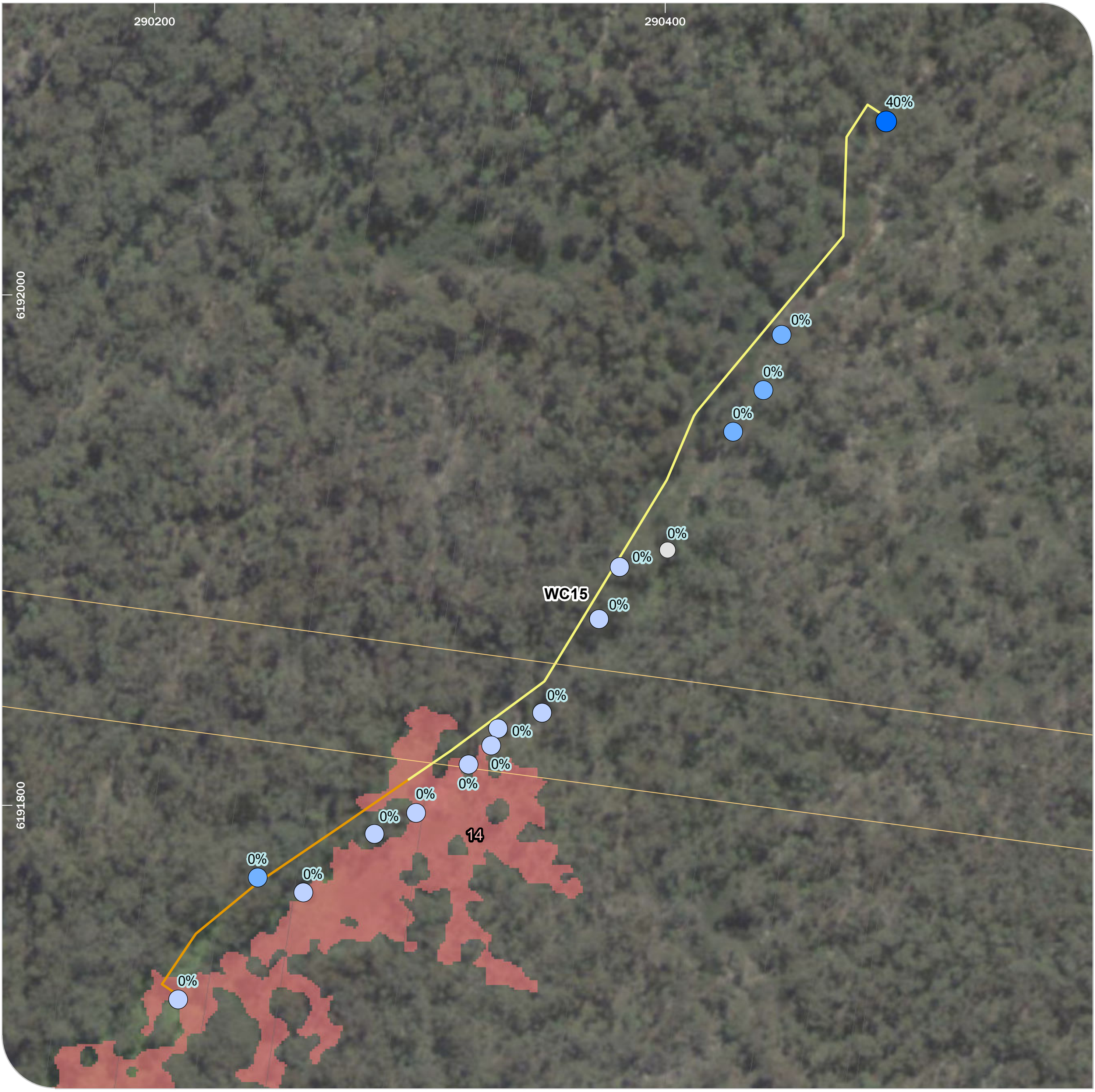
Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

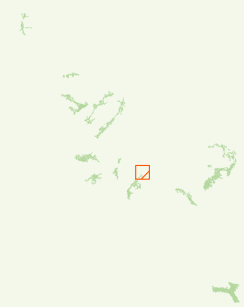
Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Figure 5o

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM





Longwall Progression

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

Very Shallow <25cm

Shallow 50-25cm

Moderate 100-50cm

Deep >100cm

Threatened frog monitoring impact transect

RMZ (<400m)

Above longwall

Veg sub-community mapping from 2021 LiDAR analysis

Upland swamp impact site

Area 3A and 3B Longwalls

Mined

niche Environment and Heritage

0 50
m
GDA 1994 MGA Zone 56

Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 5p

Longwall Progession

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

Very Shallow <25cm

Shallow 50-25cm

Moderate 100-50cm

Deep >100cm

Iron flocculent

Threatened frog monitoring impact transect

Above longwall

Area 3A and 3B Longwalls

Mined

Not yet mined

Drawn by: LL File: T:\spatial\projects\a6600\a6639_DendrobiumMonitoring_NSW\Maps\report\6639_Figure_5_Frog_Transects.mxd Last updated: 06-Apr-22 12:40:39 PM

niche Environment and Heritage

0 20 m

GDA 1994 MGA Zone 56

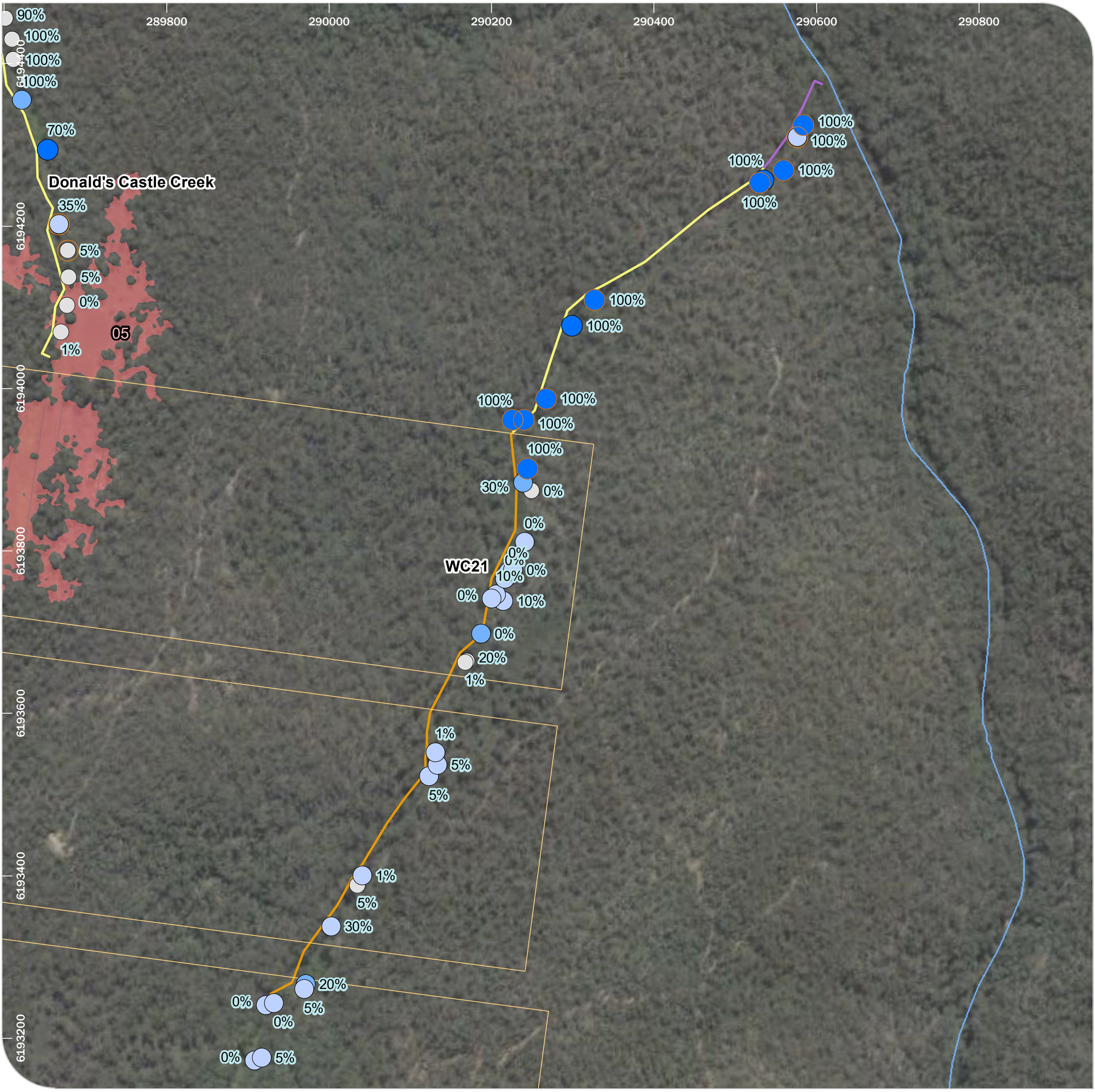
Location of threatened frog monitoring transects used in the 2021 program

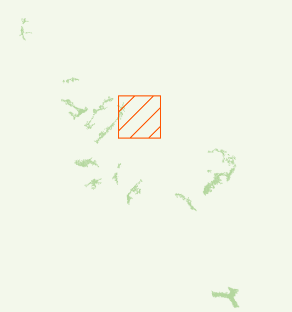
Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 5q

v2.0





Longwall Progession

Perennial Stream

Threatened frog monitoring breeding pool

Size of pools (percentage of capacity labelled)

Very Shallow <25cm

Shallow 50-25cm

Moderate 100-50cm

Deep >100cm

Iron flocculent

Threatened frog monitoring impact transect

RMZ (<400m)

Above longwall

>400m

Veg sub-community mapping from 2021 LiDAR analysis

Upland swamp impact site

Area 3A and 3B Longwalls

Mined

niche Environment and Heritage

0 150 m

GDA 1994 MGA Zone 56

Location of threatened frog monitoring transects used in the 2021 program

Dendrobium Areas 3A and 3B - Terrestrial Ecology Monitoring Program Annual Report 2021

Niche PM: Sian Griffiths
Niche Proj. #: 6639
Client: South32

Figure 5r

Annex 1 Upland swamp and frog monitoring site attributes

The following tables present the key attributes of swamp (Table 50) and frog transect (Table 51) monitoring sites that form part of the current program, which informed the review of pairing control sites discussed in Section 2.4.

Table 50: Upland swamp monitoring site attributes overview

Swamp	Distance from longwalls (2021)	Swamp extent (ha) (2021)	Subcommunities present (2021)	Dominant subcommunity	Area	Setting	Transect monitoring	LiDAR monitoring
Impact swamps								
01a	Directly mined beneath	8.95	BT, TT, SH	BT	3b	Valley infill	Y	Y
01b	Directly mined beneath	11.03	BT, SH	SH	3b	Headwater	Y	Y
5	Directly mined beneath	10.83	BT, TT, SH	BT	3b	Valley infill	Y	Y
11	Directly mined beneath	9.67	BT, TT, SH	BT	3b	Headwater	Y	Y
13	Directly mined beneath	3.38	BT, TT, SH	BT	3b	Headwater	Y	Y
14	Directly mined beneath	8.06	BT, TT, SH	BT	3b	Valley infill	Y	Y
15a(2)	Directly mined beneath	4.04	BT, SH	BT	3a	Valley infill*	Y	Y
15b	Directly mined beneath	7.45	BT, TT, SH	BT	3a	Valley infill*	Y	Y
23	Directly mined beneath	5.1	BT, TT	BT	3b	Valley infill*	Y	Y
Control swamps								
15a(1)	> 400 m	16.96	BT, TT, SH	BT	3a	Valley infill*	Y	Y
22	> 400 m	19.7	BT, TT, SH	SH	Outside	Valley infill*	Y	Y
33	> 400 m	6.28	BT, TT	BT	Outside	Valley infill*	Y	Y
85	> 400 m	2.73	BT, SH	SH	Outside	Valley infill*	N	Y
86	> 400 m	4.19	SH, TT	SH	Outside	Headwater*	Y	Y
87	> 400 m	15.7*	BT, TT, SH*	SH*	Outside	Valley infill*	Y	N
88	> 400 m	4.6*	BT, TT, SH*	SH*	Outside	Headwater*	Y	N

**Aerial imagery assessment and/or photo interpretation*
Note: BT = Banksia Thicket, TT = Tea-tree Thicket, SH = Sedgeland-heath Complex

Table 51: Frog monitoring transect attributes overview

Transect	Area	Tributary/sub-catchment	Monitoring commenced	Transect length (m)	Stream order	No. pools (total mapped pools)	Large and moderate pools (2021)	Shallow and very shallow pools (2021)	Pool per metre of transect
Control transects (average)						**16**	**4**	**12**	**4**
DC8	3b	Donalds Castle Creek	2013	432	3	3	3	0	0.69
ND1	3b	Native Dog Creek	2011	742	2	26	10	16	3.5
SC7(1)	3a	Sandy Creek	2006	474	2	20	3	19	4.22
SC7(2)	3a	Sandy Creek	2008	436	1	9	1	8	2.07
SC7A	3a	Sandy Creek	2006	453	2	22	8	13	4.85
SC8	3a	Sandy Creek	2007	315	1	21	4	18	6.66
WC10	3a	Wattle Creek	2010	346	1	19	5	14	5.48
WC11	3a	Wattle Creek	2010	176	1	6	1	4	3.4
Impact transects (average)						**16**	**5**	**13**	**3**
DC(1)	3b	Donalds Castle Creek	2013	642	1	17	5	12	2.65
DC13	3b	Donalds Castle Creek	2010	641	2	16	1	16	2.5
6CDL	3a	Sandy Creek	2009	89	1	8	2	7	9
SC10(1)	3a	Sandy Creek	2006	539	2	15	9	11	2.78
SC10(2)	3a	Sandy Creek	2006	950	2	36	6	30	3.79
SC10C	3a	Sandy Creek	2006	481	1	12	3	9	2.5
LA2	3b	Tributary of Lake Avon	2017	593	1	23	7	17	3.88
LA4	3b	Tributary of Lake Avon	2007	209	2	3	0	4	1.44
WC15	3b	Wattle Creek	2011	478	1	5	5	11	1.05
WC17	3a	Wattle Creek	2011	177	2	7	2	5	3.95
WC21	3b	Wattle Creek	2013	1399	2	33	11	22	2.36

Transect	Area	Tributary/sub-catchment	Monitoring commenced	Transect length (m)	Stream order	No. pools (total mapped pools)	Large and moderate pools (2021)	Shallow and very shallow pools (2021)	Pool per metre of transect
Pre-mining sites (average)						**13**	**8**	**5**	**9**
ND2	3b	Native Dog Creek	2010	123	1	7	2	5	5.68
NDC	3b	Native Dog Creek	2007	555	3	18	13	5	3.24

Note: mapped pools refer to previously marked breeding pools as part of the program.

Annex 2 LiDAR analysis – Upland Swamps

Table 52: Results of LiDAR analysis completed in 2021 for all years of available data

Swamp	Subcommunity	2014	2016	2017	2018	2019	2020	2021
Control swamps								
22	Banksia Thicket							3.50
	Sedgeland-heath Complex	18.27						15.15
	Tea-tree Thicket							1.05
	Total	18.27						19.70
33	Banksia Thicket	4.65	4.72	4.98	4.75	4.55	4.06	4.20
	Tea-tree Thicket	2.26	2.34	2.16	2.18	2.02	2.15	2.07
	Total	6.90	7.06	7.14	6.93	6.58	6.20	6.27
85	Banksia Thicket	0.78	0.81	0.86	0.87	0.81	0.79	1.05
	Sedgeland-heath Complex	1.82	1.96	2.16	2.01	2.04	1.89	1.68
	Tea-tree Thicket	0.00						
	Total	2.60	2.77	3.02	2.88	2.85	2.69	2.73
86	Banksia Thicket	0.00						
	Sedgeland-heath Complex	4.06						4.11
	Tea-tree Thicket	0.10						0.08
	Total	4.15						4.19
15A(1)	Banksia Thicket	10.52	10.23	10.22	10.58	10.20	9.52	9.55
	Sedgeland-heath Complex	6.24	6.26	5.63	5.09	4.78	4.58	4.59
	Tea-tree Thicket	2.41	2.28	2.80	2.95	2.83	2.81	2.82
	Total	19.18	18.77	18.65	18.62	17.81	16.91	16.96
Area 3A impact swamps								
15A(2)	Banksia Thicket	4.88	4.76	4.55	4.37	4.33	4.10	3.99
	Sedgeland-heath Complex	0.15	0.14	0.14	0.10	0.10	0.04	0.04
	Tea-tree Thicket	0.09	0.07	0.05	0.03			
	Total	5.12	4.97	4.74	4.50	4.42	4.14	4.03
15B	Banksia Thicket	7.83	7.56	7.58	7.30	6.41	6.24	6.09
	Sedgeland-heath Complex	0.62	0.58	0.60	0.65	0.60	0.47	0.47

Swamp	Subcommunity	2014	2016	2017	2018	2019	2020	2021
	Tea-tree Thicket	1.50	1.44	1.31	1.00	0.96	0.89	0.89
	Total	9.94	9.58	9.49	8.95	7.98	7.60	7.45
Area 3B impact swamps								
11	Banksia Thicket	7.86	7.36	8.03	8.60	7.64	6.97	6.94
	Sedgeland-heath Complex	1.91	1.89	1.88	1.90	1.74	1.70	1.79
	Tea-tree Thicket	1.46	1.49	1.38	1.13	1.13	0.93	0.94
	Total	11.23	10.74	11.29	11.63	10.52	9.61	9.67
13	Banksia Thicket	2.96	2.75	2.97	2.90	2.75	2.64	2.60
	Sedgeland-heath Complex	0.51	0.84	0.78	0.79	0.78	0.63	0.63
	Tea-tree Thicket	0.44	0.21	0.17	0.18	0.17	0.16	0.16
	Total	3.91	3.80	3.92	3.87	3.71	3.43	3.39
14	Banksia Thicket	4.72	4.76	5.32	5.26	4.94	4.20	4.74
	Sedgeland-heath Complex	1.41	1.63	1.09	1.12	1.13	1.04	1.19
	Tea-tree Thicket	2.82	2.58	2.65	2.66	2.24	2.12	2.13
	Total	8.94	8.97	9.06	9.04	8.31	7.36	8.06
01A	Banksia Thicket	7.33	7.14	7.94	8.32	7.59	6.36	6.44
	Sedgeland-heath Complex	2.20	2.03	2.28	2.14	1.53	1.60	2.18
	Tea-tree Thicket	1.07	1.00	0.76	0.76	0.71	0.50	0.33
	Total	10.61	10.18	10.98	11.22	9.83	8.46	8.95
01B	Banksia Thicket	0.02	0.02	0.02	0.03	0.03	0.06	0.05
	Sedgeland-heath Complex	13.07	12.20	13.10	14.29	12.14	11.03	10.98
	Tea-tree Thicket	0.12	0.12	0.10	0.12	0.12		
	Total	13.22	12.33	13.22	14.44	12.29	11.09	11.03
5	Banksia Thicket	6.59	6.50	8.08	9.48	8.32	7.71	7.58
	Sedgeland-heath Complex	5.07	4.83	4.52	3.62	3.06	2.50	2.68
	Tea-tree Thicket	1.47	1.63	1.07	1.09	0.73	0.61	0.57
	Total	13.13	12.95	13.67	14.19	12.11	10.81	10.83
23	Banksia Thicket	5.34	5.14	5.57	5.29	5.04	4.69	4.68
	Tea-tree Thicket	0.54	0.60	0.54	0.56	0.59	0.42	0.42
	Total	5.87	5.74	6.11	5.85	5.62	5.11	5.10

Annex 3 Statistical analysis – Upland Swamps

Task 1A - Analysis of total flora species richness at swamps within the Dendrobium region

Data collected up to and including 2021

Final

22 March 2022

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Project History and Version Control

Date	Amendments	Person
9 March 2022	Received revised data from Sian Griffiths (Niche)	JP
10 March 2022	Draft report submitted to Sian Griffiths (Niche)	JP
22 March 2022	Final report submitted to Sian Griffiths (Niche)	JP

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1 Data Summary

On 9 March 2022, The Analytical Edge (hereafter, TAE) received a revised data set from Sian Griffiths (Niche) via e-mail. It contained data collected during flora swamp monitoring within the Dendrobium region up to and including 2021 (*'dendrobium_flora_annual_monitoring-2022-02-24_DW Edit.xlsx'*, 18.7 MB). Many species names and complexes had been revised since the previous analysis.

All data relating to swamp S1 were omitted from the analysis.

Errors:

(1) A total of 78 records were missing species-level information (29 and 49 records in 2020 and 2021, respectively). Also, 12 records were referred to as either 'QUADRAT IS DEAD' or 'QUADRAT DEAD'. These were excluded from the analysis. There errors were referred to Sian for correction in the parent database.

(2) For impact sites S11 and S15A(2) when PrePost = Pre (i.e., prior to impact), the treatment was listed as 'control'. These records were changed manually to 'impact' sites, and referred to Sian for correction in the parent database.

(3) Swamp11-V1 in spring 2021 was incorrectly labelled Swamp1-V1 in the data set. These records were changed manually and referred to Sian for correction in the parent database.

(4) One species complex (*Blandfordia Burchardia Caladenia Haemodorum Microtis Thelymitra* species complex) occasionally had an additional space after the record (i.e., '*Blandfordia Burchardia Caladenia Haemodorum Microtis Thelymitra* species complex '). These records were changed manually and referred to Sian for correction in the parent database.

Disclaimer: Excluding the corrections mentioned above, this data file is assumed to be error-free. Any further errors detected by Niche may invalidate the results and conclusions made in this report and will require the analysis to be re-run under the proviso of new contract agreements.

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2 Methods

Following reporting in 2021, a complete analysis was undertaken of all historical data. This is similar to the second round of reports submitted to Niche in 2021 and previously for Biosis, e.g., the mean total species richness (TSR) as calculated from data pooled from 2 consecutive years at impact swamps was contrasted against the mean TSR of all control swamp data from prior to the impact. Similarly, we compared TSR for impact and control swamps calculated from pooled data for 3-year, 4-year, and where applicable, 5-year periods. All control swamps were used for each impact swamp (Table 1).

Where applicable, a before–after control–impact (BACI) style analysis was completed, whereby differences in group means before impact between the control and impact swamps, and after impact, were tested to explore whether they were different from 0. If there was only a single year of before-impact monitoring (i.e., swamps S1A and S23), a control–impact analysis was completed, whereby differences in group means after impact at the control and impact swamps was tested to explore whether they were different from 0.

Conducting multiple testing such as this can lead to erroneous interpretation of results; through statistical chance alone, 5% of tests may be concluded significant, and this chance is elevated when multiple tests are conducted. Methods exist for multiple correction (e.g., Holm 1979) but this will decrease the power to detect a difference, if one exists. TAE has previously proposed alternative methods to analyse these data (e.g., using a broken-stick approach), and this will be explored in Task 2 (to be undertaken).

All analyses were conducted in R (v. 4.1.2, R Core Team 2022).

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Table 1. The region of each impact swamp and their paired control swamps.

Region	Impact Swamps	Paired control swamps
3A	S15A(2)	S86, S87, S88, S15A(1), S22, S33
3A	S15B	S86, S87, S88, S15A(1), S22, S33
3B	S11	S86, S87, S88, S15A(1), S22, S33
3B	S13	S86, S87, S88, S15A(1), S22, S33
3B	S14	S86, S87, S88, S15A(1), S22, S33
3B	S1A	S86, S87, S88, S15A(1), S22, S33
3B	S1B	S86, S87, S88, S15A(1), S22, S33
3B	S5	S86, S87, S88, S15A(1), S22, S33
3B	S23	S86, S87, S88, S15A(1), S22, S33

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3 Results - Swamp S15A(2)

Monitoring at swamp S15A(2) began in 2009, and this swamp was impacted in 2013. The boxplot of TSR data (Figure 1) shows that throughout the monitoring period, TSR at control sites was more variable (with a wider minimum and maximum TSR observation) and typically lower than TSR at the impact swamp. Since 2017, TSR at swamp S15A(2) appears to have declined to lower levels than before impact.

For each year of monitoring prior to and post-impact, we calculated the difference in mean TSR between the control and impact swamps. Within-year comparisons (Figure 2) show that TSR remains higher at swamp S15A(2) compared with the control swamps (i.e., the difference of the means is always negative), but this is trending towards 0, and indeed reaches 0 in the 2021 monitoring (i.e., TSR at swamp S15A(2) is declining to become more similar to the control swamps over time).

When data from each 2-consecutive-year period were pooled, our analysis showed a statistically significant difference between TSR at swamp S15A(2) and the control swamps in 2016, and again in 2018 and 2019 (Table 2). A statistically significant difference in pooled data from 3-year periods was found from 2016 (Table 3) and pooled data from 4-year periods from 2015 (Table 4).

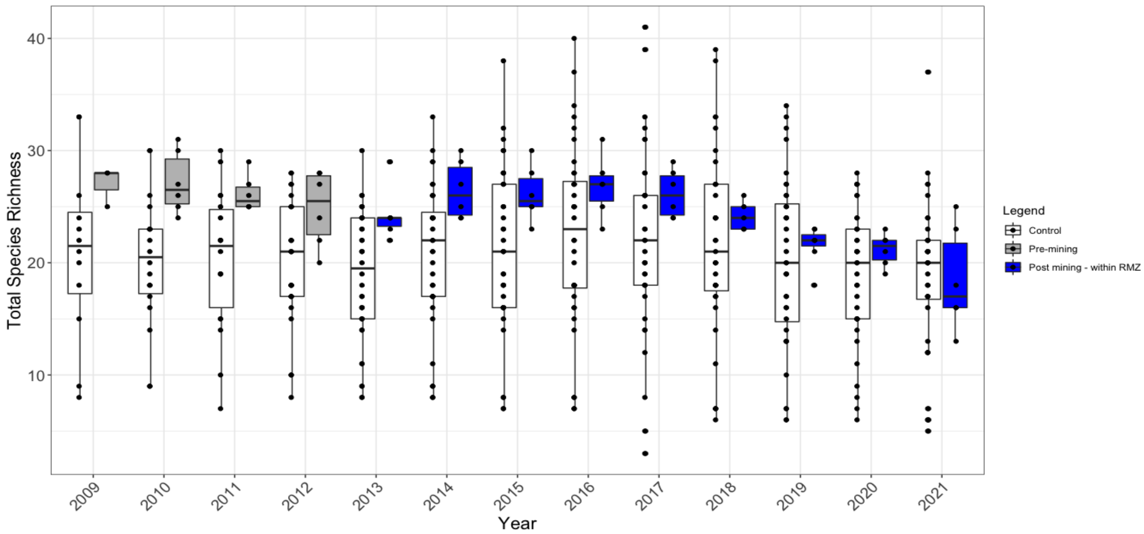

Figure 1. Boxplot of the total species richness for each transect at impact swamp S15A(2), contrasted against all control swamps. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

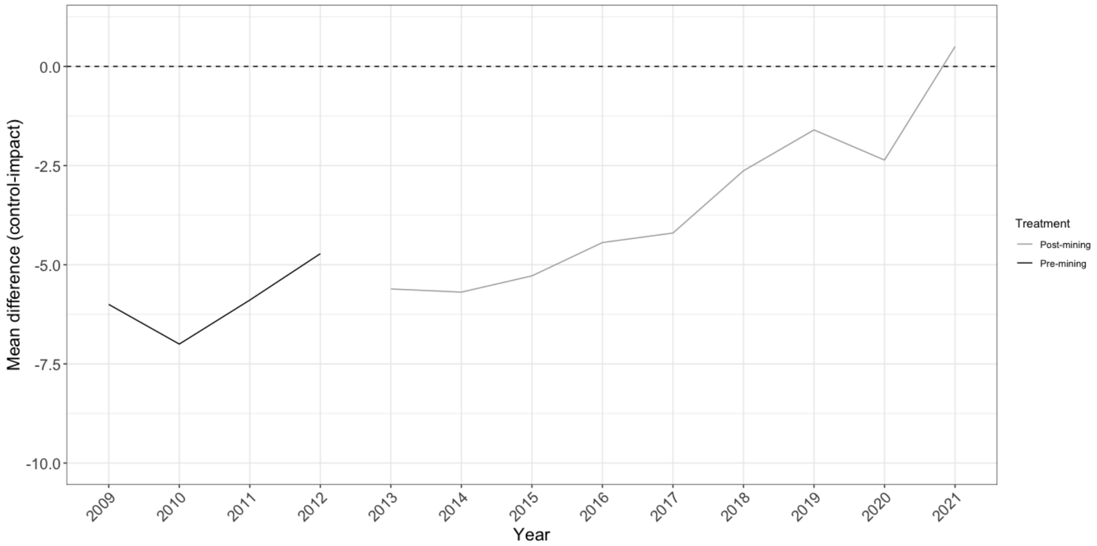

Figure 2. Difference between means for the control swamps and the impact swamp, shaded as black (pre-impact) and light grey (post-impact). Horizontal line at 0 is highlighted.

Table 2. Comparison of mean TSR between swamp S15A(2) and control swamps as calculated from data pooled for 2-year periods.

Comparison	Test statistic	D.f.	P-value
2013–2014	0.54	3.04	0.627
2014–2015	0.82	3.84	0.460
2015–2016	1.66	3.31	0.187
2016–2017	3.28	3.37	0.039
2017–2018	2.72	1.76	0.129
2018–2019	5.45	2.71	0.016
2019–2020	6.52	3.58	0.004
2020–2021	3.31	1.22	0.150

Table 3. Comparison of mean TSR between swamp S15A(2) and control swamps as calculated from data pooled for 3-year periods.

Comparison	Test statistic	D.f.	P-value
2013–2015	0.78	3.42	0.487
2014–2016	1.29	4.99	0.254
2015–2017	2.21	4.90	0.079
2016–2018	2.92	4.31	0.040
2017–2019	3.48	3.48	0.032
2018–2020	6.63	4.81	0.001
2019–2021	4.87	3.18	0.014

Table 4. Comparison of mean TSR between swamp S15A(2) and control swamps as calculated from data pooled for 4-year periods.

Comparison	Test statistic	D.f.	P-value
2013–2016	1.18	4.97	0.290
2014–2017	1.71	5.56	0.141
2015–2018	2.44	5.83	0.052
2016–2019	3.28	5.35	0.020
2017–2020	4.46	5.86	0.005
2018–2021	5.16	5.19	0.003

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4 Results - Swamp S15B

Monitoring at swamp S15B began in 2003, and this swamp was impacted in 2010. The boxplot of TSR data (Figure 3) shows that throughout the monitoring period, the TSR at control sites was more variable (with a wider minimum and maximum TSR observation) than at control swamps. Since impact, TSR at this swamp appears to have declined to lower levels than before impact.

For each year of monitoring prior to and post-impact, we calculated the difference in mean TSR between the control and impact swamps. Within-year comparisons (Figure 4) show that TSR prior to impact was initially higher at swamp S15B compared with the control swamps (i.e., the difference of the means was negative), and since impact, this became positive (i.e., TSR at swamp S15B became lower than the control swamps over time).

When data from each 2-consecutive-year period were pooled, our analysis showed a statistically significant difference between TSR at swamp S15B and the control sites in 2012, 2014, and again from 2016 (Table 5). Statistically significant differences between means were found in pooled data from 3-year periods in 2011 and again from 2014 (Table 6), and 4-year periods in 2010, and again from 2012 (Table 7).

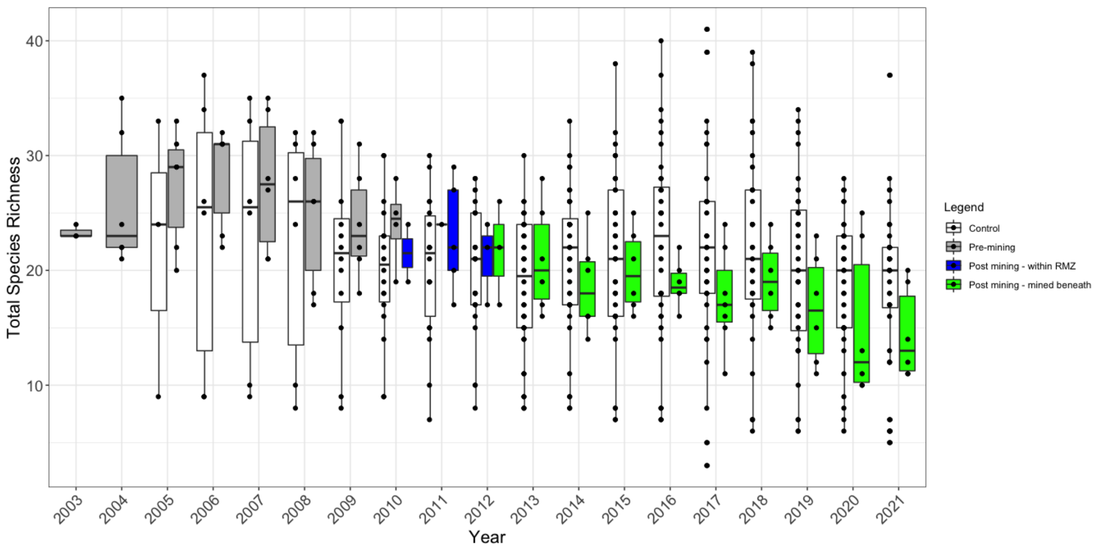

Figure 3. Boxplot of the total species richness for each transect at impact swamp S15B, contrasted against all control swamps. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

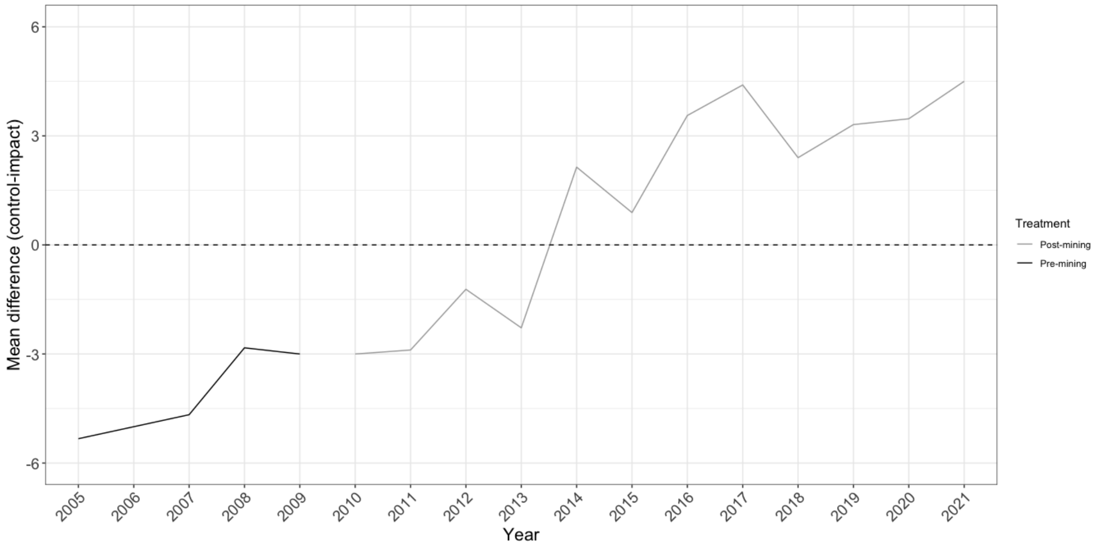

Figure 4. Difference between means for the control swamps and the impact swamp, shaded as black (pre-impact) and light grey (post-impact). Horizontal line at 0 is highlighted.

Table 3. Comparison of mean TSR between swamp S15B and control swamps as calculated from data pooled for 2-year periods.

Comparison	Test statistic	D.f.	P-value
2010–2011	2.33	4.09	0.079
2011–2012	2.14	1.86	0.175
2012–2013	3.25	3.14	0.045
2013–2014	1.80	1.11	0.302
2014–2015	6.98	2.57	0.010
2015–2016	4.46	1.32	0.094
2016–2017	12.16	4.06	0.000
2017–2018	6.71	1.59	0.037
2018–2019	10.14	3.74	0.001
2019–2020	14.31	4.18	0.000
2020–2021	11.12	3.25	0.001

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Table 4. Comparison of mean TSR between swamp S15B and control swamps as calculated from data pooled for 3-year periods.

Comparison	Test statistic	D.f.	P-value
2010–2012	2.31	4.96	0.069
2011–2013	2.85	5.56	0.032
2012–2014	2.59	2.63	0.092
2013–2015	3.12	2.65	0.062
2014–2016	6.83	3.85	0.003
2015–2017	6.03	3.00	0.009
2016–2018	9.77	4.93	0.000
2017–2019	9.68	4.95	0.000
2018–2020	11.67	5.95	0.000
2019–2021	12.36	6.00	0.000

Table 5. Comparison of mean TSR between swamp S15B and control swamps as calculated from data pooled for 4-year periods.

Comparison	Test statistic	D.f.	P-value
2010–2013	2.75	6.93	0.029
2011–2014	2.51	4.29	0.062
2012–2015	3.59	4.60	0.018
2013–2016	3.88	4.05	0.017
2014–2017	7.40	5.49	0.000
2015–2018	7.56	5.56	0.000
2016–2019	11.41	6.94	0.000
2017–2020	11.40	6.94	0.000
2018–2021	11.21	6.98	0.000

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5 Results - Swamp S11

Monitoring at swamp S11 began in 2003, and this swamp was impacted in 2016. The boxplot of TSR data (Figure 5) shows that throughout the monitoring period, the TSR at control sites was more variable (with a wider minimum and maximum TSR observation) than TSR at this impact swamp. Immediately after impact (2016), TSR rose to the highest levels ever recorded at this swamp, and has since declined to levels recorded immediately before impact (i.e., 2015).

For each year of monitoring prior to and post-impact, we calculated the difference in mean TSR between the control and impact swamps. Within-year comparisons (Figure 6) show that TSR prior to, and post impact, was similar between swamp S11 and the control swamps (i.e., the mean difference hovers around 0).

Prior to 2021, no significant difference between TSR at this swamp and the control sites was found for data pooled for 2-year, 3-year, 4-year or 5-year periods (Tables 8, 9, 10 and 11). However, in 2021 TSR was significantly different between swamp S11 and the control sites for data pooled for 2-year, 4-year and 5-year periods (see Tables 8, 10 and 11, respectively).

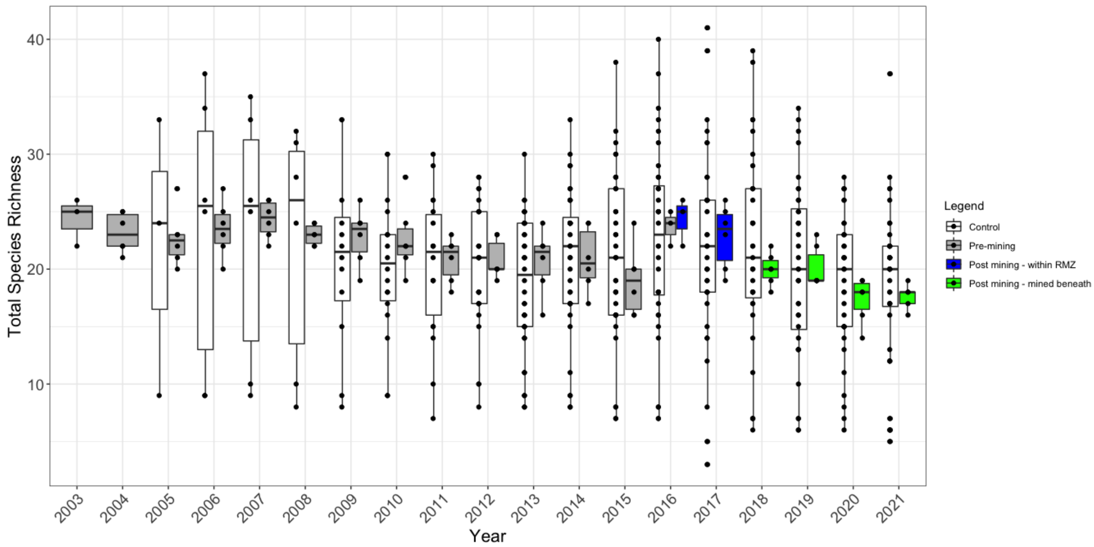

Figure 5. Boxplot of the total species richness for each transect at impact swamp S11, contrasted against all control swamps. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

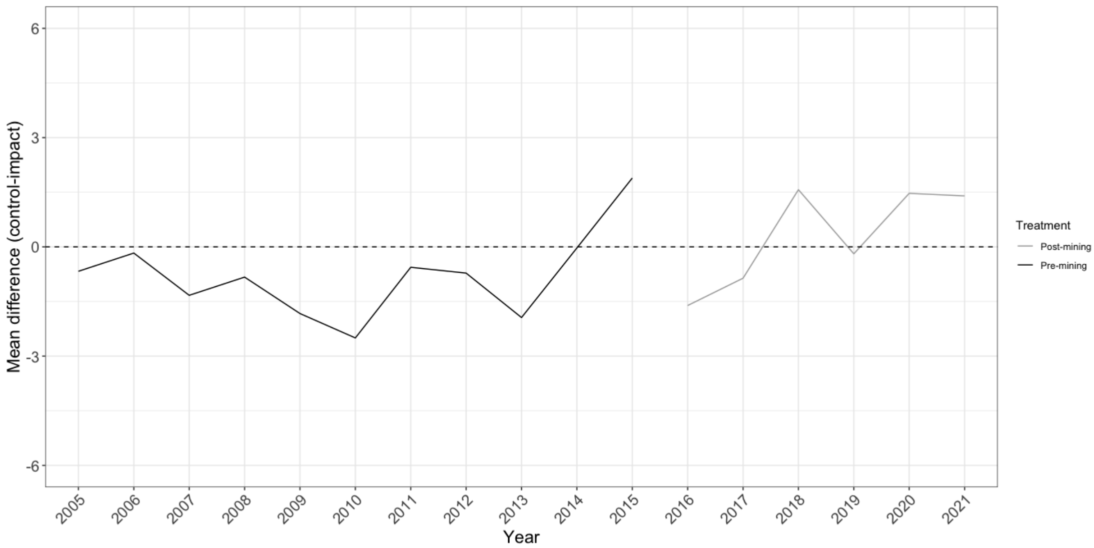

Figure 6. Difference between means for the control swamps and the impact swamp, shaded as black (pre-impact) and light grey (post-impact). Horizontal line at 0 is highlighted.

Table 8. Comparison of mean TSR between swamp S11 and control swamps as calculated from data pooled for 2-year periods.

Comparison	Test statistic	D.f.	P-value
2016–2017	-0.86	3.32	0.446
2017–2018	0.90	1.18	0.513
2018–2019	1.56	1.35	0.313
2019–2020	1.58	1.39	0.303
2020–2021	6.24	10.19	0.000

Table 6. Comparison of mean TSR between swamp S11 and control swamps as calculated from data pooled for 3-year periods.

Comparison	Test statistic	D.f.	P-value
2016–2018	0.48	2.57	0.670
2017–2019	1.19	3.04	0.317
2018–2020	2.59	3.73	0.065
2019–2021	2.60	3.94	0.061

Table 7. Comparison of mean TSR between swamp S11 and control swamps as calculated from data pooled for 4-year periods.

Comparison	Test statistic	D.f.	P-value
2016–2019	0.68	4.75	0.531
2017–2020	1.83	5.22	0.124
2018–2021	3.37	7.66	0.010

Table 8. Comparison of mean TSR between swamp S11 and control swamps as calculated from data pooled for 5-year periods.

Comparison	Test statistic	D.f.	P-value
2016–2020	1.20	6.66	0.272
2017–2021	2.38	8.16	0.044

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6 Results - Swamp S13

Monitoring at swamp S13 began in 2013, and this swamp was impacted in 2017. The boxplot of TSR data (Figure 7) shows that throughout the monitoring period, the TSR at control sites was more variable (with a wider minimum and maximum TSR observation) than TSR at the impact swamp. Prior to impact, TSR at swamp S13 was typically higher than the control swamps, and post-impact there has been a decline in TSR at swamp S13 that was greater than the decline in TSR at the control swamps within the same period.

For each year of monitoring prior to and post-impact, we calculated the difference in mean TSR between the control and impact swamps. Within-year comparisons (Figure 8) show that prior to impact, TSR was higher at the impact swamp, and post impact, it decreased to become more similar to the TSR observed at the control swamps (i.e., the mean difference hovers around 0).

A comparison of TSR between the impact and control swamp as calculated from data pooled for 2-year periods was statistically significant in 2018 (Table 12). For data pooled across 3-year periods, TSR was significantly different between swamp S13 and control swamps in 2017 and 2018 (Table 13). For data pooled across 4-year periods, TSR was significantly different in 2017 and 2018 (Table 14). A five-year pooled data comparison was also found to be significant (2017-2021, Table 15).

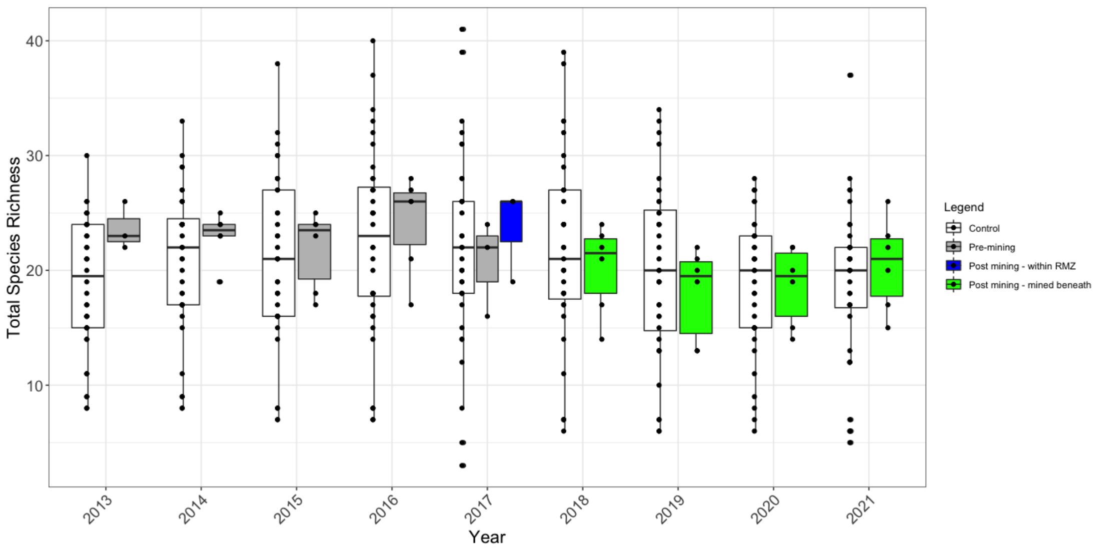

Figure 7. Boxplot of the total species richness for each transect at impact swamp S13, contrasted against all control swamps. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

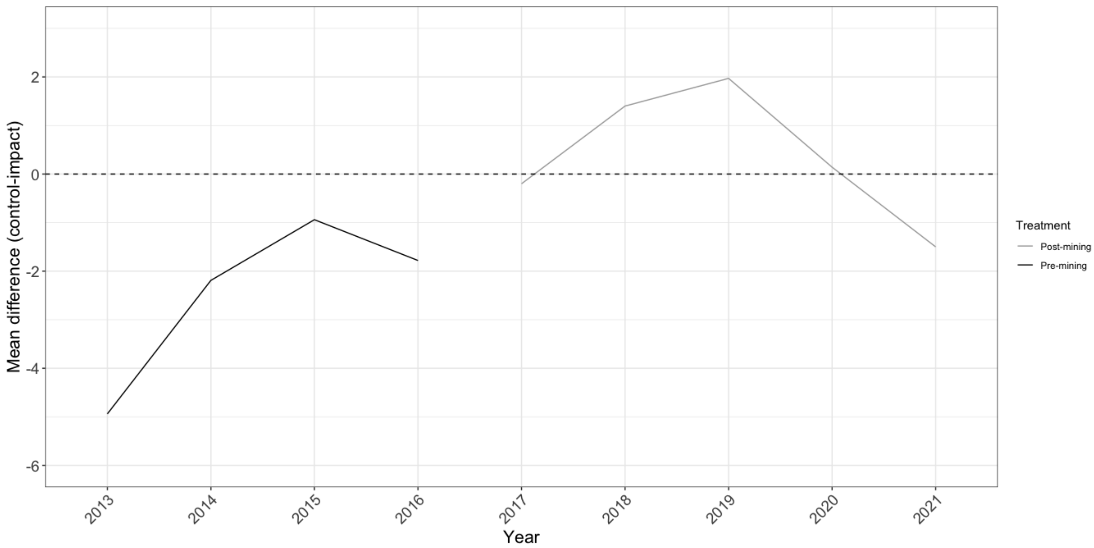

Figure 8. Difference between means for the control swamps and the impact swamp, shaded as black (pre-impact) and light grey (post-impact). Horizontal line at 0 is highlighted.

Table 9. Comparison of mean TSR between swamp S13 and control swamps as calculated from data pooled for 2-year periods.

Comparison	Test statistic	D.f.	P-value
2017–2018	2.60	3.24	0.075
2018–2019	4.55	3.56	0.014
2019–2020	2.79	2.83	0.073
2020–2021	1.49	3.16	0.227

Table 10. Comparison of mean TSR between swamp S13 and control swamps as calculated from data pooled for 3-year periods.

Comparison	Test statistic	D.f.	P-value
2017–2019	3.25	4.97	0.023
2018–2020	3.56	4.72	0.018
2019–2021	2.01	4.45	0.107

Table 11. Comparison of mean TSR between swamp S13 and control swamps as calculated from data pooled for 4-year periods.

Comparison	Test statistic	D.f.	P-value
2017–2020	3.27	4.88	0.023
2018–2021	2.56	5.92	0.043

Table 12. Comparison of mean TSR between swamp S13 and control swamps as calculated from data pooled for 5-year periods.

Comparison	Test statistic	D.f.	P-value
2017–2021	2.66	5.68	0.039

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7 Results - Swamp S14

Monitoring at swamp S14 began in 2017, and this swamp was impacted in the same year. The boxplot of TSR data (Figure 9) shows that throughout the short monitoring period, the TSR at control swamps was more variable (with a wider minimum and maximum TSR observation) than at the impact swamp. This impact swamp has lower TSR than the control swamps.

Since monitoring of this swamp began in the same year that the site was impacted, we only had 2 years of pre-mining TSR data (2017 and 2018) to compare with control site data. Data for transects that were undermined were also only available for two years: 2019 and 2020. Within-year comparisons (Figure 10) show that TSR at the impact swamp is consistently lower than the control swamps and the difference has been relatively consistent over the (short) monitoring period.

The TSR as calculated from data pooled for 2-year, 3-year and 4-year periods was not found to differ significantly between swamp S14 and control swamps (Tables 16, 17 and 18, respectively). As more data are collected, we recommended that effects are tested only post-impact, as the before-impact monitoring period for this swamp is short.

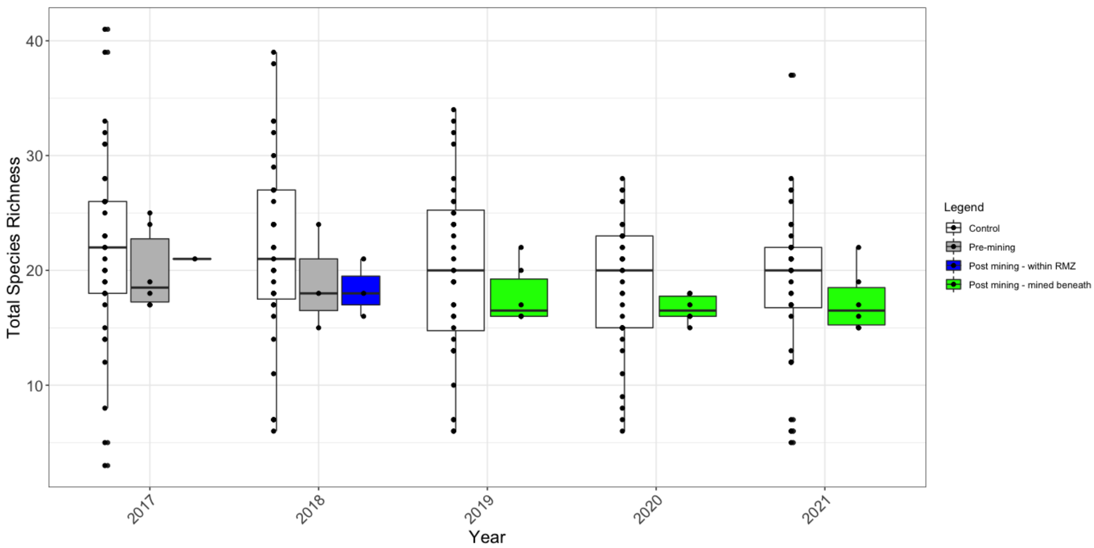

Figure 9. Boxplot of the total species richness for each transect at impact swamp S14, contrasted against all control swamps. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

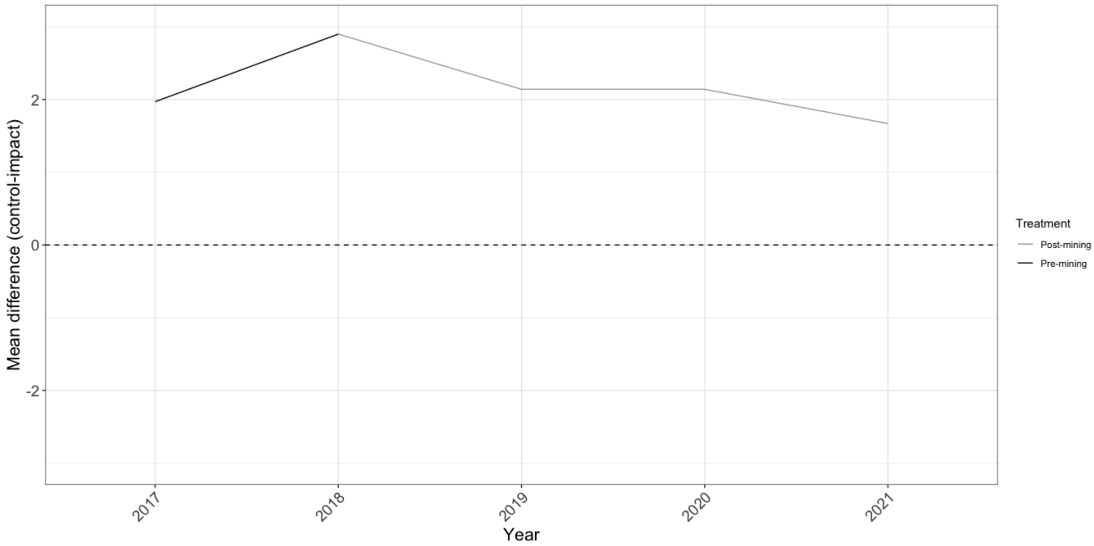

Figure 10. Difference between means for the control swamps and the impact swamp, shaded as black (pre-impact) and light grey (post-impact). Horizontal line at 0 is highlighted.

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Table 13. Comparison of mean TSR between swamp S14 and control swamps as calculated from data pooled for 2-year periods.

Comparison	Test statistic	D.f.	P-value
2018–2019	-0.14	2.27	0.898
2019–2020	-0.63	1.00	0.640
2020–2021	-1.02	1.48	0.446

Table 14. Comparison of mean TSR between swamp S14 and control swamps as calculated from data pooled for 3-year periods.

Comparison	Test statistic	D.f.	P-value
2018–2020	-0.49	3.85	0.650
2019–2021	-0.92	1.23	0.502

Table 15. Comparison of mean TSR between swamp S14 and control swamps as calculated from data pooled for 4-year periods.

Comparison	Test statistic	D.f.	P-value
2018–2021	-0.94	4.3	0.396

8 Results - Swamp S1A

Monitoring at swamp S1A began in 2012, and this swamp was impacted in 2013. The boxplot of TSR data (Figure 11) shows that prior to impact, the TSR at the impact swamp was slightly higher than at the control swamps. Overall, TSR at the control swamps was more variable (with a wider minimum and maximum TSR observation) than TSR at swamp S1A, and was relatively stable across the monitoring period. In 2014, immediately after impact, TSR at the impact swamp rose, but it has declined progressively ever since.

For each year of monitoring prior to and post-impact, we calculated the difference in mean TSR between the control and impact swamps. Within-year comparisons (Figure 12) show that TSR remains higher at swamp S1A compared with the control swamps (i.e., the difference of the means is always negative), and this is trending towards 0 (i.e., TSR at swamp S1A is declining to become more similar to the control swamps over time).

In 2014, TSR was significantly different between swamp S1A and the control sites for data pooled by 2-year periods (Table 19). Between 2013 and 2016, the TSR calculated for 3-year pooled data was statistically significant (Table 20), and TSR for 4-year pooled data was significant between 2013 and 2016 (Table 21). The TSR as calculated from 5-year pooled data was also significantly different between 2013 and 2016 (Table 22).

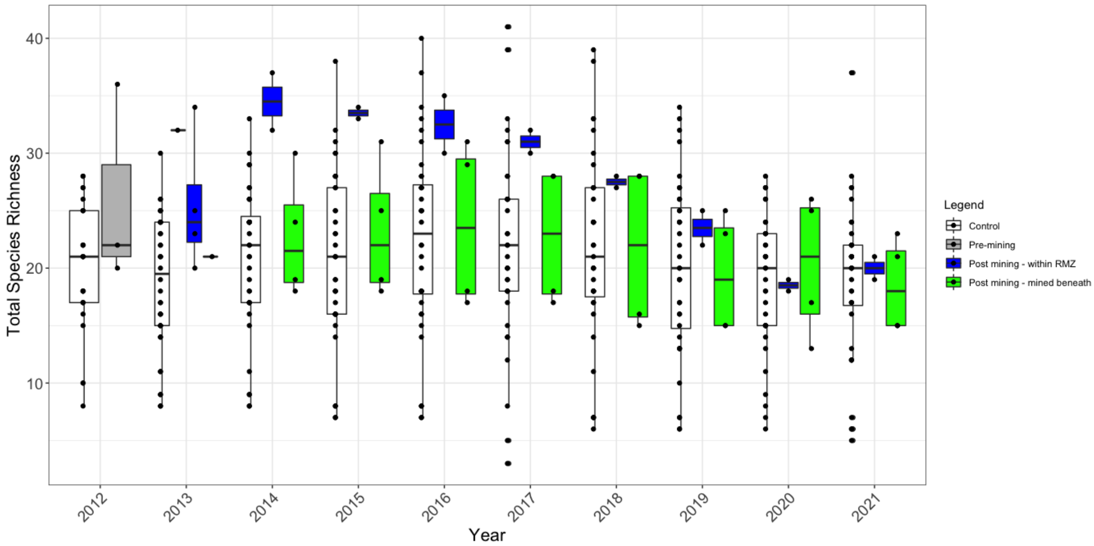

Figure 11. Boxplot of the total species richness for each transect at impact swamp S1A, contrasted against all control swamps. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

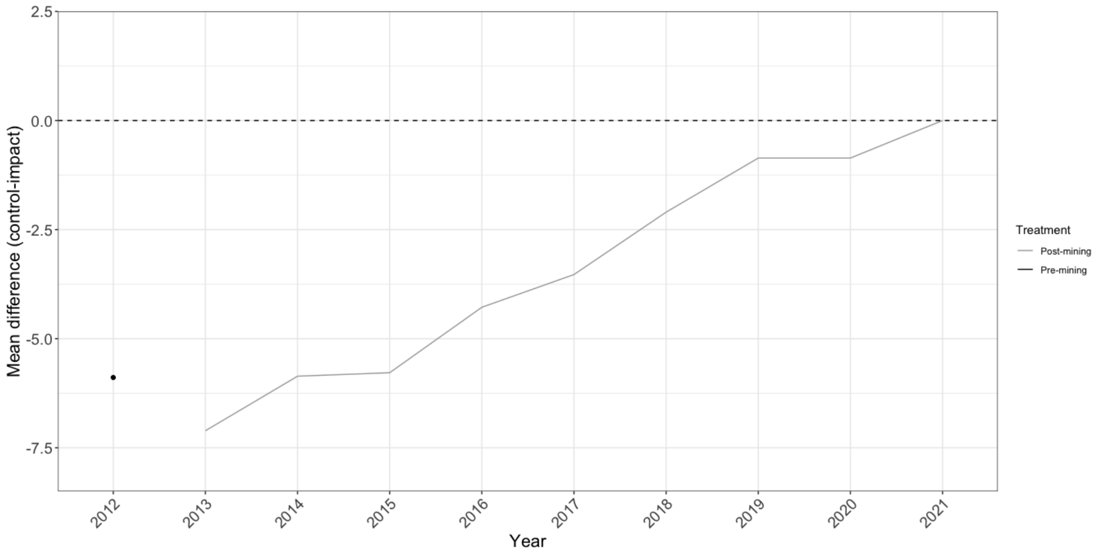

Figure 12. Difference between means for the control swamps and the impact swamp. Pre-impact data is shown as a single point since only one year's data was available. Post-impact data is shown as a grey line. Horizontal line at 0 is highlighted.

Table 16. Comparison of mean TSR between swamp S1A and control swamps as calculated from data pooled for 2-year periods.

Comparison	Test statistic	D.f.	P-value
2013–2014	-10.38	1	0.061
2014–2015	-145.50	1	0.004
2015–2016	-6.71	1	0.094
2016–2017	-10.41	1	0.061
2017–2018	-3.94	1	0.158
2018–2019	-2.39	1	0.253
2020–2021	-1.00	1	0.500

Table 17. Comparison of mean TSR between swamp S1A and control swamps as calculated from data pooled for 3-year periods.

Comparison	Test statistic	D.f.	P-value
2013–2015	-14.51	2	0.005
2014–2016	-10.33	2	0.009
2015–2017	-6.85	2	0.021
2016–2018	-5.17	2	0.035
2017–2019	-2.80	2	0.107
2018–2020	-3.08	2	0.091
2019–2021	-2.00	2	0.184

Table 18. Comparison of mean TSR between swamp S1A and control swamps as calculated from data pooled for 4-year periods.

Comparison	Test statistic	D.f.	P-value
2013–2016	-9.94	3	0.002
2014–2017	-8.47	3	0.003
2015–2018	-5.12	3	0.014
2016–2019	-3.54	3	0.038
2017–2020	-2.89	3	0.063
2018–2021	-2.21	3	0.114

Table 19. Comparison of mean TSR between swamp S1A and control swamps as calculated from data pooled for 5-year periods.

Comparison	Test statistic	D.f.	P-value
2013–2017	-8.40	4	0.001
2014–2018	-6.08	4	0.004
2015–2019	-3.88	4	0.018
2016–2020	-3.35	4	0.028
2017–2021	-2.39	4	0.075

9 Results - Swamp S1B

Monitoring at swamp S1B began in 2005, and this swamp was impacted in 2013. Please note, this impact swamp was not monitored in 2010 and 2011. The boxplot of TSR data (Figure 13) shows that prior to impact, the TSR at control sites was more variable (with a wider minimum and maximum TSR observation), and often had a lower mean than TSR at the impact swamps. Since 2016, TSR at this swamp appears to have declined to lower levels than before impact.

For each year of monitoring prior to and post-impact, we calculated the difference in mean TSR between the control and impact swamps. Within-year comparisons (Figure 14) show that TSR was higher at swamp S1B compared with the control swamps (i.e., the difference of the means is always negative), but this is trending towards 0 (i.e., TSR at swamp S1B is declining to become more similar to the control swamps over time).

The mean TSR for swamp S1B was significantly different to that of control swamps, as calculated from data pooled across 2-year periods in 2017 and again from 2019 (Table 23). For data pooled across 3-year and 4-year periods, TSR was significantly different between sites from 2017 onwards (Tables 24 and 25, respectively), and 5-year pooled data showed that TSR differed from 2016 onwards (Table 26).

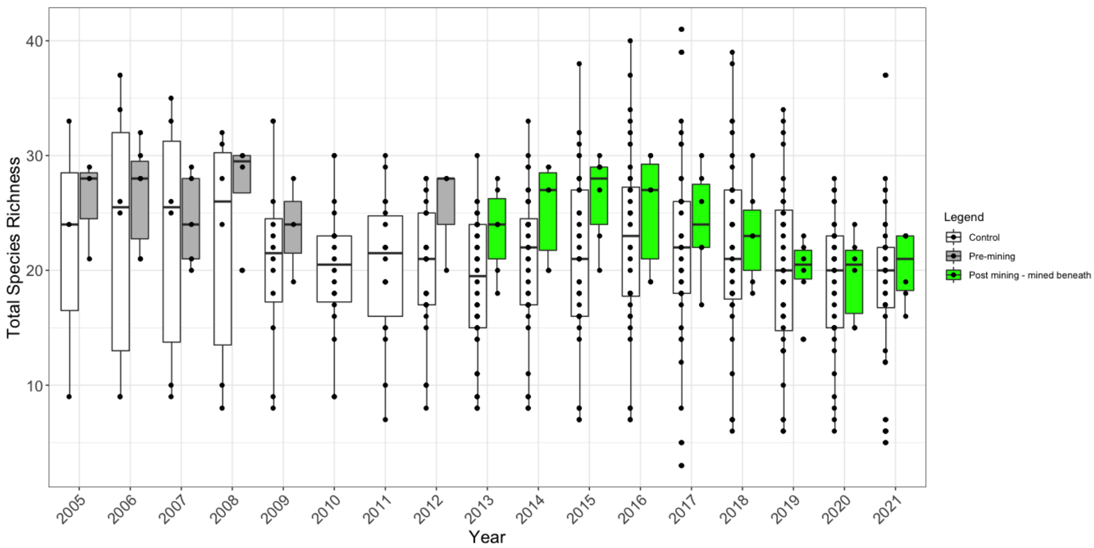

Figure 13. Boxplot of the total species richness for each transect at impact swamp S1B, contrasted against all control swamps. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

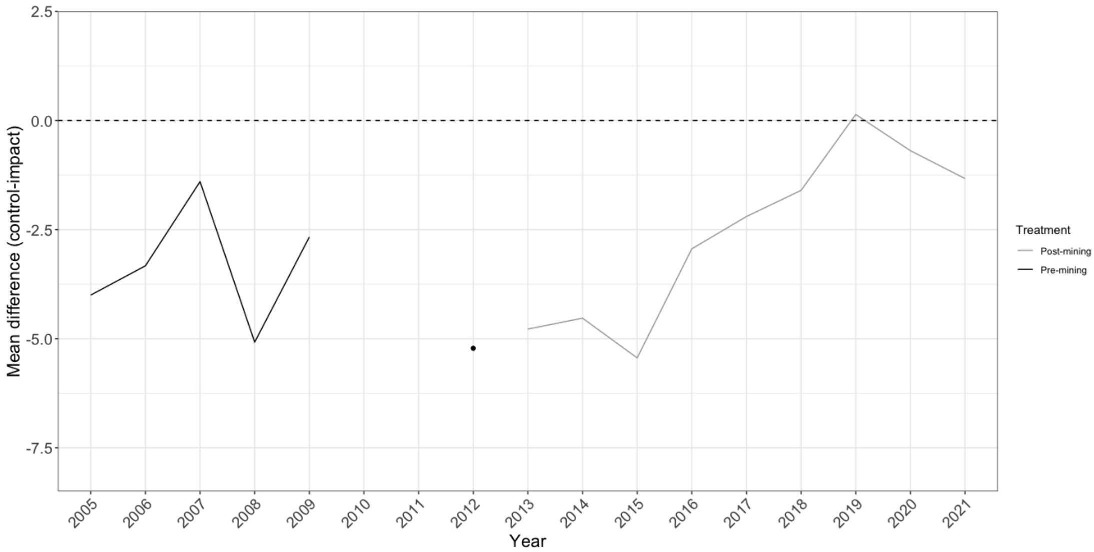

Figure 14. Difference between means for the control swamps and the impact swamp, shaded as black (pre-impact) and light grey (post-impact). Horizontal line at 0 is highlighted.

Table 20. Comparison of mean TSR between swamp S1B and control swamps as calculated from data pooled for 2-year periods.

Comparison	Test statistic	D.f.	P-value
2013–2014	-1.70	5.39	0.146
2014–2015	-1.82	4.66	0.133
2015–2016	-0.41	1.50	0.731
2016–2017	1.49	5.52	0.192
2017–2018	2.56	5.95	0.043
2018–2019	2.73	2.08	0.107
2019–2020	4.59	5.09	0.006
2020–2021	3.84	5.87	0.009

Table 21. Comparison of mean TSR between swamp S1B and control swamps as calculated from data pooled for 3-year periods.

Comparison	Test statistic	D.f.	P-value
2013–2015	-1.98	6.57	0.091
2014–2016	-0.73	4.73	0.502
2015–2017	0.08	3.57	0.942
2016–2018	1.92	7.00	0.096
2017–2019	2.60	4.93	0.049
2018–2020	3.71	6.48	0.009
2019–2021	4.07	6.92	0.005

Table 22. Comparison of mean TSR between swamp S1B and control swamps as calculated from data pooled for 4-year periods.

Comparison	Test statistic	D.f.	P-value
2013–2016	-1.01	7.86	0.344
2014–2017	-0.17	6.55	0.871
2015–2018	0.55	5.88	0.601
2016–2019	2.21	7.11	0.062
2017–2020	3.21	7.92	0.013
2018–2021	3.85	7.79	0.005

Table 23. Comparison of mean TSR between swamp S1B and control swamps as calculated from data pooled for 5-year periods.

Comparison	Test statistic	D.f.	P-value
2013–2017	-0.42	8.87	0.681
2014–2018	0.29	8.29	0.776
2015–2019	1.11	7.13	0.304
2016–2020	2.67	9.00	0.026
2017–2021	3.44	8.38	0.008

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10 Results - Swamp S5

Monitoring at swamp S5 began in 2012, and this swamp was impacted in 2013 (at a single transect). The boxplot of TSR data (Figure 15) shows that prior to impact, the TSR at control sites was more variable (with a wider minimum and maximum TSR observation), and TSR was often higher, than at the impact swamp. Since impact, TSR at swamp S5 appears to be lower (and more variable) than before impact.

For each year of monitoring prior to and post-impact, we calculated the difference in mean TSR between the control and impact swamps. Within-year comparisons (Figure 16) show that TSR remains lower at swamp S5 compared with the control swamps (i.e., the difference of the means is always positive), but this is trending towards 0 (i.e., TSR at swamp S5 is increasing to become more similar to the control swamps over time). However, the difference remained stable in the recent monitoring results.

Analyses of data pooled across 2-year, 3-year, 4-year and 5-year periods did not detect a significant difference between TSR at swamp S5 and control sites (Tables 27, 28, 29 and 30, respectively).

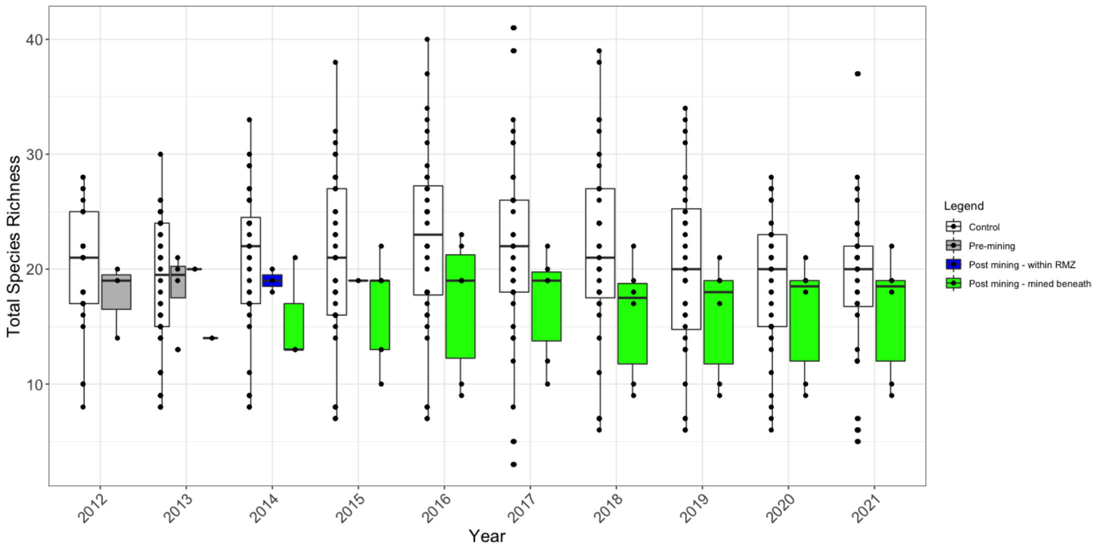

Figure 15. Boxplot of the total species richness for each transect at impact swamp S5, contrasted against all control swamps. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

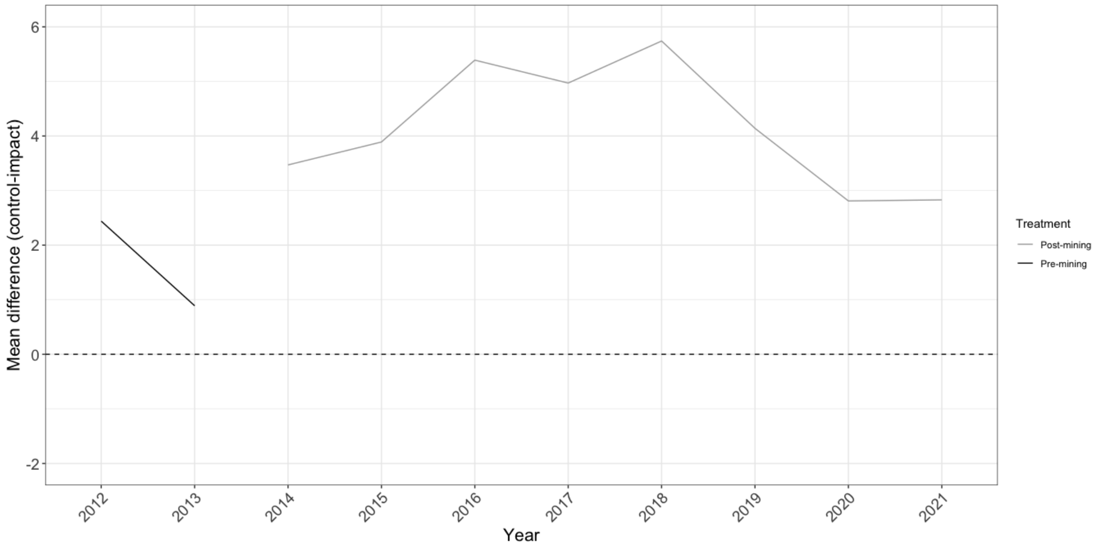

Figure 16. Difference between means for the control swamps and the impact swamp, shaded as black (pre-impact) and light grey (post-impact). Horizontal line at 0 is highlighted.

Table 24. Comparison of mean TSR between swamp S5 and control swamps as calculated from data pooled for 2-year periods.

Comparison	Test statistic	D.f.	P-value
2014–2015	2.51	1.15	0.215
2015–2016	2.76	2.00	0.110
2016–2017	4.38	1.15	0.119
2017–2018	4.26	1.47	0.085
2018–2019	2.94	2.00	0.099
2019–2020	1.77	1.95	0.221
2020–2021	1.49	1.00	0.376

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Table 25. Comparison of mean TSR between swamp S5 and control swamps as calculated from data pooled for 3-year periods.

Comparison	Test statistic	D.f.	P-value
2014–2016	2.67	2.11	0.110
2015–2017	3.45	1.68	0.095
2016–2018	4.59	1.17	0.110
2017–2019	3.64	1.73	0.084
2018–2020	2.23	2.81	0.118
2019–2021	1.79	1.66	0.240

Table 26. Comparison of mean TSR between swamp S5 and control swamps as calculated from data pooled for 4-year periods.

Comparison	Test statistic	D.f.	P-value
2014–2017	3.09	1.72	0.109
2015–2018	3.82	1.57	0.090
2016–2019	4.00	1.42	0.098
2017–2020	2.76	2.39	0.090
2018–2021	2.13	2.67	0.134

Table 27. Comparison of mean TSR between swamp S5 and control swamps as calculated from data pooled for 5-year periods.

Comparison	Test statistic	D.f.	P-value
2014–2018	3.40	1.69	0.096
2015–2019	3.71	1.45	0.105
2016–2020	3.15	2.01	0.087
2017–2021	2.51	2.26	0.114

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11 Results - Swamp S23

Monitoring at swamp S23 began in 2017, and this swamp was impacted in 2018. The boxplot of TSR data (Figure 17) shows that prior to impact, the TSR at the impact swamp was much lower than the control swamps. Overall, TSR at the control swamps was variable (with a wider minimum and maximum TSR observation) compared with the impact swamp, and relatively stable across the monitoring period.

For each year of monitoring prior to and post-impact, we calculated the difference in mean TSR between the control and impact swamps. Within-year comparisons (Figure 18) show that TSR remains lower at swamp S23 compared with the control swamps (i.e., the difference of the means is always positive) and this difference has remained stable over the monitoring period.

Analyses of data pooled for 2-year, 3-year and 4-year periods showed that TSR was statistically different between swamp S23 and the control sites from 2017 onwards (Tables 31, 32 and 33, respectively).

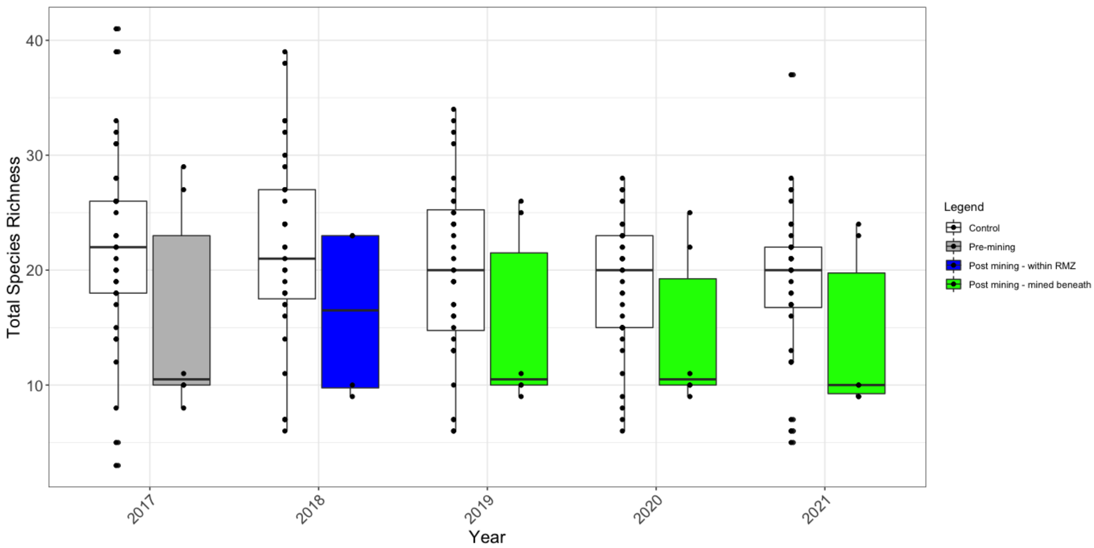

Figure 17. Boxplot of the total species richness for each transect at impact swamp S23, contrasted against all control swamps. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

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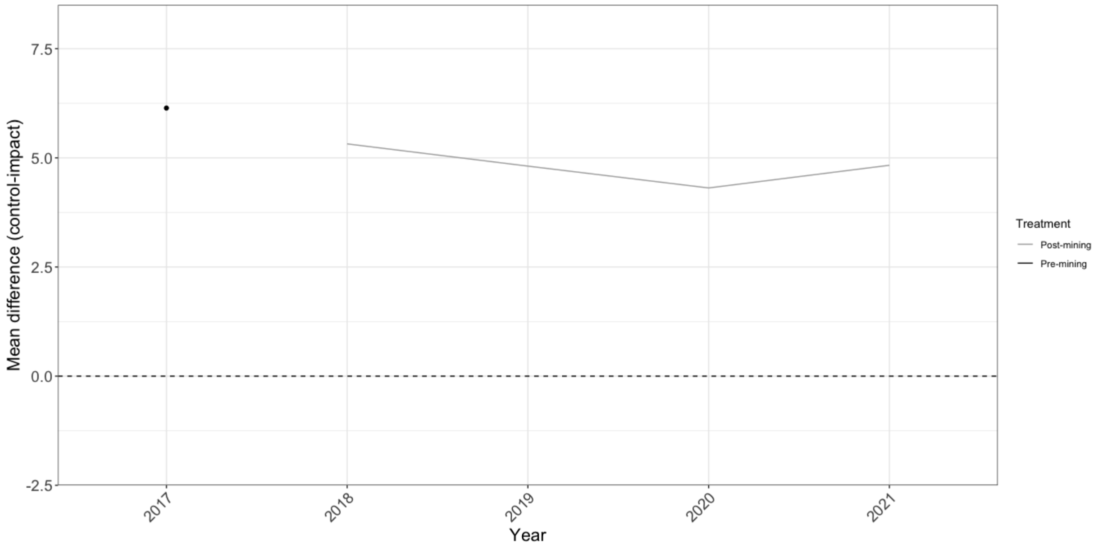

Figure 18: Difference between means for the control swamps and the impact swamp. Pre-impact data is shown as a single point since only one year's data was available. Post-impact data is shown as a light grey line. Horizontal line at 0 is highlighted.

Table 28. Comparison of mean TSR between swamp S23 and control swamps as calculated from data pooled for 2-year periods.

Comparison	Test statistic	D.f.	P-value
2018–2019	19.86	1	0.032
2019–2020	18.24	1	0.035
2020–2021	17.58	1	0.036

Table 29. Comparison of mean TSR between swamp S23 and control swamps as calculated from data pooled for 3-year periods.

Comparison	Test statistic	D.f.	P-value
2018–2020	16.51	2	0.004
2019–2021	27.34	2	0.001

Table 30. Comparison of mean TSR between swamp S23 and control swamps as calculated from data pooled across 4 years.

Comparison	Test statistic	D.f.	P-value
2018–2021	29.9	2	0.001

12 References

Holm, S. (1979). A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics 6, 65–70.

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL *https://www.R-project.org/*.

Analytical Edge (2021). *Analysis of flora species composition at impact swamps within the Dendrobium region, Data collected up to, and including, 2020*. Unpublished report submitted to Niche.

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STATISTICAL CONSULTING

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Task 1B - Analysis of flora species composition at impact swamps within the Dendrobium region

Data collected up to and including 2021

Final

22 March 2022

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Project History and Version Control

Date	Amendments	Person
9 March 2022	Received revised data from Sian Griffiths (Niche)	JP
11 March 2022	Draft report submitted to Sian Griffiths (Niche)	JP
22 March 2022	Final report submitted to Sian Griffiths (Niche)	JP

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1 Data Summary

On 9 March 2022, The Analytical Edge (hereafter, TAE) received a revised data set from Sian Griffiths (Niche) via e-mail. It contained data collected during flora swamp monitoring within the Dendrobium region up to and including 2021 (*'dendrobium_flora_annual_monitoring-2022-02-24_DW Edit.xlsx'*, 18.7 MB). Many species names and complexes had been revised since the previous analysis.

All data relating to swamp S1 were omitted from the analysis.

Errors:

(1) A total of 78 records were missing species-level information (29 and 49 records in 2020 and 2021, respectively). Also, 12 records were referred to as either 'QUADRAT IS DEAD' or 'QUADRAT DEAD'. These were excluded from the analysis. These errors were referred to Sian for correction in the parent database.

(2) For impact sites S11 and S15A(2) when PrePost = Pre (i.e., prior to impact), the treatment was listed as 'control'. These records were changed manually to 'impact sites', and referred to Sian for correction in the parent database.

(3) Swamp11-V1 in spring 2021 was incorrectly labelled Swamp1-V1 in the data set. These records were changed manually and referred to Sian for correction in the parent database.

(4) One species complex ('Blandfordia Burchardia Caladenia Haemodorum Microtis Thelymitra species complex') occasionally had an additional space after the record (i.e., 'Blandfordia Burchardia Caladenia Haemodorum Microtis Thelymitra species complex '). These records were changed manually and referred to Sian for correction in the parent database.

Disclaimer: Excluding the corrections mentioned above, this data file is assumed to be error-free. Any further errors detected by Niche may invalidate the results and conclusions made in this report and will require the analysis to be re-run under the proviso of new contract agreements.

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2 Methods

Flora data were used to determine species assemblages – or community composition – at each transect, within each swamp during each survey (i.e., simply a list of all unique species detected each visit). These multivariate data have been traditionally analysed within a distance-based framework, using methods like principal components analysis or non-metric multidimensional scaling. However, among other problems, these methods cannot offer a formal framework in which to test the hypothesis that treatment-effects influence species assemblages (Warton et al., 2012; Wang et al., 2012).

Instead, we can use model-based approaches when dealing with complex, multivariate data such as species assemblages. Here, multivariate presence-absence models were fitted using the 'manyglm' function in the 'mvabund' package (v.4.2.1, Wang, 2022) in program R (v. 4.1.2, R Core Team 2022). These models fit multiple presence-absence models to each detected species, correcting for the correlation between species (thus violating an assumption of standard GLMs) using generalized estimating equations (GEEs). Analysis of variance (ANOVA) was used to formally test the significance of explanatory variables (i.e., 'Mining Status'). Separate models were fitted to data collected at each swamp. If 'Mining Status' was found to be significant, univariate tests were completed to determine which species were driving the change in flora community composition.

Following reporting in 2021, a complete analysis was undertaken of the entire historical data. This is like the second round of reports submitted to Niche in 2021 and previously for Biosis. That is, data were pooled into 2-consecutive-year periods and analysed within a multivariate framework to determine if species composition in any given 2-year period after impact differed from composition prior to impact. For example, if a swamp was impacted in 2013, species composition in 2013 and 2014 at the impact swamp was compared with the species composition prior to the impact. This was then repeated for 2014–2015, 2015–2016, 2017–2018, 2018–2019, 2019–2020 and 2020–2021. The same analyses were repeated for pooled data from 3-year and 4-year periods, and where applicable 5-year periods (i.e., swamps in Area 3B).

In this approach, not all data are assessed in a single model, and therefore power is lost as data are omitted from the analysis. For example, a small change may never be statistically significant when comparing the data between 2 consecutive years, but might be significant at a different timescale, such as over the entire survey. TAE has previously proposed alternative methods to analyse these data (e.g., using a broken-stick approach), and this will be explored in Task 2 (to be undertaken).

The years that each swamp was monitored are shown in Table 1.

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Table 1. The digit '1' indicates that a swamp was monitored in a given year. Bold columns are impact swamps.

Year	**S11**	**S13**	**S14**	S15A(1)	**S15A(2)**	**S15B**	**S1A**	**S1B**	S22	**S23**	S33	**S5**	S86	S87	S88
2003	**1**	**0**	**0**	0	**0**	**1**	**0**	**0**	0	**0**	0	**0**	0	0	0
2004	**1**	**0**	**0**	0	**0**	**1**	**0**	**0**	0	**0**	0	**0**	0	0	0
2005	**1**	**0**	**0**	1	**0**	**1**	**0**	**1**	0	**0**	0	**0**	0	0	0
2006	**1**	**0**	**0**	1	**0**	**1**	**0**	**1**	0	**0**	0	**0**	0	0	0
2007	**1**	**0**	**0**	1	**0**	**1**	**0**	**1**	0	**0**	0	**0**	0	0	0
2008	**1**	**0**	**0**	1	**0**	**1**	**0**	**1**	0	**0**	0	**0**	0	0	0
2009	**1**	**0**	**0**	1	**1**	**1**	**0**	**1**	1	**0**	1	**0**	0	0	0
2010	**1**	**0**	**0**	1	**1**	**1**	**0**	**0**	1	**0**	1	**0**	0	0	0
2011	**1**	**0**	**0**	1	**1**	**1**	**0**	**0**	1	**0**	1	**0**	0	0	0
2012	**1**	**0**	**0**	1	**1**	**1**	**1**	**1**	1	**0**	1	**1**	1	1	1
2013	**1**	**1**	**0**	1	**1**	**1**	**1**	**1**	1	**0**	1	**1**	1	1	1
2014	**1**	**1**	**0**	1	**1**	**1**	**1**	**1**	1	**0**	1	**1**	1	1	1
2015	**1**	**1**	**0**	1	**1**	**1**	**1**	**1**	1	**0**	1	**1**	1	1	1
2016	**1**	**1**	**0**	1	**1**	**1**	**1**	**1**	1	**0**	1	**1**	1	1	1
2017	**1**	**1**	**1**	1	**1**	**1**	**1**	**1**	1	**1**	1	**1**	1	1	1
2018	**1**	**1**	**1**	1	**1**	**1**	**1**	**1**	1	**1**	1	**1**	1	1	1
2019	**1**	**1**	**1**	1	**1**	**1**	**1**	**1**	1	**1**	1	**1**	1	1	1
2020	**1**	**1**	**1**	1	**1**	**1**	**1**	**1**	1	**1**	1	**1**	1	1	1
2021	**1**	**1**	**1**	1	**1**	**1**	**1**	**1**	1	**1**	1	**1**	1	1	1

3 Results - Swamp S15A(2)

Monitoring of S15A(2) commenced in 2009, and mining within the RMZ commenced in 2013. A total of 66 unique species were detected, of which 8% were detected only once.

Differences in species composition at this swamp were first statistically significant in 2019 for 2-year pooled data (Table 2), meaning that by 2019, species composition was significantly different to composition prior to impact. Differences in comparisons of 3-year pooled data were first statistically significant in 2018 (Table 4) and differences in 4-year pooled data comparisons were first statistically significant in 2018 (Table 6). Species that were consistently found to be more common prior to impact for each 2-year, 3-year, and 4-year comparison are given in Tables 3, 5 and 7, respectively.

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Table 2. Species composition at swamp S15A(2) based on data pooled for 2-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021
prepostMining	0.738	0.652	0.537	0.433	0.375	0.131	0.022	0.013
PercDev	0.497	0.545	0.520	0.417	0.452	0.383	0.392	0.395
Species 1	*Leptospermum.juniperinum*	*Lepidosperma.filiforme..urophorum.complex*	*Thysanotus.juncifolius*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Baeckea.imbricata*	*Boronia.parviflora*	*Boronia.parviflora*	*Baeckea.imbricata*
Species 2	*Drosera.spatulata*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Leptospermum.lanigerum*	*Caesia.parviflora.var..parviflora*	*Gonocarpus.sp_.complex*	*Baeckea.imbricata*	*Boronia.parviflora*
Species 3	*Pteridium.esculentum*	*Leptospermum.lanigerum*	*Leptospermum.lanigerum*	*Baeckea.imbricata*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Leptospermum.juniperinum*	*Lepidosperma.filiforme..urophorum.complex*	*Bauera.microphylla..rubioides.sp.complex*
Species 4	*Lepyrodia.muelleri..scariosa.complex*	*Leptospermum.juniperinum*	*Caesia.parviflora.var..parviflora*	*Caesia.parviflora.var..parviflora*	*Leptospermum.lanigerum*	*Baloskion.gracile*	*Bauera.microphylla..rubioides.sp.complex*	*Leptospermum.polygalifolium..trinervium.complex*
Species 5	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.neesii..Ptilothrix.deusta.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Platysace.linearifolia*	*Platysace.linearifolia*	*Baeckea.imbricata*	*Gonocarpus.sp_.complex*	*Baloskion.gracile*

Table 3. Whether the 5 most influential species for each 2-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2019–2020	*Boronia.parviflora*	Yes
	Baeckea.imbricata	Yes
	Lepidosperma.filiforme..urophorum.complex	No
	Bauera.microphylla..rubioides.sp.complex	Yes
	Gonocarpus.sp_.complex	Yes
2020–2021	*Baeckea.imbricata*	Yes
	Boronia.parviflora	Yes
	Bauera.microphylla..rubioides.sp.complex	Yes
	Leptospermum.polygalifolium..trinervium.complex	Yes
	Baloskion.gracile	Yes

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Table 4. Species composition at swamp S15A(2) based on data pooled for 3-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2013–2015	2014–2016	2015–2017	2016–2018	2017–2019	2018–2020	2019–2021
prepostMining	0.679	0.432	0.384	0.273	0.181	0.040	0.010
PercDev	0.462	0.512	0.462	0.435	0.413	0.392	0.408
Species 1	*Leptospermum.juniperinum*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Baeckea.imbricata*	*Boronia.parviflora*	*Boronia.parviflora*
Species 2	*Lepidosperma.filiforme..urophorum.complex*	*Leptospermum.lanigerum*	*Leptospermum.lanigerum*	*Caesia.parviflora.var..parviflora*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Baeckea.imbricata*	*Baeckea.imbricata*
Species 3	*Drosera.spatulata*	*Leptospermum.juniperinum*	*Caesia.parviflora.var..parviflora*	*Leptospermum.lanigerum*	*Caesia.parviflora.var..parviflora*	*Leptospermum.juniperinum*	*Bauera.microphylla..rubioides.sp.complex*
Species 4	*Lepyrodia.muelleri..scariosa.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Baeckea.imbricata*	*Lepidosperma.filiforme..urophorum.complex*	*Gonocarpus.sp_.complex*	*Baloskion.gracile*
Species 5	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Thysanotus.juncifolius*	*Lepidosperma.neesii..Ptilothrix.deusta.complex*	*Platysace.linearifolia*	*Boronia.parviflora*	*Baloskion.gracile*	*Hibbertia.riparia.species.complex*

Table 5. Whether the 5 most influential species for each 3-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2018–2020	*Boronia.parviflora*	Yes
	Baeckea.imbricata	Yes
	Leptospermum.juniperinum	Yes
	Gonocarpus.sp_.complex	Yes
	Baloskion.gracile	Yes
2019–2021	*Boronia.parviflora*	Yes
	Baeckea.imbricata	Yes
	Bauera.microphylla..rubioides.sp.complex	Yes
	Baloskion.gracile	Yes
	Hibbertia.riparia.species.complex	Yes

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Table 6. Species composition at swamp S15A(2) based on data pooled for 4-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2013–2016	2014–2017	2015–2018	2016–2019	2017–2020	2018–2021
prepostMining	0.557	0.336	0.261	0.173	0.063	0.015
PercDev	0.471	0.494	0.453	0.416	0.403	0.400
Species 1	*Leptospermum.juniperinum*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Baeckea.imbricata*	*Baeckea.imbricata*
Species 2	*Drosera.spatulata*	*Leptospermum.lanigerum*	*Leptospermum.lanigerum*	*Baeckea.imbricata*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Boronia.parviflora*
Species 3	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Caesia.parviflora.var..parviflora*	*Leptospermum.juniperinum*	*Boronia.parviflora*	*Baloskion.gracile*
Species 4	*Thysanotus.juncifolius*	*Lepidosperma.neesii..Ptilothrix.deusta.complex*	*Lepidosperma.neesii..Ptilothrix.deusta.complex*	*Caesia.parviflora.var..parviflora*	*Lepidosperma.filiforme..urophorum.complex*	*Gompholobium.glabratum..grandiflorum.Sp_.complex*
Species 5	*Gompholobium.glabratum..grandiflorum.Sp_.complex*	*Drosera.spatulata*	*Drosera.spatulata*	*Platysace.linearifolia*	*Caesia.parviflora.var..parviflora*	*Lepidosperma.filiforme..urophorum.complex*

Table 7. Whether the 5 most influential species for each 4-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2018–2021	*Baeckea.imbricata*	Yes
	Boronia.parviflora	Yes
	Baloskion.gracile	Yes
	Gompholobium.glabratum..grandiflorum.Sp_.complex	Yes
	Lepidosperma.filiforme..urophorum.complex	No

4 Results - Swamp S15B

Monitoring of S15B commenced in 2003, and mining within the RMZ commenced in 2010. A total of 65 unique species were detected, of which 15% were detected only once.

Analyses of pooled data for 2-year periods showed significant differences in species composition at swamp S15B since 2012 (Table 8). For data pooled across 3-year and 4-year periods, comparisons have been statistically significant since 2010 (i.e., the year that the impact occurred, Tables 10 and 12, respectively).

Species that were consistently found to be more common prior to impact for each 2-year, 3-year, and 4-year pooled data comparison are given in Tables 9, 11 and 13.

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Table 8. Species composition at swamp S15B based on data pooled for 2-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021
prepostMining	0.146	0.072	0.029	0.008	0.001	0.002	0.001	0.001	0.001	0.001	0.001
PercDev	0.481	0.463	0.440	0.438	0.437	0.465	0.405	0.357	0.392	0.377	0.338
Species 1	*Cassytha.glabella..pubescens.sp.complex*	*Cassytha.glabella..pubescens.sp.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Gonocarpus.sp_.complex*	*Epacris.obtusifolia*	*Epacris.obtusifolia*
Species 2	*Gonocarpus.sp_.complex*	*Epacris.obtusifolia*	*Lepyrodia.anarthria*	*Platysace.linearifolia*	*Sprengelia.incarnata*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Epacris.obtusifolia*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*
Species 3	*Drosera.binata*	*Bossiaea.heterophylla*	*Platysace.linearifolia*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Sprengelia.incarnata*	*Platysace.linearifolia*	*Platysace.linearifolia*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Pultenaea.divaricata*
Species 4	*Bossiaea.heterophylla*	*Gonocarpus.sp_.complex*	*Cassytha.glabella..pubescens.sp.complex*	*Bossiaea.heterophylla*	*Banksia.robur*	*Banksia.robur*	*Epacris.obtusifolia*	*Epacris.obtusifolia*	*Platysace.linearifolia*	*Platysace.linearifolia*	*Sprengelia.incarnata*
Species 5	*Tetrarrhena.turfosa..Hemarthria.uncinata.complex*	*Lepyrodia.anarthria*	*Bossiaea.heterophylla*	*Pultenaea.divaricata*	*Platysace.linearifolia*	*Platysace.linearifolia*	*Banksia.robur*	*Banksia.robur*	*Acacia.terminalis*	*Pultenaea.divaricata*	*Platysace.linearifolia*

Table 9. Whether the 5 most influential species for each 2-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2012–2013	*Gonocarpus.sp_.complex*	Yes
	Lepyrodia.anarthria	Yes
	Platysace.linearifolia	Yes
	Cassytha.glabella..pubescens.sp.complex	Yes
	Bossiaea.heterophylla	Yes
2013–2014	*Gonocarpus.sp_.complex*	Yes
	Platysace.linearifolia	Yes
	Mitrasacme.polymorpha..pilosa.species.complex	Yes
	Bossiaea.heterophylla	Yes
	Pultenaea.divaricata	Yes
2014–2015	*Gonocarpus.sp_.complex*	Yes
	Sprengelia.incarnata	Yes
	Xanthosia.dissecta.pilosa..tridentata.species.complex	Yes
	Banksia.robur	Yes
	Platysace.linearifolia	Yes
2015–2016	*Gonocarpus.sp_.complex*	Yes
	Xanthosia.dissecta.pilosa..tridentata.species.complex	Yes
	Sprengelia.incarnata	Yes
	Banksia.robur	Yes
	Platysace.linearifolia	Yes
2016–2017	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	Yes
	Gonocarpus.sp_.complex	Yes
	Platysace.linearifolia	Yes
	Epacris.obtusifolia	Yes
	Banksia.robur	Yes
2017–2018	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	Yes
	Gonocarpus.sp_.complex	Yes
	Platysace.linearifolia	Yes

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Year	Species	More common before
	Epacris.obtusifolia	Yes
	Banksia.robur	Yes
2018–2019	*Gonocarpus.sp_.complex*	Yes
	Epacris.obtusifolia	Yes
	Xanthosia.dissecta.pilosa..tridentata.species.complex	Yes
	Platysace.linearifolia	Yes
	Acacia.terminalis	Yes
2019–2020	*Epacris.obtusifolia*	Yes
	Gonocarpus.sp_.complex	Yes
	Xanthosia.dissecta.pilosa..tridentata.species.complex	Yes
	Platysace.linearifolia	Yes
	Pultenaea.divaricata	Yes
2020–2021	*Epacris.obtusifolia*	Yes
	Gonocarpus.sp_.complex	Yes
	Pultenaea.divaricata	Yes
	Sprengelia.incarnata	Yes
	Platysace.linearifolia	Yes

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Table 10. Species composition at swamp S15B based on data pooled for 3-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2010–2012	2011–2013	2012–2014	2013–2015	2014–2016	2015–2017	2016–2018	2017–2019	2018–2020	2019–2021
prepostMining	0.05	0.018	0.004	0.001	0.001	0.001	0.001	0.001	0.001	0.001
PercDev	0.499	0.445	0.416	0.424	0.473	0.424	0.397	0.39	0.387	0.358
Species 1	*Cassytha.glabella..pubescens.sp.complex*	*Cassytha.glabella..pubescens.sp.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Epacris.obtusifolia*	*Gonocarpus.sp_.complex*	*Epacris.obtusifolia*
Species 2	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Platysace.linearifolia*	*Platysace.linearifolia*	*Sprengelia.incarnata*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Epacris.obtusifolia*	*Gonocarpus.sp_.complex*
Species 3	*Epacris.obtusifolia*	*Bossiaea.heterophylla*	*Bossiaea.heterophylla*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Sprengelia.incarnata*	*Platysace.linearifolia*	*Gonocarpus.sp_.complex*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Pultenaea.divaricata*
Species 4	*Bossiaea.heterophylla*	*Epacris.obtusifolia*	*Cassytha.glabella..pubescens.sp.complex*	*Sprengelia.incarnata*	*Platysace.linearifolia*	*Platysace.linearifolia*	*Epacris.obtusifolia*	*Platysace.linearifolia*	*Platysace.linearifolia*	*Platysace.linearifolia*
Species 5	*Baumea.articulata..rubiginosa..teretifolia.sp..Chorizandra.cymbaria..sphaerocephalum.species.complex*	*Lepyrodia.anarthria*	*Epacris.obtusifolia*	*Banksia.robur*	*Banksia.robur*	*Banksia.robur*	*Sprengelia.incarnata*	*Banksia.robur*	*Sprengelia.incarnata*	*Acacia.terminalis*

Table 11. Whether the 5 most influential species for each 3-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2010–2012	*Cassytha.glabella..pubescens.sp.complex*	Yes
	Gonocarpus.sp_.complex	Yes
	Epacris.obtusifolia	Yes
	Bossiaea.heterophylla	Yes
	Baumea.articulata..rubiginosa..teretifolia.sp..Chorizandra.cymbaria..sphaerocephalum.species.complex	Yes
2011–2013	*Cassytha.glabella..pubescens.sp.complex*	Yes
	Gonocarpus.sp_.complex	Yes
	Bossiaea.heterophylla	Yes
	Epacris.obtusifolia	Yes
	Lepyrodia.anarthria	Yes
2012–2014	*Gonocarpus.sp_.complex*	Yes
	Platysace.linearifolia	Yes
	Bossiaea.heterophylla	Yes
	Cassytha.glabella..pubescens.sp.complex	Yes
	Epacris.obtusifolia	Yes
2013–2015	*Gonocarpus.sp_.complex*	Yes
	Platysace.linearifolia	Yes
	Mitrasacme.polymorpha..pilosa.species.complex	Yes
	Sprengelia.incarnata	Yes
	Banksia.robur	Yes
2014–2016	*Gonocarpus.sp_.complex*	Yes
	Sprengelia.incarnata	Yes
	Xanthosia.dissecta.pilosa..tridentata.species.complex	Yes
	Platysace.linearifolia	Yes
	Banksia.robur	Yes
2015–2017	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	Yes
	Gonocarpus.sp_.complex	Yes
	Sprengelia.incarnata	Yes

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Year	Species	More common before
	Platysace.linearifolia	Yes
	Banksia.robur	Yes
2016–2018	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	Yes
	Gonocarpus.sp_.complex	Yes
	Platysace.linearifolia	Yes
	Epacris.obtusifolia	Yes
	Sprengelia.incarnata	Yes
2017–2019	*Epacris.obtusifolia*	Yes
	Xanthosia.dissecta.pilosa..tridentata.species.complex	Yes
	Gonocarpus.sp_.complex	Yes
	Platysace.linearifolia	Yes
	Banksia.robur	Yes
2018–2020	*Gonocarpus.sp_.complex*	Yes
	Epacris.obtusifolia	Yes
	Xanthosia.dissecta.pilosa..tridentata.species.complex	Yes
	Platysace.linearifolia	Yes
	Sprengelia.incarnata	Yes
2019–2021	*Epacris.obtusifolia*	Yes
	Gonocarpus.sp_.complex	Yes
	Pultenaea.divaricata	Yes
	Platysace.linearifolia	Yes
	Acacia.terminalis	Yes

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Table 12. Species composition at swamp S15B based on data pooled for 4-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2010–2013	2011–2014	2012–2015	2013–2016	2014–2017	2015–2018	2016–2019	2017–2020	2018–2021
prepostMining	0.010	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
PercDev	0.479	0.428	0.402	0.452	0.441	0.413	0.413	0.382	0.363
Species 1	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Epacris.obtusifolia*	*Epacris.obtusifolia*
Species 2	*Cassytha.glabella..pubescens.sp.complex*	*Cassytha.glabella..pubescens.sp.complex*	*Platysace.linearifolia*	*Platysace.linearifolia*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*
Species 3	*Bossiaea.heterophylla*	*Bossiaea.heterophylla*	*Bossiaea.heterophylla*	*Sprengelia.incarnata*	*Sprengelia.incarnata*	*Sprengelia.incarnata*	*Epacris.obtusifolia*	*Xanthosia.dissecta.pilosa..tridentata.species.complex*	*Platysace.linearifolia*
Species 4	*Platysace.linearifolia*	*Platysace.linearifolia*	*Cassytha.glabella..pubescens.sp.complex*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Platysace.linearifolia*	*Platysace.linearifolia*	*Platysace.linearifolia*	*Platysace.linearifolia*	*Pultenaea.divaricata*
Species 5	*Epacris.obtusifolia*	*Epacris.obtusifolia*	*Banksia.robur*	*Banksia.robur*	*Banksia.robur*	*Banksia.robur*	*Sprengelia.incarnata*	*Sprengelia.incarnata*	*Sprengelia.incarnata*

Table 13. Whether the 5 most influential species for each 4-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2010–2013	*Gonocarpus.sp_.complex*	Yes
	Cassytha.glabella..pubescens.sp.complex	Yes
	Bossiaea.heterophylla	Yes
	Platysace.linearifolia	Yes
	Epacris.obtusifolia	Yes
2011–2014	*Gonocarpus.sp_.complex*	Yes
	Cassytha.glabella..pubescens.sp.complex	Yes
	Bossiaea.heterophylla	Yes
	Platysace.linearifolia	Yes
	Epacris.obtusifolia	Yes
2012–2015	*Gonocarpus.sp_.complex*	Yes
	Platysace.linearifolia	Yes
	Bossiaea.heterophylla	Yes
	Cassytha.glabella..pubescens.sp.complex	Yes
	Banksia.robur	Yes
2013–2016	*Gonocarpus.sp_.complex*	Yes
	Platysace.linearifolia	Yes
	Sprengelia.incarnata	Yes
	Mitrasacme.polymorpha..pilosa.species.complex	Yes
	Banksia.robur	Yes
2014–2017	*Gonocarpus.sp_.complex*	Yes
	Xanthosia.dissecta.pilosa..tridentata.species.complex	Yes
	Sprengelia.incarnata	Yes
	Platysace.linearifolia	Yes
	Banksia.robur	Yes
2015–2018	*Gonocarpus.sp_.complex*	Yes
	Xanthosia.dissecta.pilosa..tridentata.species.complex	Yes
	Sprengelia.incarnata	Yes

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Year	Species	More common before
	Platysace.linearifolia	Yes
	Banksia.robur	Yes
2016–2019	*Gonocarpus.sp_.complex*	Yes
	Xanthosia.dissecta.pilosa..tridentata.species.complex	Yes
	Epacris.obtusifolia	Yes
	Platysace.linearifolia	Yes
	Sprengelia.incarnata	Yes
2017–2020	*Epacris.obtusifolia*	Yes
	Gonocarpus.sp_.complex	Yes
	Xanthosia.dissecta.pilosa..tridentata.species.complex	Yes
	Platysace.linearifolia	Yes
	Sprengelia.incarnata	Yes
2018–2021	*Epacris.obtusifolia*	Yes
	Gonocarpus.sp_.complex	Yes
	Platysace.linearifolia	Yes
	Pultenaea.divaricata	Yes
	Sprengelia.incarnata	Yes

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5 Results - Swamp S11

Monitoring of S11 commenced in 2003, and mining within the RMZ commenced in 2016. A total of 61 unique species were detected, of which 8% were detected only once.

Differences in species composition at this swamp, as calculated from data pooled for 2-consecutive-year periods, have been statistically significant since 2017 (Table 14). Analyses of data pooled for 3 and 4 consecutive year periods show statistically significant differences since 2016 (i.e., the year that the impact occurred, Tables 16 and 18, respectively). Analysis of data pooled across 5 years showed statistically significant differences in composition from 2016 onwards (Table 20).

Species that were consistently found to be more common prior to impact for each 2-year, 3-year, 4-year, and 5-year pooled data comparison are given in Tables 15, 17, 19 and 21.

Table 14. Species composition at swamp S11 based on data pooled for 2-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021
prepostMining	0.243	0.038	0.005	0.001	0.001
PercDev	0.350	0.334	0.462	0.494	0.606
Species 1	*Lindsaea.linearis*	*Lindsaea.linearis*	*Gonocarpus.sp_.complex*	*Almaleea.paludosa*	*Almaleea.paludosa*
Species 2	*Empodisma.minus*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Almaleea.paludosa*	*Gonocarpus.sp_.complex*	*Epacris.obtusifolia*
Species 3	*Dillwynia.floribunda.retorta.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Sphaerolobium.Stackhousia.species.complex*	*Sphaerolobium.Stackhousia.species.complex*	*Boronia.parviflora*
Species 4	*Acacia.rubida*	*Gonocarpus.sp_.complex*	*Schizaea.bifida*	*Schizaea.bifida*	*Sphaerolobium.Stackhousia.species.complex*
Species 5	*Lepidosperma.filiforme..urophorum.complex*	*Almaleea.paludosa*	*Goodenia.dimorpha..stelligera..bellidifolia.sp.complex*	*Goodenia.dimorpha..stelligera..bellidifolia.sp.complex*	*Gonocarpus.sp_.complex*

Table 15. Whether the 5 most influential species for each 2-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2017–2018	*Lindsaea.linearis*	No
	Grevillea.patulifolia.sericea.speciosa.complex	Yes
	Lepidosperma.filiforme..urophorum.complex	No
	Gonocarpus.sp_.complex	Yes
	Almaleea.paludosa	Yes
2018–2019	*Gonocarpus.sp_.complex*	Yes
	Almaleea.paludosa	Yes
	Sphaerolobium.Stackhousia.species.complex	Yes
	Schizaea.bifida	Yes
	Goodenia.dimorpha..stelligera..bellidifolia.sp.complex	Yes
2019–2020	*Almaleea.paludosa*	Yes
	Gonocarpus.sp_.complex	Yes
	Sphaerolobium.Stackhousia.species.complex	Yes
	Schizaea.bifida	Yes
	Goodenia.dimorpha..stelligera..bellidifolia.sp.complex	Yes
2020–2021	*Almaleea.paludosa*	Yes
	Epacris.obtusifolia	Yes
	Boronia.parviflora	Yes
	Sphaerolobium.Stackhousia.species.complex	Yes
	Gonocarpus.sp_.complex	Yes

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Table 16. Species composition at swamp S11 based on data pooled for 3-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2016–2018	2017–2019	2018–2020	2019–2021
prepostMining	0.021	0.006	0.002	0.001
PercDev	0.392	0.359	0.505	0.516
Species 1	*Grevillea.oleoides*	*Grevillea.oleoides*	*Almaleea.paludosa*	*Almaleea.paludosa*
Species 2	*Lindsaea.linearis*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*
Species 3	*Lepidosperma.filiforme..urophorum.complex*	*Lindsaea.linearis*	*Sphaerolobium.Stackhousia.species.complex*	*Sphaerolobium.Stackhousia.species.complex*
Species 4	*Almaleea.paludosa*	*Almaleea.paludosa*	*Schizaea.bifida*	*Epacris.obtusifolia*
Species 5	*Empodisma.minus*	*Sphaerolobium.Stackhousia.species.complex*	*Goodenia.dimorpha..stelligera..bellidifolia.sp.complex*	*Boronia.parviflora*

Table 17. Whether the 5 most influential species for each 3-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2016–2018	*Grevillea.oleoides*	No
	Lindsaea.linearis	No
	Lepidosperma.filiforme..urophorum.complex	No
	Almaleea.paludosa	Yes
	Empodisma.minus	No
2017–2019	*Grevillea.oleoides*	No
	Gonocarpus.sp_.complex	Yes
	Lindsaea.linearis	No
	Almaleea.paludosa	Yes
	Sphaerolobium.Stackhousia.species.complex	Yes
2018–2020	*Almaleea.paludosa*	Yes
	Gonocarpus.sp_.complex	Yes
	Sphaerolobium.Stackhousia.species.complex	Yes
	Schizaea.bifida	Yes
	Goodenia.dimorpha..stelligera..bellidifolia.sp.complex	Yes
2019–2021	*Almaleea.paludosa*	Yes
	Gonocarpus.sp_.complex	Yes
	Sphaerolobium.Stackhousia.species.complex	Yes
	Epacris.obtusifolia	Yes
	Boronia.parviflora	Yes

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Table 18. Species composition at swamp S11 based on data pooled for 4-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2016–2019	2017–2020	2018–2021
prepostMining	0.002	0.001	0.001
PercDev	0.362	0.389	0.487
Species 1	*Grevillea.oleoides*	*Almaleea.paludosa*	*Almaleea.paludosa*
Species 2	*Lindsaea.linearis*	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*
Species 3	*Almaleea.paludosa*	*Sphaerolobium.Stackhousia.species.complex*	*Sphaerolobium.Stackhousia.species.complex*
Species 4	*Gonocarpus.sp_.complex*	*Grevillea.oleoides*	*Schizaea.bifida*
Species 5	*Goodenia.dimorpha..stelligera..bellidifolia.sp.complex*	*Lindsaea.linearis*	*Boronia.parviflora*

Table 1. Whether the 5 most influential species for each 4-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2016–2019	*Grevillea.oleoides*	No
	Lindsaea.linearis	No
	Almaleea.paludosa	Yes
	Gonocarpus.sp_.complex	Yes
	Goodenia.dimorpha..stelligera..bellidifolia.sp.complex	Yes
2017–2020	*Almaleea.paludosa*	Yes
	Gonocarpus.sp_.complex	Yes
	Sphaerolobium.Stackhousia.species.complex	Yes
	Grevillea.oleoides	No
	Lindsaea.linearis	No
2018–2021	*Almaleea.paludosa*	Yes
	Gonocarpus.sp_.complex	Yes
	Sphaerolobium.Stackhousia.species.complex	Yes
	Schizaea.bifida	Yes
	Boronia.parviflora	Yes

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Table 20. Species composition at swamp S11 based on data pooled for 4-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2016–2020	2017–2021
prepostMining	0.002	0.001
PercDev	0.388	0.418
Species 1	*Almaleea.paludosa*	*Almaleea.paludosa*
Species 2	*Gonocarpus.sp_.complex*	*Gonocarpus.sp_.complex*
Species 3	*Sphaerolobium.Stackhousia.species.complex*	*Sphaerolobium.Stackhousia.species.complex*
Species 4	*Lindsaea.linearis*	*Boronia.parviflora*
Species 5	*Grevillea.oleoides*	*Grevillea.oleoides*

Table 21. Whether the 5 most influential species for each 5-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2016–2019	*Almaleea.paludosa*	Yes
	Gonocarpus.sp_.complex	Yes
	Sphaerolobium.Stackhousia.species.complex	Yes
	Lindsaea.linearis	No
	Grevillea.oleoides	No
2017–2020	*Almaleea.paludosa*	Yes
	Gonocarpus.sp_.complex	Yes
	Sphaerolobium.Stackhousia.species.complex	Yes
	Boronia.parviflora	Yes
	Grevillea.oleoides	No

6 Results - Swamp S13

Monitoring of S13 commenced in 2013, and mining within the RMZ commenced in 2017. A total of 66 unique species were detected, of which 21% were detected only once.

Differences in species composition at swamp S13, as calculated from data pooled across 2 consecutive years, were statistically significant from 2019 onwards (Table 22). For data pooled over 3 consecutive years, differences were first statistically significant in 2019 (Table 24) and for 4-year pooled data, comparison was found to be statistically significant in 2018 (Table 26).

Species that were consistently found to be more common prior to impact for each 2-year, 3-year, and 4-year pooled data period are given in Tables 23 and 25.

Table 22. Species composition at swamp S13 based on data pooled for 2-year periods. The p-value for PrePostMining and the percentage of deviance explained by the five most influential species are shown.

	2017–2018	2018–2019	2019–2020	2020–2021
prepostMining	0.551	0.168	0.038	0.039
PercDev	0.534	0.476	0.359	0.327
Species 1	*Dillwynia.floribunda.retorta.complex*	*Dillwynia.floribunda.retorta.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.filiforme..urophorum.complex*
Species 2	*Dampiera.stricta*	*Lepidosperma.filiforme..urophorum.complex*	*Dampiera.stricta*	*Dampiera.stricta*
Species 3	*Grevillea.oleoides*	*Almaleea.paludosa*	*Dillwynia.floribunda.retorta.complex*	*Tetraria.capillaris*
Species 4	*Grevillea.patulifolia.sericea.speciosa.complex*	*Dampiera.stricta*	*Sphaerolobium.Stackhousia.species.complex*	*Dillwynia.floribunda.retorta.complex*
Species 5	*Lepyrodia.anarthria*	*Lepyrodia.anarthria*	*Acacia.rubida*	*Almaleea.paludosa*

Table 23. Whether the 5 most influential species for each 2-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2019–2020	*Lepidosperma.filiforme..urophorum.complex*	Yes
	Dampiera.stricta	Yes
	Dillwynia.floribunda.retorta.complex	Yes
	Sphaerolobium.Stackhousia.species.complex	Yes
	Acacia.rubida	Yes
2020–2021	*Lepidosperma.filiforme..urophorum.complex*	Yes
	Dampiera.stricta	Yes
	Tetraria.capillaris	Yes
	Dillwynia.floribunda.retorta.complex	Yes
	Almaleea.paludosa	Yes

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Table 24. Species composition at swamp S13 based on data pooled for 3-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2017–2019	2018–2020	2019–2021
prepostMining	0.279	0.055	0.029
PercDev	0.501	0.378	0.402
Species 1	*Dillwynia.floribunda.retorta.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.filiforme..urophorum.complex*
Species 2	*Dampiera.stricta*	*Dillwynia.floribunda.retorta.complex*	*Dillwynia.floribunda.retorta.complex*
Species 3	*Lepidosperma.filiforme..urophorum.complex*	*Dampiera.stricta*	*Dampiera.stricta*
Species 4	*Epacris.obtusifolia*	*Almaleea.paludosa*	*Almaleea.paludosa*
Species 5	*Lepyrodia.anarthria*	*Sphaerolobium.Stackhousia.species.complex*	*Sphaerolobium.Stackhousia.species.complex*

Table 25. Whether the 5 most influential species for each 3-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2019–2021	*Lepidosperma.filiforme..urophorum.complex*	Yes
	Dillwynia.floribunda.retorta.complex	Yes
	Dampiera.stricta	Yes
	Almaleea.paludosa	Yes
	Sphaerolobium.Stackhousia.species.complex	Yes

Table 26. Species composition at swamp S13 based on data pooled for 4-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2017–2020	2018–2021
prepostMining	0.102	0.044
PercDev	0.378	0.420
Species 1	*Dampiera.stricta*	*Lepidosperma.filiforme..urophorum.complex*
Species 2	*Dillwynia.floribunda.retorta.complex*	*Dillwynia.floribunda.retorta.complex*
Species 3	*Lepidosperma.filiforme..urophorum.complex*	*Almaleea.paludosa*
Species 4	*Epacris.obtusifolia*	*Dampiera.stricta*
Species 5	*Banksia.marginata*	*Epacris.obtusifolia*

7 Results - Swamp S14

Monitoring of S14 commenced in 2017, and mining within the RMZ commenced in 2018. A total of 39 unique species were detected, of which 10% were detected only once.

Analysis of data pooled for 2-consecutive-year periods showed that species composition was significantly different from pre-impact at this swamp in 2020 (Table 27) but no set of 3-consecutive-year pooled data (Table 29) was statistically significant. Species that were consistently found to be more common prior to impact for each 2-year comparison are given in Table 28.

Table 27. Species composition at swamp S14 based on data pooled for 2-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2018–2019	2019–2020	2020–2021
prepostMining	0.419	0.264	0.029
PercDev	0.625	0.487	0.536
Species 1	*Lepyrodia.anarthria*	*Lepyrodia.muelleri..scariosa.complex*	*Lepyrodia.muelleri..scariosa.complex*
Species 2	*Leptomeria.acida*	*Lepyrodia.anarthria*	*Epacris.obtusifolia*
Species 3	*Drosera.binata*	*Leptomeria.acida*	*Lepyrodia.anarthria*
Species 4	*Cassytha.glabella..pubescens.sp.complex*	*Bauera.microphylla..rubioides.sp.complex*	*Leptomeria.acida*
Species 5	*Bauera.microphylla..rubioides.sp.complex*	*Pultenaea.divaricata*	*Symphionema.paludosum*

Table 2: Whether the 5 most influential species for each 2-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species Name	More common before
2020-2021	*Lepyrodia.muelleri..scariosa.complex*	Yes
2020-2021	*Epacris.obtusifolia*	Yes
2020-2021	*Lepyrodia.anarthria*	Yes
2020-2021	*Leptomeria.acida*	Yes
2020-2021	*Symphionema.paludosum*	Yes

Table 29. Species composition at swamp S14 based on data pooled for 3-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2018–2020	2019–2021
prepostMining	0.163	0.107
PercDev	0.494	0.516
Species 1	*Lepyrodia.anarthria*	*Lepyrodia.muelleri..scariosa.complex*
Species 2	*Leptomeria.acida*	*Lepyrodia.anarthria*
Species 3	*Lepyrodia.muelleri..scariosa.complex*	*Leptomeria.acida*
Species 4	*Symphionema.paludosum*	*Epacris.obtusifolia*
Species 5	*Drosera.binata*	*Pultenaea.divaricata*

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8 Results - Swamp S1A

Monitoring of S1A commenced in 2012, and mining within the RMZ commenced in 2013. A total of 67 unique species were detected, of which 7% were detected only once.

Comparisons of data pooled for 2-year, 3-year, 4-year and 5-year periods found no statistically significant changes this swamp (Tables 30, 31, 32 and 33, respectively).

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Table 30. Species composition at swamp S1A based on data pooled for 2-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021
prepostMining	0.775	0.905	0.825	0.747	0.606	0.639	0.260	0.078
PercDev	0.483	0.538	0.504	0.447	0.409	0.407	0.338	0.298
Species 1	*Monotaxis.linifolia*	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Boronia.parviflora*	*Boronia.parviflora*	*Boronia.parviflora*	*Gymnoschoenus.sphaerocephalus*	*Epacris.obtusifolia*
Species 2	*Lepidosperma.filiforme..urophorum.complex*	*Hakea.teretifolia..sericea.sp.complex*	*Boronia.parviflora*	*Lepidosperma.filiforme..urophorum.complex*	*Drosera.binata*	*Drosera.binata*	*Boronia.parviflora*	*Gymnoschoenus.sphaerocephalus*
Species 3	*Billardiera.scandens.var..scandens*	*Monotaxis.linifolia*	*Hakea.teretifolia..sericea.sp.complex*	*Grevillea.sphacelata*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Lepyrodia.muelleri..scariosa.complex*	*Lepyrodia.muelleri..scariosa.complex*	*Dampiera.stricta*
Species 4	*Leptomeria.acida*	*Lepyrodia.muelleri..scariosa.complex*	*Lepyrodia.muelleri..scariosa.complex*	*Drosera.binata*	*Grevillea.sphacelata*	*Grevillea.sphacelata*	*Epacris.obtusifolia*	*Sphaerolobium.Stackhousia.species.complex*
Species 5	*Hakea.teretifolia..sericea.sp.complex*	*Dillwynia.floribunda.retorta.complex*	*Monotaxis.linifolia*	*Lepyrodia.muelleri..scariosa.complex*	*Symphionema.paludosum*	*Symphionema.paludosum*	*Bauera.microphylla..rubioides.sp.complex*	*Boronia.parviflora*

Table 31. Species composition at swamp S1A based on data pooled for 3-year periods. The p-value for PrePostMining and the percentage of deviance explained by 5 most influential species are shown.

	2013–2015	2014–2016	2015–2017	2016–2018	2017–2019	2018–2020	2019–2021
prepostMining	0.805	0.870	0.798	0.720	0.741	0.589	0.482
PercDev	0.446	0.518	0.457	0.444	0.434	0.382	0.437
Species 1	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Boronia.parviflora*	*Boronia.parviflora*	*Boronia.parviflora*	*Epacris.obtusifolia*
Species 2	*Hakea.teretifolia..sericea.sp.complex*	*Hakea.teretifolia..sericea.sp.complex*	*Boronia.parviflora*	*Drosera.binata*	*Drosera.binata*	*Drosera.binata*	*Boronia.parviflora*
Species 3	*Monotaxis.linifolia*	*Lepyrodia.muelleri..scariosa.complex*	*Hakea.teretifolia..sericea.sp.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Lepyrodia.muelleri..scariosa.complex*	*Lepyrodia.muelleri..scariosa.complex*	*Dampiera.stricta*
Species 4	*Lepyrodia.muelleri..scariosa.complex*	*Boronia.parviflora*	*Lepyrodia.muelleri..scariosa.complex*	*Sphaerolobium.Stackhousia.species.complex*	*Sphaerolobium.Stackhousia.species.complex*	*Bauera.microphylla..rubioides.sp.complex*	*Lepyrodia.muelleri..scariosa.complex*
Species 5	*Leptomeria.acida*	*Monotaxis.linifolia*	*Monotaxis.linifolia*	*Hakea.teretifolia..sericea.sp.complex*	*Hakea.teretifolia..sericea.sp.complex*	*Sphaerolobium.Stackhousia.species.complex*	*Bauera.microphylla..rubioides.sp.complex*

Table 32. Species composition at swamp S1A based on data pooled for 4-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2013–2016	2014–2017	2015–2018	2016–2019	2017–2020	2018–2021
prepostMining	0.797	0.828	0.768	0.794	0.691	0.503
PercDev	0.46	0.48	0.409	0.434	0.4	0.357
Species 1	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Boronia.parviflora*	*Boronia.parviflora*	*Boronia.parviflora*	*Boronia.parviflora*
Species 2	*Hakea.teretifolia..sericea.sp.complex*	*Hakea.teretifolia..sericea.sp.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Drosera.binata*	*Drosera.binata*	*Epacris.obtusifolia*
Species 3	*Monotaxis.linifolia*	*Boronia.parviflora*	*Hakea.teretifolia..sericea.sp.complex*	*Lepyrodia.muelleri..scariosa.complex*	*Lepyrodia.muelleri..scariosa.complex*	*Gymnoschoenus.sphaerocephalus*
Species 4	*Lepyrodia.muelleri..scariosa.complex*	*Monotaxis.linifolia*	*Lepyrodia.muelleri..scariosa.complex*	*Sphaerolobium.Stackhousia.species.complex*	*Sphaerolobium.Stackhousia.species.complex*	*Lepyrodia.muelleri..scariosa.complex*
Species 5	*Persoonia.levis*	*Lepyrodia.muelleri..scariosa.complex*	*Grevillea.sphacelata*	*Hakea.teretifolia..sericea.sp.complex*	*Epacris.obtusifolia*	*Sphaerolobium.Stackhousia.species.complex*

Table 33. Species composition at swamp S1A based on data pooled for 5-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2013–2017	2014–2018	2015–2019	2016–2020	2017–2021
prepostMining	0.717	0.795	0.803	0.769	0.682
PercDev	0.447	0.430	0.407	0.402	0.362
Species 1	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Boronia.parviflora*	*Boronia.parviflora*	*Boronia.parviflora*
Species 2	*Hakea.teretifolia..sericea.sp.complex*	*Boronia.parviflora*	*Lepyrodia.muelleri..scariosa.complex*	*Drosera.binata*	*Sphaerolobium.Stackhousia.species.complex*
Species 3	*Monotaxis.linifolia*	*Hakea.teretifolia..sericea.sp.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Lepyrodia.muelleri..scariosa.complex*	*Lepyrodia.muelleri..scariosa.complex*
Species 4	*Boronia.parviflora*	*Lepyrodia.muelleri..scariosa.complex*	*Grevillea.sphacelata*	*Sphaerolobium.Stackhousia.species.complex*	*Epacris.obtusifolia*
Species 5	*Lepyrodia.muelleri..scariosa.complex*	*Monotaxis.linifolia*	*Hakea.teretifolia..sericea.sp.complex*	*Epacris.obtusifolia*	*Drosera.binata*

9 Results - Swamp S1B

Monitoring of S1B commenced in 2005, and mining within the RMZ commenced in 2013. A total of 65 unique species were detected, of which 8% were detected only once.

Differences in species composition at this swamp, as calculated from data pooled across 2-consecutive-year periods, were first significant from 2014 (Table 34). Comparisons of data pooled for 3-year, 4-year and 5-year periods were all statistically significant from 2013 onwards (i.e., when the impact first occurred, Tables 36, 38 and 40, respectively).

Species that were consistently found to be more common prior to impact for each 2-year, 3-year, 4-year and 5-year pooled data comparison are given in Tables 35, 37, 39 and 41.

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Table 34. Species composition at swamp S1B based on data pooled for 2-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021
prepostMining	0.123	0.016	0.004	0.002	0.001	0.001	0.001	0.001
PercDev	0.458	0.562	0.482	0.421	0.454	0.389	0.392	0.274
Species 1	*Sprengelia.incarnata*	*Lepidosperma.filiforme..urophorum.complex*	*Caesia.parviflora.var..parviflora*	*Tetraria.capillaris*	*Grevillea.oleoides*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Lepidosperma.limicola*
Species 2	*Lepidosperma.filiforme..urophorum.complex*	*Caesia.parviflora.var..parviflora*	*Lepidosperma.filiforme..urophorum.complex*	*Caesia.parviflora.var..parviflora*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Almaleea.paludosa*	*Caesia.parviflora.var..parviflora*
Species 3	*Banksia.oblongifolia*	*Banksia.paludosa*	*Tetraria.capillaris*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Lepidosperma.limicola*	*Lepidosperma.limicola*	*Epacris.obtusifolia*
Species 4	*Tetraria.capillaris*	*Tetraria.capillaris*	*Banksia.paludosa*	*Lepidosperma.filiforme..urophorum.complex*	*Tetraria.capillaris*	*Grevillea.oleoides*	*Epacris.obtusifolia*	*Almaleea.paludosa*
Species 5	*Goodenia.hederacea..heterophylla.Sp_.complex*	*Banksia.oblongifolia*	*Banksia.oblongifolia*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Banksia.paludosa*	*Epacris.obtusifolia*	*Boronia.parviflora*	*Grevillea.oleoides*

Table 35. Whether the 5 most influential species for each 2-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2014–2015	*Lepidosperma.filiforme..urophorum.complex*	No
	Caesia.parviflora.var..parviflora	No
	Banksia.paludosa	Yes
	Tetraria.capillaris	No
	Banksia.oblongifolia	No
2015–2016	*Caesia.parviflora.var..parviflora*	No
	Lepidosperma.filiforme..urophorum.complex	No
	Tetraria.capillaris	No
	Banksia.paludosa	Yes
	Banksia.oblongifolia	No
2016–2017	*Tetraria.capillaris*	No
	Caesia.parviflora.var..parviflora	No
	Grevillea.patulifolia.sericea.speciosa.complex	Yes
	Lepidosperma.filiforme..urophorum.complex	No
	Mitrasacme.polymorpha..pilosa.species.complex	Yes
2017–2018	*Grevillea.oleoides*	No
	Grevillea.patulifolia.sericea.speciosa.complex	Yes
	Mitrasacme.polymorpha..pilosa.species.complex	Yes
	Tetraria.capillaris	No
	Banksia.paludosa	Yes
2018–2019	*Mitrasacme.polymorpha..pilosa.species.complex*	Yes
	Grevillea.patulifolia.sericea.speciosa.complex	Yes
	Lepidosperma.limicola	Yes
	Grevillea.oleoides	No
	Epacris.obtusifolia	Yes
2019–2020	*Mitrasacme.polymorpha..pilosa.species.complex*	Yes
	Almaleea.paludosa	Yes
	Lepidosperma.limicola	Yes

Year	Species	More common before
	Epacris.obtusifolia	Yes
	Boronia.parviflora	Yes
2020–2021	*Lepidosperma.limicola*	Yes
	Caesia.parviflora.var..parviflora	No
	Epacris.obtusifolia	Yes
	Almaleea.paludosa	Yes
	Grevillea.oleoides	No

Table 36. Species composition at swamp S1B based on data pooled for 3-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2013–2015	2014–2016	2015–2017	2016–2018	2017–2019	2018–2020	2019–2021
prepostMining	0.019	0.003	0.001	0.002	0.001	0.001	0.001
PercDev	0.466	0.510	0.446	0.412	0.370	0.357	0.313
Species 1	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Lepidosperma.limicola*
Species 2	*Caesia.parviflora.var..parviflora*	*Caesia.parviflora.var..parviflora*	*Caesia.parviflora.var..parviflora*	*Tetraria.capillaris*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Lepidosperma.limicola*	*Epacris.obtusifolia*
Species 3	*Sprengelia.incarnata*	*Tetraria.capillaris*	*Tetraria.capillaris*	*Grevillea.oleoides*	*Grevillea.oleoides*	*Epacris.obtusifolia*	*Mitrasacme.polymorpha..pilosa.species.complex*
Species 4	*Banksia.oblongifolia*	*Banksia.paludosa*	*Banksia.paludosa*	*Caesia.parviflora.var..parviflora*	*Lepidosperma.limicola*	*Almaleea.paludosa*	*Almaleea.paludosa*
Species 5	*Tetraria.capillaris*	*Banksia.oblongifolia*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Epacris.obtusifolia*	*Caesia.parviflora.var..parviflora*	*Caesia.parviflora.var..parviflora*

Table 37. Whether the 5 most influential species for each 3-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2013–2015	*Lepidosperma.filiforme..urophorum.complex*	No
	Caesia.parviflora.var..parviflora	No
	Sprengelia.incarnata	Yes
	Banksia.oblongifolia	No
	Tetraria.capillaris	No
2014–2016	*Lepidosperma.filiforme..urophorum.complex*	No
	Caesia.parviflora.var..parviflora	No
	Tetraria.capillaris	No
	Banksia.paludosa	Yes
	Banksia.oblongifolia	No
2015–2017	*Lepidosperma.filiforme..urophorum.complex*	No
	Caesia.parviflora.var..parviflora	No
	Tetraria.capillaris	No
	Banksia.paludosa	Yes
	Grevillea.patulifolia.sericea.speciosa.complex	Yes
2016–2018	*Grevillea.patulifolia.sericea.speciosa.complex*	Yes
	Tetraria.capillaris	No
	Grevillea.oleoides	No
	Caesia.parviflora.var..parviflora	No
	Mitrasacme.polymorpha..pilosa.species.complex	Yes
2017–2019	*Mitrasacme.polymorpha..pilosa.species.complex*	Yes
	Grevillea.patulifolia.sericea.speciosa.complex	Yes
	Grevillea.oleoides	No
	Lepidosperma.limicola	Yes
	Epacris.obtusifolia	Yes
2018–2020	*Mitrasacme.polymorpha..pilosa.species.complex*	Yes
	Lepidosperma.limicola	Yes
	Epacris.obtusifolia	Yes

Year	Species	More common before
	Almaleea.paludosa	Yes
	Caesia.parviflora.var..parviflora	No
2019–2021	*Lepidosperma.limicola*	Yes
	Epacris.obtusifolia	Yes
	Mitrasacme.polymorpha..pilosa.species.complex	Yes
	Almaleea.paludosa	Yes
	Caesia.parviflora.var..parviflora	No

Table 38. Species composition at swamp S1B based on data pooled for 4-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2013–2016	2014–2017	2015–2018	2016–2019	2017–2020	2018–2021
prepostMining	0.002	0.001	0.001	0.001	0.001	0.001
PercDev	0.455	0.473	0.404	0.346	0.347	0.326
Species 1	*Caesia.parviflora.var..parviflora*	*Lepidosperma.filiforme..urophorum.complex*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Lepidosperma.limicola*
Species 2	*Lepidosperma.filiforme..urophorum.complex*	*Caesia.parviflora.var..parviflora*	*Caesia.parviflora.var..parviflora*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Lepidosperma.limicola*	*Mitrasacme.polymorpha..pilosa.species.complex*
Species 3	*Tetraria.capillaris*	*Tetraria.capillaris*	*Tetraria.capillaris*	*Banksia.paludosa*	*Epacris.obtusifolia*	*Epacris.obtusifolia*
Species 4	*Sprengelia.incarnata*	*Banksia.paludosa*	*Lepidosperma.filiforme..urophorum.complex*	*Caesia.parviflora.var..parviflora*	*Almaleea.paludosa*	*Grevillea.oleoides*
Species 5	*Goodenia.hedercacea..heterophylla.Sp_.complex*	*Banksia.oblongifolia*	*Banksia.paludosa*	*Tetraria.capillaris*	*Banksia.paludosa*	*Grevillea.patulifolia.sericea.speciosa.complex*

Table 39. Whether the 5 most influential species for each 4-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2013–2016	*Caesia.parviflora.var..parviflora*	No
	Lepidosperma.filiforme..urophorum.complex	No
	Tetraria.capillaris	No
	Sprengelia.incarnata	Yes
	Goodenia.hedercacea..heterophylla.Sp_.complex	Yes
2014–2017	*Lepidosperma.filiforme..urophorum.complex*	No
	Caesia.parviflora.var..parviflora	No
	Tetraria.capillaris	No
	Banksia.paludosa	Yes
	Banksia.oblongifolia	No
2015–2018	*Grevillea.patulifolia.sericea.speciosa.complex*	Yes
	Caesia.parviflora.var..parviflora	No
	Tetraria.capillaris	No
	Lepidosperma.filiforme..urophorum.complex	No
	Banksia.paludosa	Yes
2016–2019	*Grevillea.patulifolia.sericea.speciosa.complex*	Yes
	Mitrasacme.polymorpha..pilosa.species.complex	Yes
	Banksia.paludosa	Yes
	Caesia.parviflora.var..parviflora	No
	Tetraria.capillaris	No
2017–2020	*Mitrasacme.polymorpha..pilosa.species.complex*	Yes
	Lepidosperma.limicola	Yes
	Epacris.obtusifolia	Yes
	Almaleea.paludosa	Yes
	Banksia.paludosa	Yes
2018–2021	*Lepidosperma.limicola*	Yes
	Mitrasacme.polymorpha..pilosa.species.complex	Yes

Year	Species	More common before
	Epacris.obtusifolia	Yes
	Grevillea.oleoides	No
	Grevillea.patulifolia.sericea.speciosa.complex	Yes

Table 40. Species composition at swamp S1B based on data pooled for 5-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2013-2017	2014-2018	2015-2019	2016-2020	2017-2021
prepostMining	0.002	0.001	0.001	0.001	0.001
PercDev	0.442	0.416	0.349	0.331	0.335
Species 1	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Caesia.parviflora.var..parviflora*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Mitrasacme.polymorpha..pilosa.species.complex*
Species 2	*Caesia.parviflora.var..parviflora*	*Caesia.parviflora.var..parviflora*	*Banksia.paludosa*	*Caesia.parviflora.var..parviflora*	*Lepidosperma.limicola*
Species 3	*Tetraria.capillaris*	*Banksia.paludosa*	*Mitrasacme.polymorpha..pilosa.species.complex*	*Banksia.paludosa*	*Epacris.obtusifolia*
Species 4	*Sprengelia.incarnata*	*Tetraria.capillaris*	*Tetraria.capillaris*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Grevillea.patulifolia.sericea.speciosa.complex*
Species 5	*Banksia.paludosa*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Lepidosperma.limicola*	*Grevillea.oleoides*

Table 41. Whether the 5 most influential species for each 5-year-pooled-data comparison of species composition were more or less common prior to the impact.

Year	Species	More common before
2013–2017	*Lepidosperma.filiforme..urophorum.complex*	No
	Caesia.parviflora.var..parviflora	No
	Tetraria.capillaris	No
	Sprengelia.incarnata	Yes
	Banksia.paludosa	Yes
2014–2018	*Lepidosperma.filiforme..urophorum.complex*	No
	Caesia.parviflora.var..parviflora	No
	Banksia.paludosa	Yes
	Tetraria.capillaris	No
	Grevillea.patulifolia.sericea.speciosa.complex	Yes
2015–2019	*Caesia.parviflora.var..parviflora*	No
	Banksia.paludosa	Yes
	Mitrasacme.polymorpha..pilosa.species.complex	Yes
	Tetraria.capillaris	No
	Lepidosperma.filiforme..urophorum.complex	No
2016–2020	*Mitrasacme.polymorpha..pilosa.species.complex*	Yes
	Caesia.parviflora.var..parviflora	No
	Banksia.paludosa	Yes
	Grevillea.patulifolia.sericea.speciosa.complex	Yes
	Lepidosperma.limicola	Yes
2017–2021	*Mitrasacme.polymorpha..pilosa.species.complex*	Yes
	Lepidosperma.limicola	Yes
	Epacris.obtusifolia	Yes
	Grevillea.patulifolia.sericea.speciosa.complex	Yes
	Grevillea.oleoides	No

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9 Results - Swamp S5

Monitoring of S5 commenced in 2012, and mining within the RMZ commenced in 2013. A total of 48 unique species were detected, of which 10% were detected only once.

Comparisons of species composition as calculated from pooled data for 2-year, 3-year, 4-year and 5-year consecutive periods were not found to be statistically significant at this swamp (Tables 42, 43, 45 and 45, respectively).

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Table 42. Species composition at swamp S5 based on data pooled for 2-year periods. The p-value for PrePostMining and the percentage of deviance explained by the five most influential species are shown.

	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021
prepostMining	0.511	0.947	0.876	0.765	0.627	0.824	0.651	0.705
PercDev	0.597	0.602	0.685	0.722	0.706	0.637	0.571	0.566
Species 1	*Grevillea.oleoides*	*Acacia.rubida*	*Acacia.rubida*	*Banksia.robur*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Acacia.rubida*	*Grevillea.oleoides*	*Acacia.rubida*
Species 2	*Grevillea.patulifolia.sericea.speciosa.complex*	*Grevillea.sphacelata*	*Epacris.obtusifolia*	*Lepidosperma.filiforme..urophorum.complex*	*Banksia.robur*	*Cassytha.glabella..pubescens.sp.complex*	*Drosera.spatulata*	*Cassytha.glabella..pubescens.sp.complex*
Species 3	*Grevillea.sphacelata*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Acacia.rubida*	*Acacia.rubida*	*Banksia.robur*	*Goodenia.dimorpha..stelligera..bellidifolia.sp.complex*	*Epacris.obtusifolia*
Species 4	*Lepidosperma.filiforme..urophorum.complex*	*Grevillea.oleoides*	*Banksia.robur*	*Epacris.obtusifolia*	*Cassytha.glabella..pubescens.sp.complex*	*Baumea.articulata..rubiginosa..teretifolia.sp..Chorizandra.cymbaria..sphaerocephalum.species.complex*	*Acacia.rubida*	*Leptospermum.juniperinum*
Species 5	*Baeckea.diosmifolia*	*Lepidosperma.filiforme..urophorum.complex*	*Grevillea.oleoides*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Epacris.obtusifolia*	*Caesia.parviflora.var..parviflora*	*Cassytha.glabella..pubescens.sp.complex*	*Banksia.robur*

Table 43. Species composition at swamp S5 based on data pooled for 3-year periods. The p-value for PrePostMining and the percentage of deviance explained by the five most influential species are shown.

	2013–2015	2014–2016	2015–2017	2016–2018	2017–2019	2018–2020	2019–2021
prepostMining	0.589	0.936	0.964	0.818	0.867	0.890	0.906
PercDev	0.534	0.595	0.728	0.761	0.676	0.555	0.560
Species 1	*Grevillea.oleoides*	*Lepidosperma.filiforme..urophorum.complex*	*Banksia.robur*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Banksia.robur*	*Banksia.robur*	*Caesia.parviflora.var..parviflora*
Species 2	*Grevillea.sphacelata*	*Grevillea.sphacelata*	*Lepidosperma.filiforme..urophorum.complex*	*Banksia.robur*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Caesia.parviflora.var..parviflora*	*Banksia.robur*
Species 3	*Grevillea.patulifolia.sericea.speciosa.complex*	*Grevillea.oleoides*	*Caesia.parviflora.var..parviflora*	*Lepidosperma.filiforme..urophorum.complex*	*Caesia.parviflora.var..parviflora*	*Goodenia.dimorpha..stelligera..bellidifolia.sp.complex*	*Leptospermum.juniperinum*
Species 4	*Banksia.robur*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Caesia.parviflora.var..parviflora*	*Epacris.obtusifolia*	*Epacris.obtusifolia*	*Epacris.obtusifolia*
Species 5	*Acacia.rubida*	*Banksia.robur*	*Drosera.binata*	*Drosera.binata*	*Lepidosperma.filiforme..urophorum.complex*	*Baumea.articulata..rubiginosa..teretifolia.sp..Chorizandra.cymbaria..sphaerocephalum.species.complex*	*Drosera.spatulata*

Table 44. Species composition at swamp S5 based on data pooled for 4-year periods. The p-value for PrePostMining and the percentage of deviance explained by the five most influential species are shown.

	2013–2016	2014–2017	2015–2018	2016–2019	2017–2020	2018–2021
prepostMining	0.547	0.942	0.924	0.845	0.908	0.913
PercDev	0.632	0.625	0.708	0.648	0.589	0.581
Species 1	*Grevillea.oleoides*	*Lepidosperma.filiforme.. urophorum.complex*	*Banksia.robur*	*Banksia.robur*	*Banksia.robur*	*Banksia.robur*
Species 2	*Lepidosperma.filiforme.. urophorum.complex*	*Grevillea.patulifolia.seric ea.speciosa.complex*	*Grevillea.patulifolia.seric ea.speciosa.complex*	*Epacris.obtusifolia*	*Caesia.parviflora.var..pa rviflora*	*Caesia.parviflora.var..pa rviflora*
Species 3	*Grevillea.sphacelata*	*Banksia.robur*	*Lepidosperma.filiforme.. urophorum.complex*	*Grevillea.patulifolia.seric ea.speciosa.complex*	*Epacris.obtusifolia*	*Epacris.obtusifolia*
Species 4	*Grevillea.patulifolia.seric ea.speciosa.complex*	*Grevillea.sphacelata*	*Caesia.parviflora.var..pa rviflora*	*Lepidosperma.filiforme.. urophorum.complex*	*Grevillea.patulifolia.seric ea.speciosa.complex*	*Leptospermum.juniperin um*
Species 5	*Acacia.rubida*	*Caesia.parviflora.var..pa rviflora*	*Drosera.binata*	*Caesia.parviflora.var..pa rviflora*	*Lepidosperma.filiforme.. urophorum.complex*	*Baumea.articulata..rubigi nosa..teretifolia.sp..Chori zandra.cymbaria..sphaer ocephalum.species.com plex*

Table 45. Species composition at swamp S5 based on data pooled for 5-year periods. The p-value for PrePostMining and the percentage of deviance explained by the five most influential species are shown.

	2013–2017	2014–2018	2015–2019	2016–2020	2017–2021
prepostMining	0.575	0.913	0.901	0.855	0.919
PercDev	0.574	0.631	0.642	0.596	0.625
Species 1	*Grevillea.patulifolia.sericea.speciosa.complex*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Banksia.robur*	*Banksia.robur*	*Banksia.robur*
Species 2	*Lepidosperma.filiforme..urophorum.complex*	*Banksia.robur*	*Epacris.obtusifolia*	*Epacris.obtusifolia*	*Caesia.parviflora.var..parviflora*
Species 3	*Grevillea.oleoides*	*Lepidosperma.filiforme..urophorum.complex*	*Caesia.parviflora.var..parviflora*	*Caesia.parviflora.var..parviflora*	*Epacris.obtusifolia*
Species 4	*Acacia.rubida*	*Epacris.obtusifolia*	*Lepidosperma.filiforme..urophorum.complex*	*Cassytha.glabella..pubescens.sp.complex*	*Grevillea.patulifolia.sericea.speciosa.complex*
Species 5	*Grevillea.sphacelata*	*Caesia.parviflora.var..parviflora*	*Grevillea.patulifolia.sericea.speciosa.complex*	*Lepidosperma.filiforme..urophorum.complex*	*Baumea.articulata..rubiginosa..teretifolia.sp..Chorizandra.cymbaria..sphaerocephalum.species.complex*

10 Results - Swamp S23

Monitoring of S23 commenced in 2017, and mining within the RMZ commenced in 2018. A total of 47 unique species were detected, of which 17% were detected only once.

Comparisons of species composition, as calculated from pooled data for both 2-year and 3-year periods, were not found to be statistically significant at this swamp (Tables 46 and 47, respectively).

Table 46. Species composition at swamp S23 based on data pooled for 2-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2018–2019	2019–2020	2020–2021
prepostMining	0.729	0.573	0.436
PercDev	0.617	0.627	0.540
Species 1	*Acacia.rubida*	*Acacia.rubida*	*Acacia.rubida*
Species 2	*Schoenus.brevifolius..lepidosperma.sp.complex*	*Baeckea.imbricata*	*Baeckea.imbricata*
Species 3	*Baeckea.linifolia*	*Lomandra.cylindrica..filiformis..micrantha.sp.complex*	*Lepidosperma.filiforme..urophorum.complex*
Species 4	*Pteridium.esculentum*	*Pteridium.esculentum*	*Lomandra.cylindrica..filiformis..micrantha.sp.complex*
Species 5	*Caesia.parviflora.var..parviflora*	*Baeckea.linifolia*	*Pteridium.esculentum*

Table 47. Species composition at swamp S23 based on data pooled for 3-year periods. The p-value for PrePostMining and the percentage of deviance explained by the 5 most influential species are shown.

	2018–2020	2019–2021
prepostMining	0.741	0.467
PercDev	0.620	0.637
Species 1	*Acacia.rubida*	*Acacia.rubida*
Species 2	*Pteridium.esculentum*	*Baeckea.imbricata*
Species 3	*Baeckea.linifolia*	*Lomandra.cylindrica..filiformis..micrantha.sp.complex*
Species 4	*Lomandra.cylindrica..filiformis..micrantha.sp.complex*	*Pteridium.esculentum*
Species 5	*Baeckea.imbricata*	*Baeckea.linifolia*

11 Discussion

- This analysis tested whether species composition at impact swamps prior to impact was significantly different to a select set of years post-impact. The set of years post-impact varied depending on the time period being assessed: data were pooled and analysed for 2-, 3-, and 4-consecutive-year periods between impact and final year of monitoring (2021), and, for swamps in area 3B, pooled data from 5-consecutive-year periods were also investigated where applicable. This differs from the TSR analysis, whereby differences in species richness were tested against a set of control swamps. Therefore, some swamps may have statistically significant differences in species composition (before compared with after impact), but not in the TSR analysis (before-after control-impact).

- Some swamps have short pre-impact monitoring periods – e.g., swamps S14, S1A, S5 and S23. As per last reporting period, no yearly comparisons at these 4 swamps were found to be statistically significant for species composition. In future, further analyses should be undertaken that omit pre-impact data and investigate yearly trends post-impact.

- As per last reporting period, statistically significant differences between pre and post impacts were found at Swamp S15A(2), S15B, S13, S1B for both TSR and species composition.

- As per last reporting period, at S11, species composition (but not TSR) was found to be statistically different pre and post impact

- As per last reporting period, at S1A and S23, species composition was not found to be statistically different pre and post impact, but TSR was (but see note above).
- As per last reporting period, at S14 and S5, no differences in species composition or TSR were found.

12 References

R Core Team (2022). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.

Wang, Y., Naumann, U., Eddelbuettel, D., Wilshire, J. and D. Warton (2022). *mvabund: Statistical Methods for Analysing Multivariate Abundance Data*. R package version 4.2.1.

Warton, D. I., S. T. Wright, and Y. Wang (2012). Distance-based multivariate analyses confound location and dispersion effects. *Methods in Ecology and Evolution*, 3(1): 89-101

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THE ANALYTICAL EDGE
STATISTICAL CONSULTING

Task 2A - Breakpoint analysis of total flora species richness at swamps within the Dendrobium region

Data collected up to and including 2021

Final

28 March 2022

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Table of Contents

Project History and Version Control

Date	Amendments	Person
9 March 2022	Received revised data from Sian Griffiths (Niche).	JP
22 March 2022	Draft report submitted to Sian Griffiths (Niche).	JP

1 Data Summary

On 9 March 2022, The Analytical Edge (hereafter, TAE) received a revised data set from Sian Griffiths (Niche) via e-mail. It contained data collected during flora swamp monitoring within the Dendrobium region up to and including 2021 (‘*dendrobium_flora_annual_monitoring-2022-02-24_DW Edit.xlsx*’, 18.7 MB). Many species names and complexes had been revised since the previous analysis.

All data relating to swamp S1 were omitted from the analysis.

Errors:

(1) A total of 78 records were missing species-level information (29 and 49 records in 2020 and 2021, respectively). Also, 12 records were referred to as either ‘QUADRAT IS DEAD’ or ‘QUADRAT DEAD’. These were excluded from the analysis. There errors were referred to Sian for correction in the parent database.

(2) For impact sites S11 and S15A(2) when PrePost=Pre (i.e., prior to impact), the treatment was listed as ‘control’. These records were changed manually to ‘impact’ sites, and referred to Sian for correction in the parent database.

(3) Swamp11-V1 in spring 2021 was incorrectly labelled Swamp1-V1 in the data set. These records were changed manually and referred to Sian for correction in the parent database.

(4) One species complex (*Blandfordia Burchardia Caladenia Haemodorum Microtis Thelymitra* species complex) occasionally had an additional space after the record (i.e., ‘*Blandfordia Burchardia Caladenia Haemodorum Microtis Thelymitra* species complex ’). These records were changed manually and referred to Sian for correction in the parent database.

Disclaimer: Excluding the corrections mentioned above, this data file is assumed to be error-free. Any further errors detected by Niche may invalidate the results and conclusions made in this report and will require the analysis to be re-run under the proviso of new contract agreements.

2 Methods

To date, analysis of total species richness (TSR) data has been undertaken in a series of 2-, 3-, and 4- yearly comparisons. Conducting multiple testing such as this can lead to erroneous interpretation of results; through statistical chance alone, 5% of tests may be concluded significant, and this chance is elevated when multiple tests are conducted. Methods exist for multiple correction (e.g., Holm 1979) but this will decrease the power to detect a difference, if one exists.

In addition, this approach doesn't identify any significant 'change points' that might exist in the data – namely, knowledge about when the impact occurred and whether that impact date caused a change in the trajectory of TSR at each swamp. TAE has previously proposed alternative methods to analyse these data (e.g., using a broken-stick approach, Muggeo 2003; Muggeo 2017), and this method is explored in this report.

In a broken-stick model with a single breakpoint, the data are essentially split into two time series: one prior to and one after the breakpoint. A linear model is fit to each portion of the data (i.e., one linear model is fit to the data subset prior to the breakpoint, and one linear model is fit to the data subset after the breakpoint). The placement of the breakpoint is optimized to ensure the error for the fitted models within each segment of the data is minimal. As the number of breakpoints fit to the data is increased, so too is the number of linear models. That is, two breakpoints create three separate linear models (one before the first breakpoint, one between the first and second breakpoints, and one after the second breakpoint). The number of breakpoints fit to the data is a model selection issue, here based on Akaike's Information Criterion (AIC, Buckland et al. 1997).

Once the final model of breakpoints is determined, the statistical significance of the linear models for each segment can then be explored. Here, the gradient of each segment is reported, along with statistical significance based on 95% confidence intervals.

All analyses were conducted in R (v. 4.1.2, R Core Team 2022), using the 'segmented' packaged (v 1.4-0, Muggeo, 2008).

3 Results - Swamp S15A(2)

Monitoring at swamp S15A(2) began in 2009, and this swamp was impacted in 2013. The boxplot of TSR data (Figure 1) shows that prior to impact, the pre-mining TSR was variable but roughly equivalent to the TSR post-mining up until 2017, after which TSR began to decline to lower levels than those recorded before impact.

From the breakpoint analysis, the best model based on AIC model selection (see Table 1) had 2 breakpoints and was plotted against the underlying data and fitted linear regression model (Figure 2(A)). However, model selection uncertainty was high, and the second-best fitting model was also plotted (dAIC = 1.39, Figure 2(B)).

The first breakpoint identified corresponds to when the impact occurred, suggesting that the TSR initially increased at the swamp, and then decreased after 2016. Estimates of the breakpoint analysis slope parameters are given in Table 2. Only slope 3 (post-impact decline in TSR) was found to be significantly different to 0. This suggests that prior to 2017, the change in TSR at this swamp was not significantly different from 0 (i.e., stable), and any identified (statistically significant) breakpoints did not coincide with when the swamp was impacted.

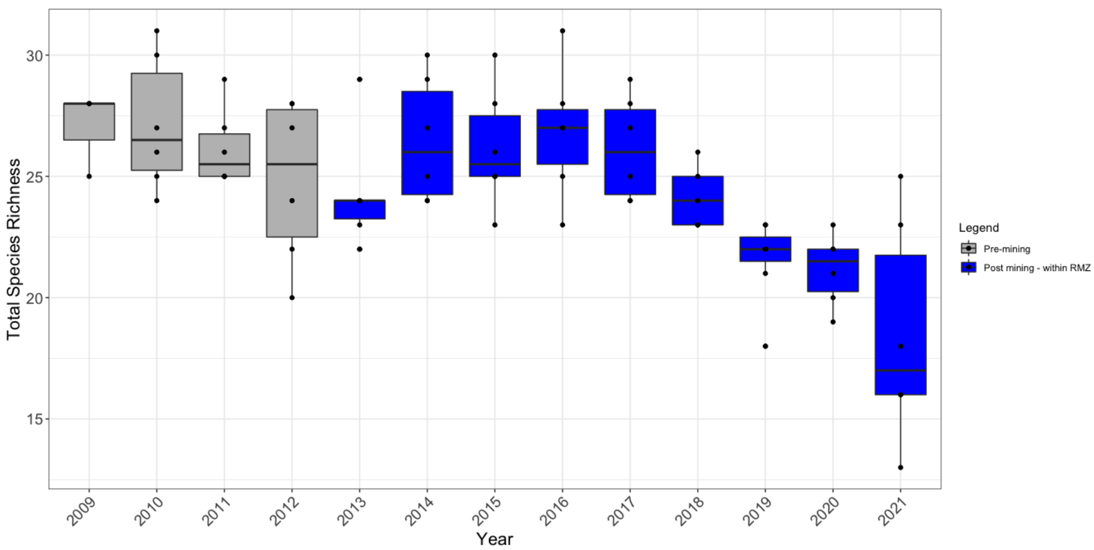

Figure 1. Boxplot of the total species richness for each transect at impact swamp S15A(2). The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

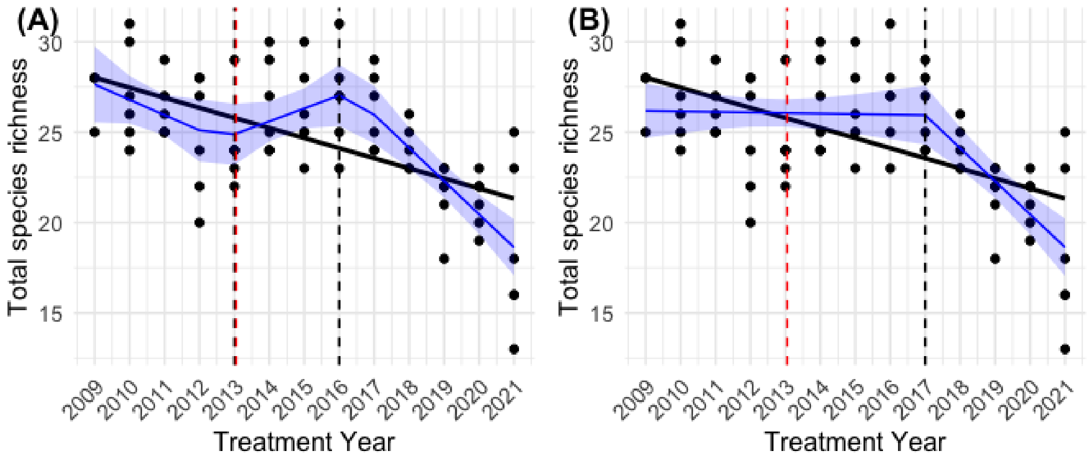

Figure 2. Best (A) and second-best (B) breakpoint analysis as determined by AIC model section (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 1. Summary of model fit.

Model	R-squared	AIC	dAIC
Two breakpoints	0.54	357.03	0.00
Single breakpoint	0.50	358.42	1.39
Linear model	0.33	376.50	19.47
Three breakpoints	NA	NA	NA

Table 2. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	-0.85	0.53	-1.90	0.20
Slope 2	0.72	0.45	-0.19	1.62
Slope 3	-1.84	0.32	-2.48	-1.19

4 Results - Swamp S15B

Monitoring at swamp S15B began in 2003, and this swamp was impacted in 2010. The boxplot of TSR data (Figure 3) shows that throughout the monitoring period, the pre-mining TSR was variable (with a wider minimum and maximum TSR observation) than post-mining TSR. Since impact, TSR at this swamp appears to have declined to lower levels than before impact.

From the breakpoint analysis, the best model based on AIC model selection (see Table 3) had 1 breakpoint and was plotted against the underlying data and fitted linear regression model (Figure 4).

Estimates of the breakpoint analysis slope parameters are given in Table 4. Only slope 2 was found to be significantly different to 0 (i.e., from 2005, TSR has been linearly declining). The breakpoint identified does not correspond to when the impact occurred, suggesting that TSR was declining at this swamp prior to impact, and this trajectory has not changed.

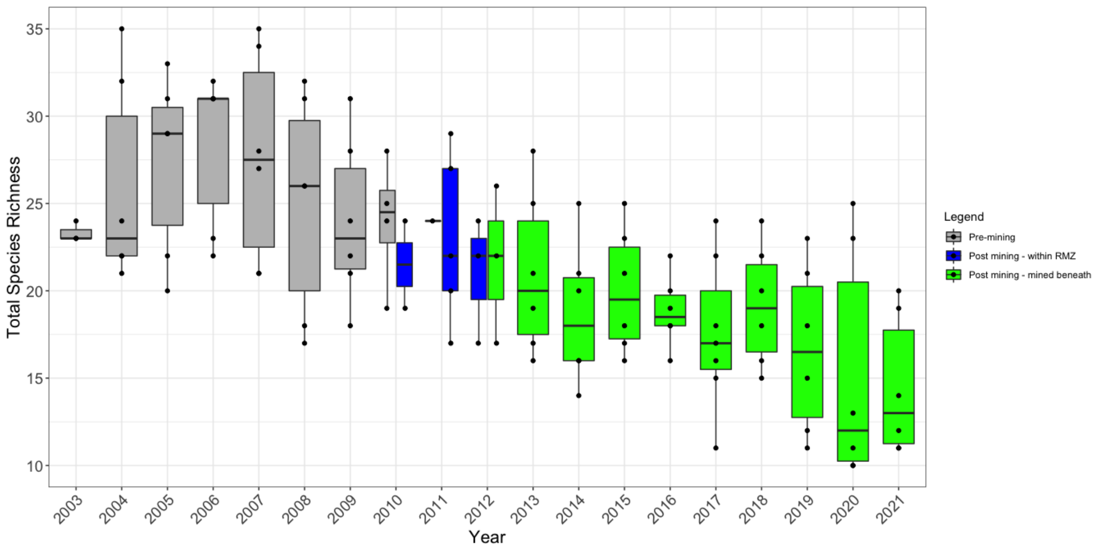

Figure 3. Boxplot of the total species richness for each transect at impact swamp S15B. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

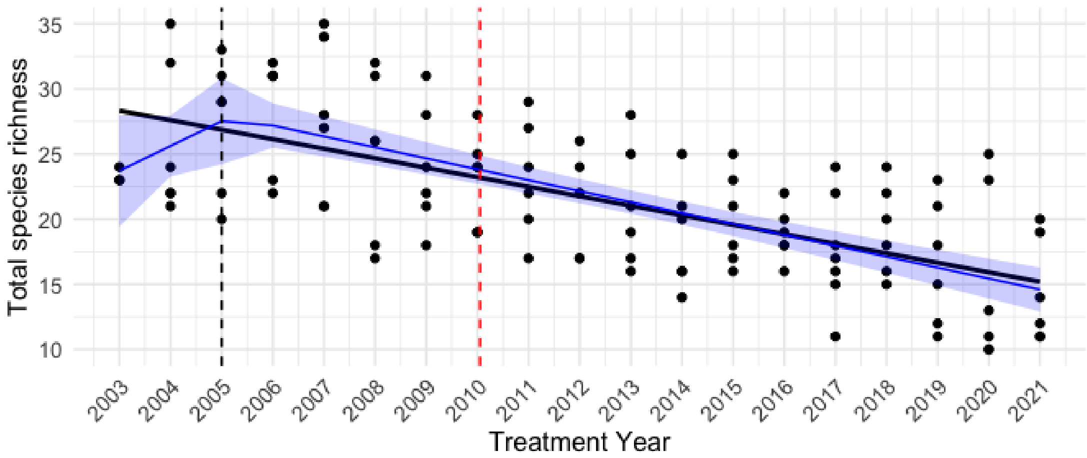

Figure 4. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 3. Summary of model fit.

Model	R-squared	AIC	dAIC
Single breakpoint	0.46	656.44	0.00
Linear model	0.43	658.62	2.18
Two breakpoints	0.47	658.98	2.54
Three breakpoints	0.47	662.32	5.88

Table 4. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	1.90	1.52	-1.12	4.92
Slope 2	-0.84	0.10	-1.03	-0.65

5 Results - Swamp S11

Monitoring at swamp S11 began in 2003, and this swamp was impacted in 2016. The boxplot of TSR data (Figure 5) shows that throughout the monitoring period, the pre-mining TSR was more variable (with a wider minimum and maximum TSR observation) than post-mining TSR. Immediately after impact (2016) TSR rose to the highest observations ever recorded at this swamp, but since 2017, TSR has been declining.

From the breakpoint analysis, the best model based on AIC model section (see Table 5) had 1 breakpoint and was plotted against the underlying data and fitted linear regression model (Figure 6). Models with more breakpoints did not converge.

Estimates of the breakpoint analysis slope parameters are given in Table 6. Both slopes were found to be significantly different to 0. This suggests prior to impact, the TSR at this swamp was declining; however the speed of the decline significantly increased after impact.

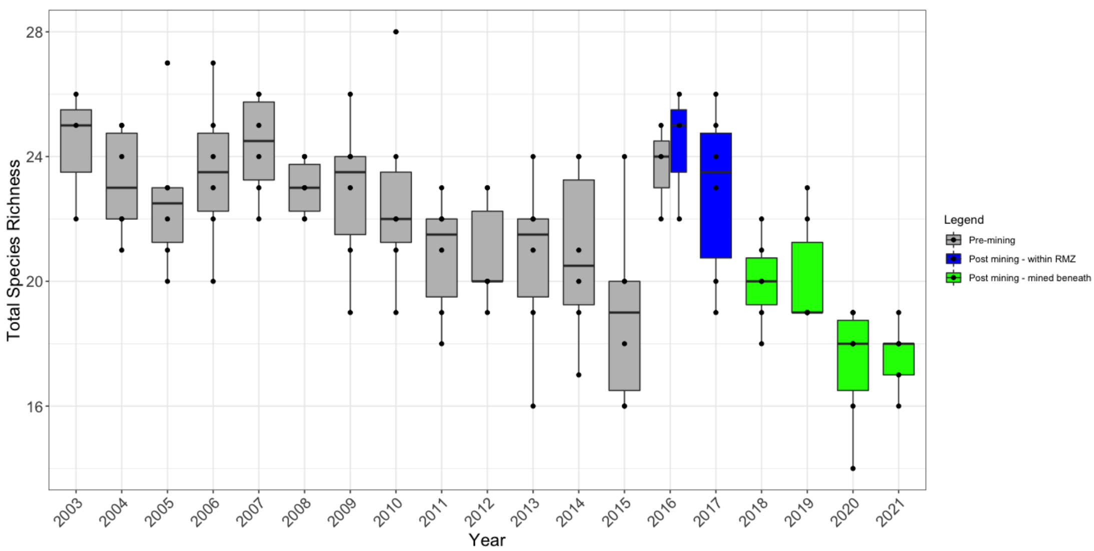

Figure 5. Boxplot of the total species richness for each transect at impact swamp S11. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

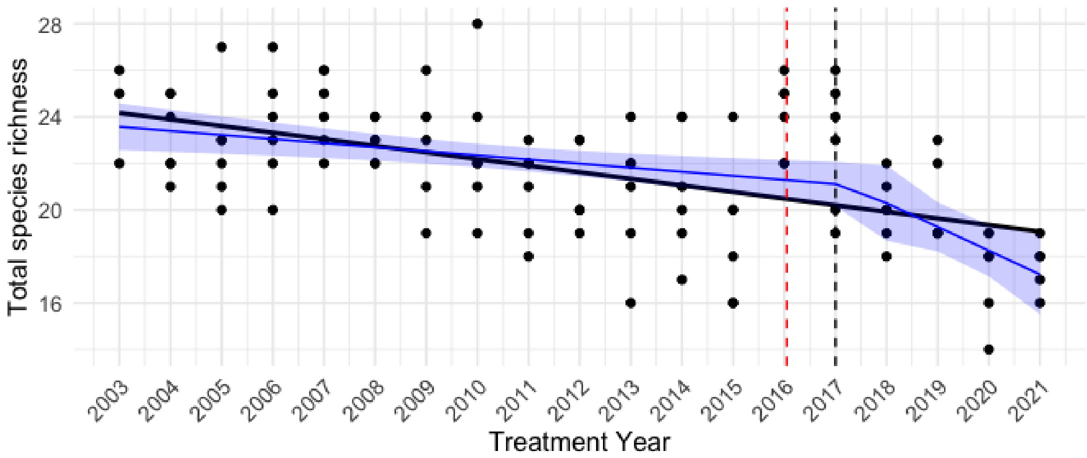

Figure 6. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 5. Summary of model fit.

Model	R-squared	AIC	dAIC
Single breakpoint	0.33	508.69	0.00
Linear model	0.28	512.92	4.23
Two breakpoints	NA	NA	NA
Three breakpoints	NA	NA	NA

Table 6. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	-0.18	0.06	-0.30	-0.05
Slope 2	-1.02	0.45	-1.92	-0.13

6 Results - Swamp S13

Monitoring at swamp S13 began in 2013, and this swamp was impacted in 2017. The boxplot of TSR data (Figure 7) shows that throughout the monitoring period, the pre-mining and post-mining TSR was variable. Prior to impact, TSR at this swamp was typically higher than post-mining, and post-impact, TSR has declined (although it has increased slightly in the last two years of monitoring – 2020 and 2021).

From the breakpoint analysis, the best model based on AIC model section (see Table 7) was the linear model (i.e., no breakpoints), however, model structure uncertainty was high, and the next best fitting model was also plotted (i.e., single breakpoint, Figure 8(B)).

The identified breakpoint did not correspond to the date of impact at this swamp. Estimates of the breakpoint analysis slope parameters are given in Table 8. Only slope 2 was found to be significantly different to 0. This suggests the linear declining trend in TSR at this swamp prior to impact did not change trajectory post-mining.

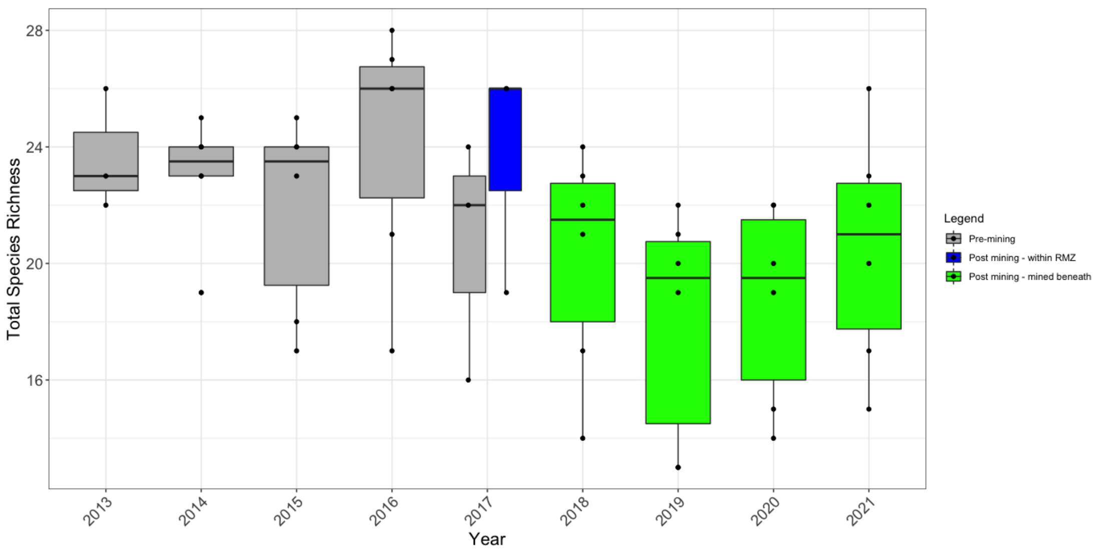

Figure 7. Boxplot of the total species richness for each transect at impact swamp S13. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

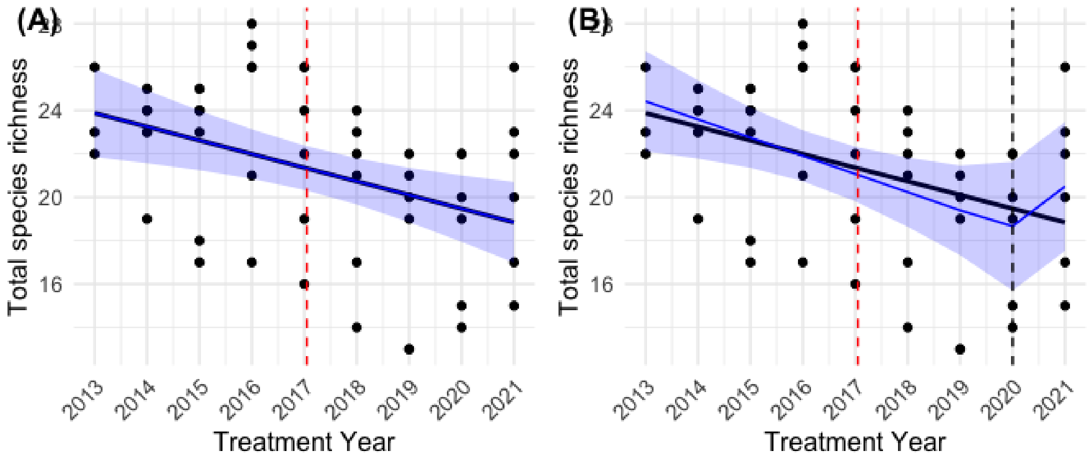

Figure 8. Best (A) and second-best (B) breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 7. Summary of model fit.

Model	R-squared	AIC	dAIC
Linear model	0.16	279.92	0.00
Single breakpoint	0.20	281.72	1.80
Two breakpoints	0.25	282.17	2.25
Three breakpoints	NA	NA	NA

Table 8. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	-0.84	0.31	-1.46	-0.22
Slope 2	1.83	2.09	-2.37	6.04

7 Results - Swamp S14

Monitoring at swamp S14 began in 2017, and this swamp was impacted in the same year. The boxplot of TSR data (Figure 9) shows that throughout the short monitoring period, the TSR at this swamp was variable and perhaps declining.

From the breakpoint analysis, the best model based on AIC model selection (see Table 9) was the linear model, i.e., had 0 breakpoints and was plotted against the underlying data and fitted linear regression model (Figure 10). Estimates of the breakpoint analysis slope parameters are given in Table 10. Slopes were found not to be significantly different to 0.

Please note, models testing for more breakpoints did not converge, and can be explored in the future as more data are collected.

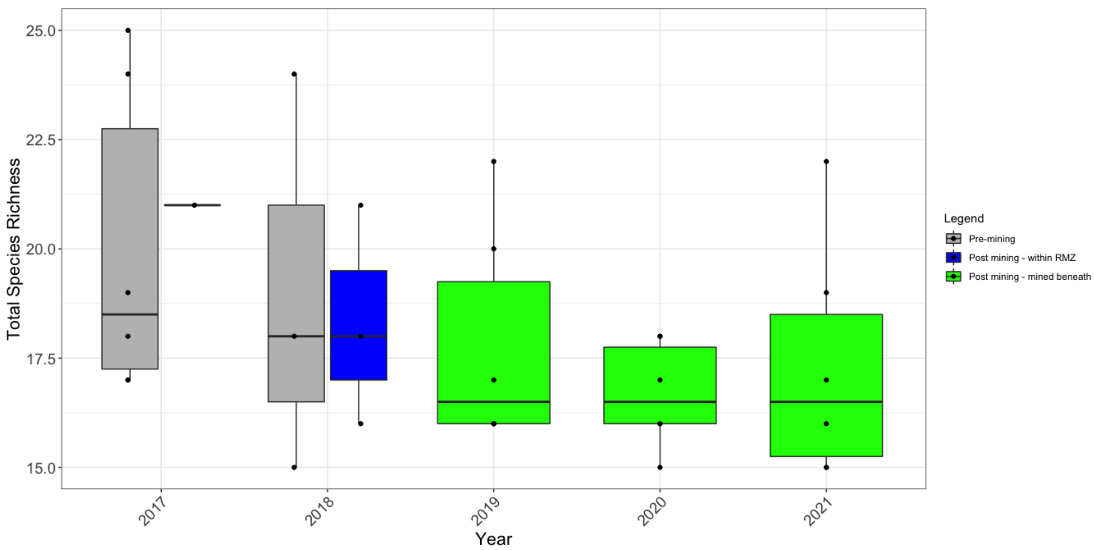

Figure 9. Boxplot of the total species richness for each transect at impact swamp S14. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

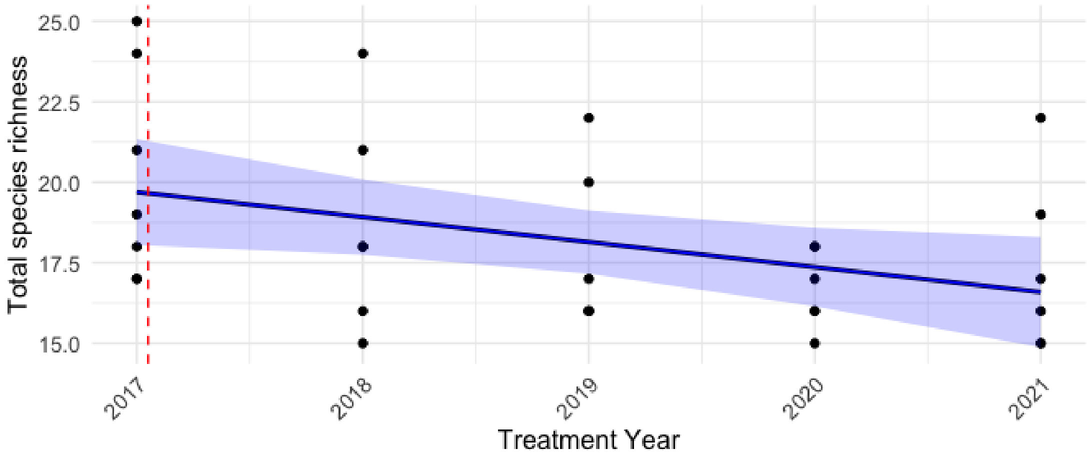

Figure 10. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 9. Summary of model fit.

Model	R-squared	AIC	dAIC
Linear model	0.16	152.73	0.00
Single breakpoint	0.19	155.47	2.74
Two breakpoints	NA	NA	NA
Three breakpoints	NA	NA	NA

Table 10. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	-1.16	0.75	-2.71	0.38
Slope 2	0.67	1.56	-2.54	3.88

8 Results - Swamp S1A

Monitoring at swamp S1A began in 2012, and this swamp was impacted in 2013. The boxplot of TSR data (Figure 11) shows that post-mining TSR was relatively stable, but some transects within the swamp declined. In 2014, immediately after impact, TSR at the impact swamp rose for transects that were mined within the RMZ, but TSR has declined progressively ever since.

From the breakpoint analysis, the best model based on AIC model selection (see Table 11) had 0 breakpoints (i.e., a linear trend) and was plotted against the underlying data (Figure 12). However, model selection uncertainty was high, and the second-best fitting model (which had a single breakpoint) was also plotted (dAIC = 1.39, Figure 2(B)).

Estimates of the breakpoint analysis slope parameters are given in Table 12. Slopes were found not to be significantly different to 0. The identified breakpoint in the second-best fitting model did not coincide with when the impact was known to occur, suggesting the linear decline in TSR at this swamp hasn't changed trajectory with the impact of mining.

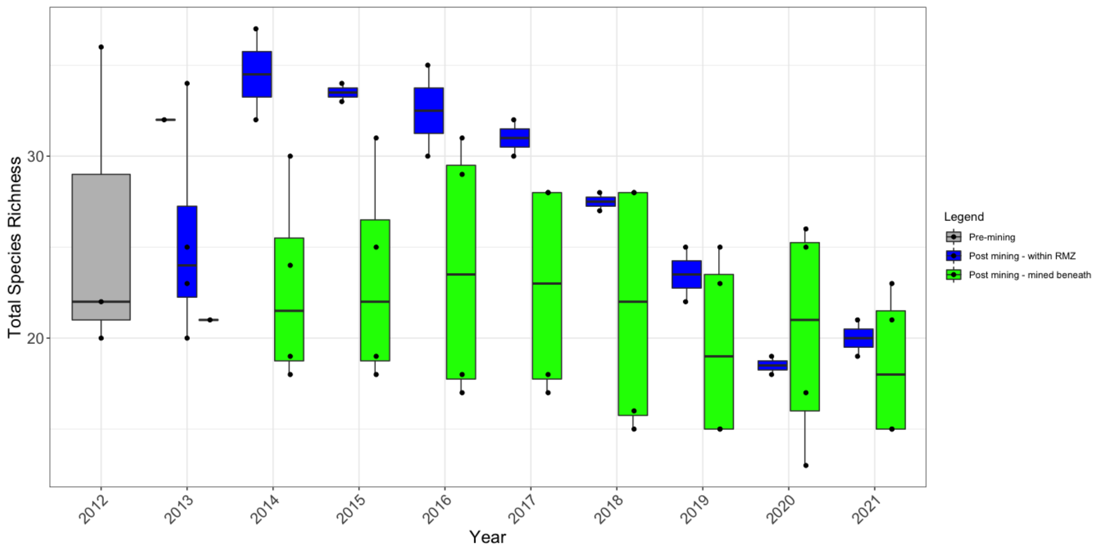

Figure 11. Boxplot of the total species richness for each transect at impact swamp S1A. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

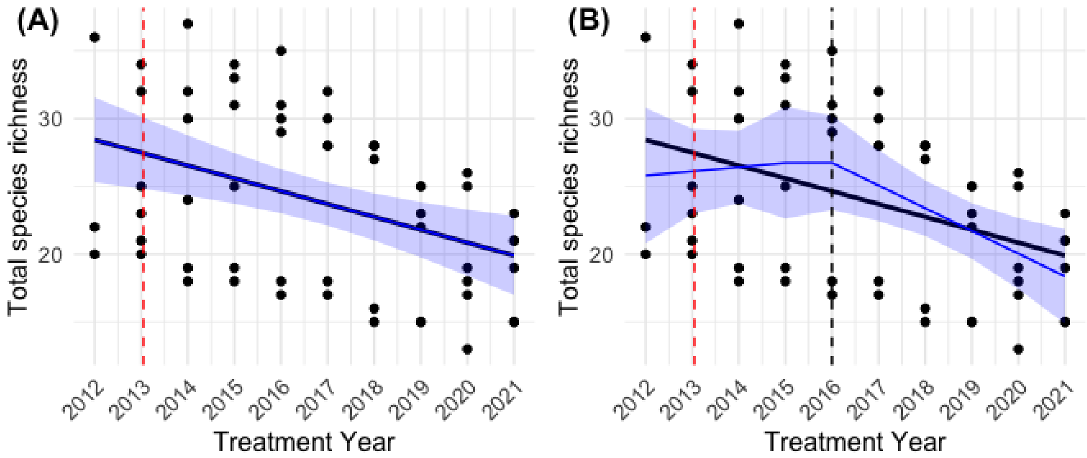

Figure 12. Best (A) and second-best (B) breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 11. Summary of model fit.

Model	R-squared	AIC	dAIC
Linear model	0.17	368.68	0.00
Single breakpoint	0.21	369.69	1.01
Two breakpoints	0.21	377.42	8.74
Three breakpoints	NA	NA	NA

Table 12. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	0.31	1.25	-2.19	2.82
Slope 2	-1.68	0.57	-2.83	-0.52

9 Results - Swamp S1B

Monitoring at swamp S1B began in 2005, and this swamp was impacted in 2013. Please note, this impact swamp was not monitored in 2010 and 2011. The boxplot of TSR data (Figure 13) shows that prior to impact, the pre-mining TSR was similar to post-mining TSR up until approximately 2016. Since 2016, TSR at this swamp appears to have declined to lower levels than before impact.

From the breakpoint analysis, the best model based on AIC model selection (see Table 13) had 1 breakpoint and was plotted against the underlying data and fitted linear regression model (Figure 14).

Estimates of the breakpoint analysis slope parameters are given in Table 14. Only slope 3 was found to be significantly different to 0, suggesting TSR at this swamp was relatively stable and the decline in TSR from 2016 does not coincide to when the impact occurred.

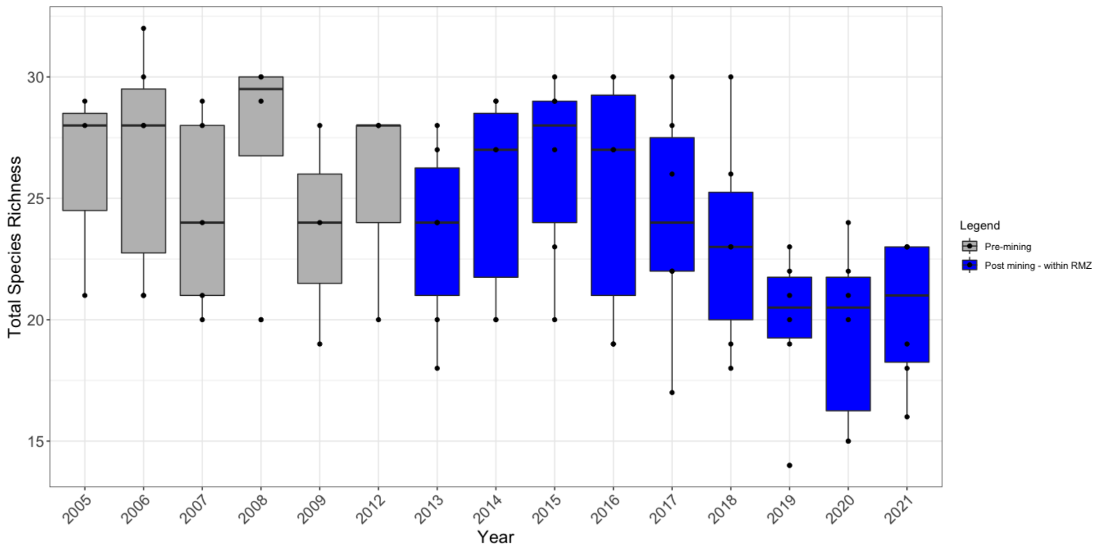

Figure 13. Boxplot of the total species richness for each transect at impact swamp S1B. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

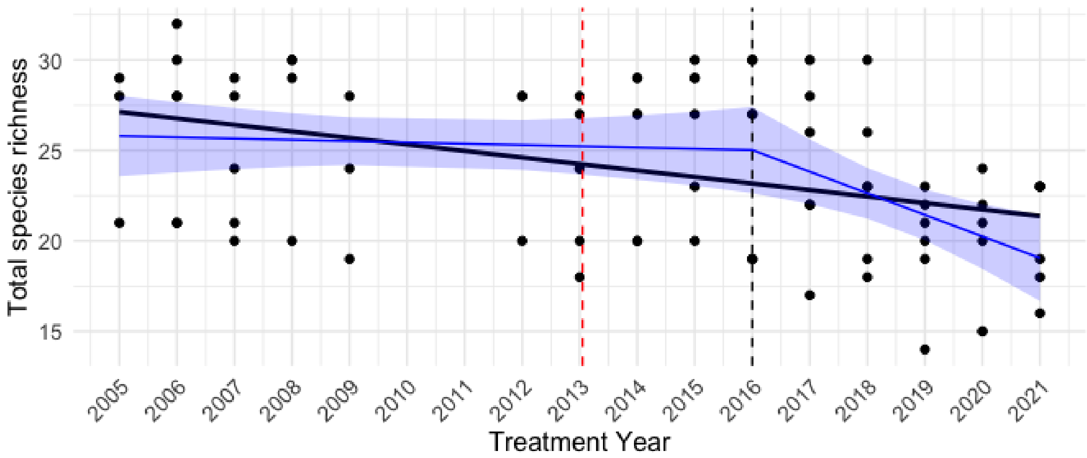

Figure 14. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 13. Summary of model fit.

Model	R-squared	AIC	dAIC
Single breakpoint	0.24	445.28	0.00
Two breakpoints	0.25	447.61	2.33
Linear model	0.16	448.77	3.49
Three breakpoints	0.27	450.10	4.82

Table 14. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	-0.07	0.17	-0.42	0.28
Slope 2	-1.19	0.39	-1.98	-0.41

10 Results - Swamp S5

Monitoring at swamp S5 began in 2012, and this swamp was impacted in 2013 (at a single transect). The boxplot of TSR data (Figure 15) shows that post impact, the TSR was more variable (with a wider minimum and maximum TSR observation) than pre-mining.

Model results were very poor. The best model (see Table 15) was the linear model (i.e., had 0 breakpoints) and was plotted against the underlying data and fitted linear regression model (Figure 16). The percentage variation in the data explained by this model was very low (R^2 = 2%, Table 15). Estimates of the breakpoint analysis slope parameters are given in Table 16. Slopes were found not to be significantly different to 0.

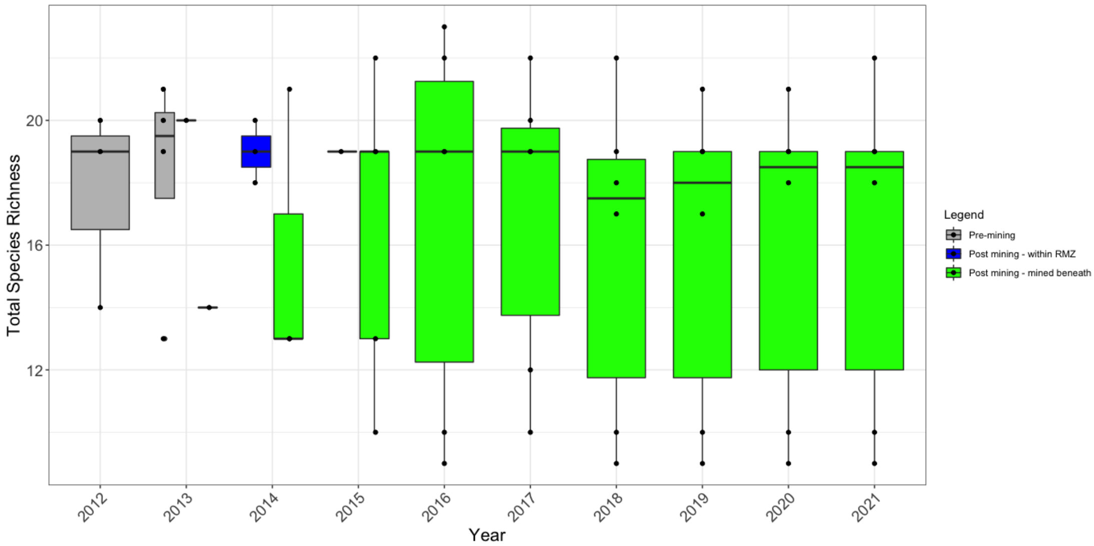

Figure 15. Boxplot of the total species richness for each transect at impact swamp S15. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

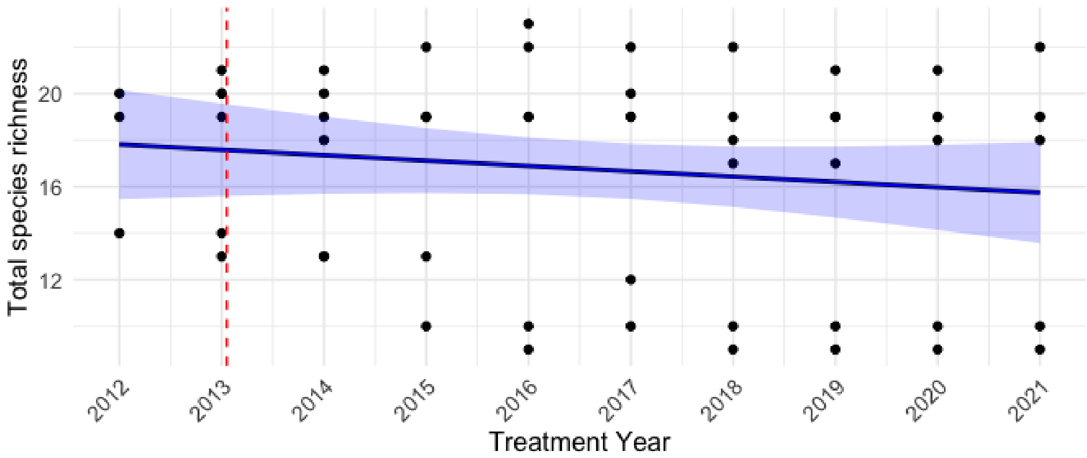

Figure 16. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 15. Summary of model fit.

Model	R-squared	AIC	dAIC
Linear model	0.02	335.68	0.00
Single breakpoint	0.02	339.56	3.88
Two breakpoints	NA	NA	NA
Three breakpoints	NA	NA	NA

Table 16. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	-0.30	0.31	-0.92	0.32
Slope 2	0.17	2.61	-5.07	5.40

11 Results - Swamp S23

Monitoring at swamp S23 began in 2017, and this swamp was impacted in 2018. This monitoring period is short, and there is no discernible trend in TSR data (Figure 17). The breakpoint analysis not carried out due to limited data – but see Figure 18 for a linear plot of the data.

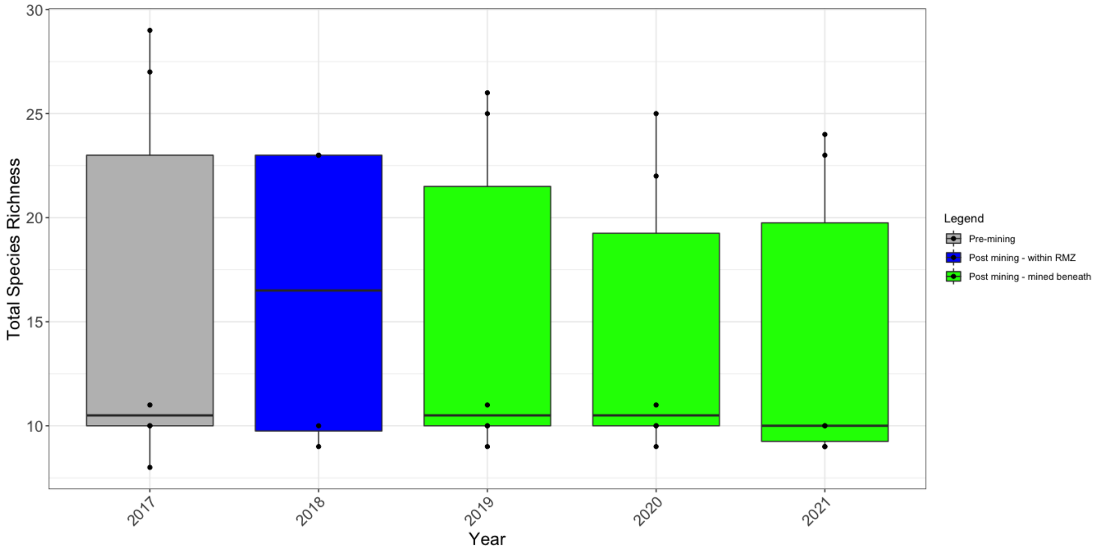

Figure 17. Boxplot of the total species richness for each transect at impact swamp S23. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

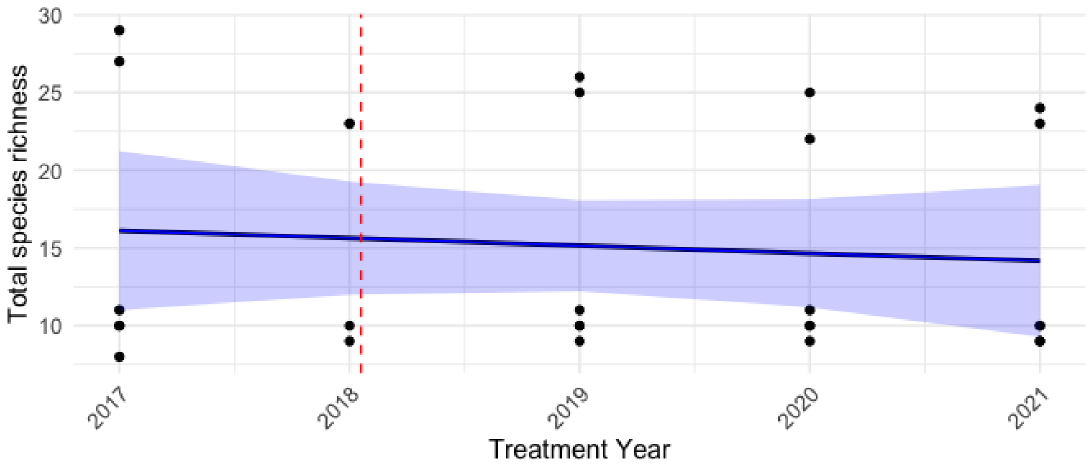

Figure 18. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

12 References

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THE ANALYTICAL EDGE
STATISTICAL CONSULTING

Task 2B - Breakpoint analysis of priority species richness at swamps within the Dendrobium region

Data collected up to and including 2021

Final

31 March 2022

Contents

Project History and Version Control

Date	Amendments	Person
9 March 2022	Received revised data from Sian Griffiths (Niche).	JP
24 March 2022	Priority species identified by Sian Griffiths (Niche).	JP
29 March 2022	Draft report submitted to Sian Griffiths (Niche).	JP
31 March 2022	Final report submitted to Sian Griffiths (Niche).	JP

1 Data Summary

On 9 March 2022, The Analytical Edge (hereafter, TAE) received a revised data set from Sian Griffiths (Niche) via e-mail. It contained data collected during flora swamp monitoring within the Dendrobium region up to and including 2021 (*'dendrobium_flora_annual_monitoring-2022-02-24_DW Edit.xlsx'*, 18.7 MB). Many species names and complexes had been revised since the previous analysis.

Errors:

(1) A total of 78 records were missing species-level information (29 and 49 records in 2020 and 2021, respectively). Also, 12 records were referred to as either 'QUADRAT IS DEAD' or 'QUADRAT DEAD'. These were excluded from the analysis. These errors were referred to Sian for correction in the parent database.

(2) For impact sites S11 and S15A(2) when PrePost=Pre (i.e., prior to impact), the treatment was listed as 'control'. These records were changed manually to 'impact' sites, and referred to Sian for correction in the parent database.

(3) Swamp11-V1 in spring 2021 was incorrectly labelled Swamp1-V1 in the data set. These records were changed manually and referred to Sian for correction in the parent database.

(4) One species complex (*Blandfordia Burchardia Caladenia Haemodorum Microtis Thelymitra* species complex) occasionally had an additional space after the record (i.e., '*Blandfordia Burchardia Caladenia Haemodorum Microtis Thelymitra* species complex '). These records were changed manually and referred to Sian for correction in the parent database.

Disclaimer: Excluding the corrections mentioned above, this data file is assumed to be error-free. Any further errors detected by Niche may invalidate the results and conclusions made in this report and will require the analysis to be re-run under the proviso of new contract agreements.

2 Methods

To date, analysis of total species richness (TSR) data has been undertaken in a series of 2-, 3-, and 4- yearly comparisons. Conducting multiple testing such as this can lead to erroneous interpretation of results; through statistical chance alone, 5% of tests may be concluded significant, and this chance is elevated when multiple tests are conducted. Methods exist for multiple correction (e.g., Holm 1979) but this will decrease the power to detect a difference, if one exists.

In addition, this approach doesn't identify any significant 'change points' that might exist in the data – namely, knowledge about when the impact occurred and whether that impact date coincided in a change in the trajectory of TSR at each swamp. TAE has previously proposed alternative methods to analyse these data (e.g., using a broken-stick approach, Muggeo 2003; Muggeo 2017), and this method was used successfully to explore trends in species richness in Task 2A.

Here, the same broken-stick methods were applied to the number of detection events for identified target species within specific swamps. In a broken-stick model with a single breakpoint, the data are essentially split into two time series: one prior to and one after the breakpoint. A linear model is fit to each portion of the data (i.e., one linear model is fit to the data subset prior to the breakpoint, and one linear model is fit to the data subset after the breakpoint). The placement of the breakpoint is optimized to ensure the error for the fitted models within each segment of the data is minimal. As the number of breakpoints fit to the data is increased, so too is the number of linear models. That is, two breakpoints create three separate linear models (one before the first breakpoint, one between the first and second breakpoints, and one after the second breakpoint). The number of breakpoints fit to the data is a model selection issue, here based on Akaike's Information Criterion (AIC, Buckland et al. 1997).

Once the final model of breakpoints is determined, the statistical significance of the linear models for each segment can be explored. Here, the gradient of each segment is reported, along with statistical significance based on 95% confidence intervals.

Target species were primarily identified based on the species composition analysis presented in Task 1B.

All analyses were conducted in R (v. 4.1.2, R Core Team 2022), using the 'segmented' packaged (v 1.4-0, Muggeo, 2008).

3 Results - Swamp S15A(2)

3.1 *Baekea imbricata*

In Task 1B, *Baeckea imbricata* was identified as a species that was more common prior to impact, compared with after impact (i.e., see Table 3, page 8, Task 1B). Figure 1 shows the number of times *B. imbricata* was detected at each transect within swamp S15A(2), slowly trending to 0 detection events by 2021.

The breakpoint analysis did not detect any significant breakpoints since the linear model had the lowest AIC (Table 1). There was a statistically significant decline in the number of detection events of this species since monitoring began (Figure 2). The model with 1 breakpoint was plotted against the underlying data and fitted linear regression model for comparison (Figure 2).

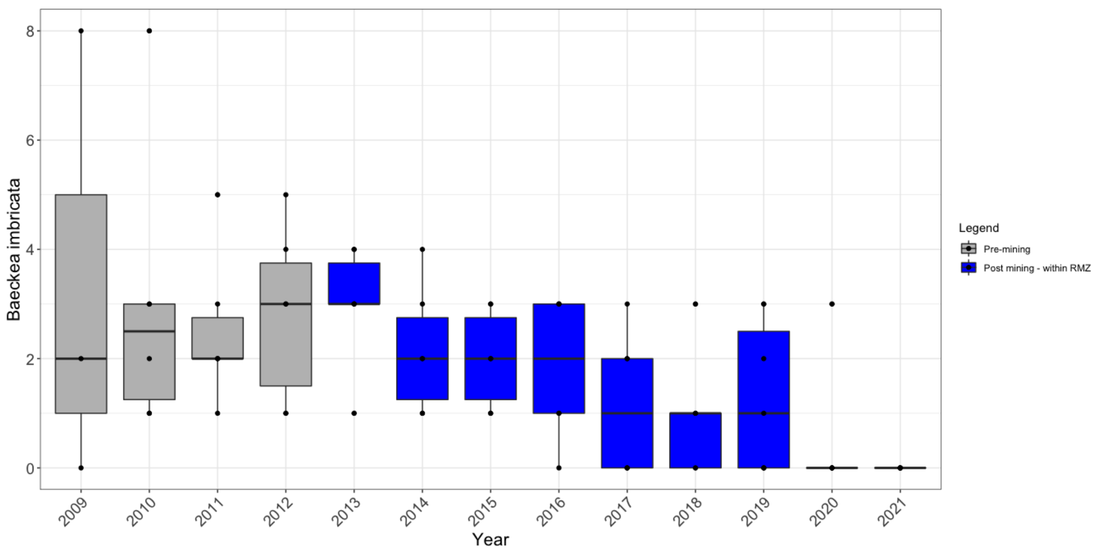

Figure 1. Boxplot of Baekea imbricata *detection events for each transect at impact swamp S15A(2). The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.*

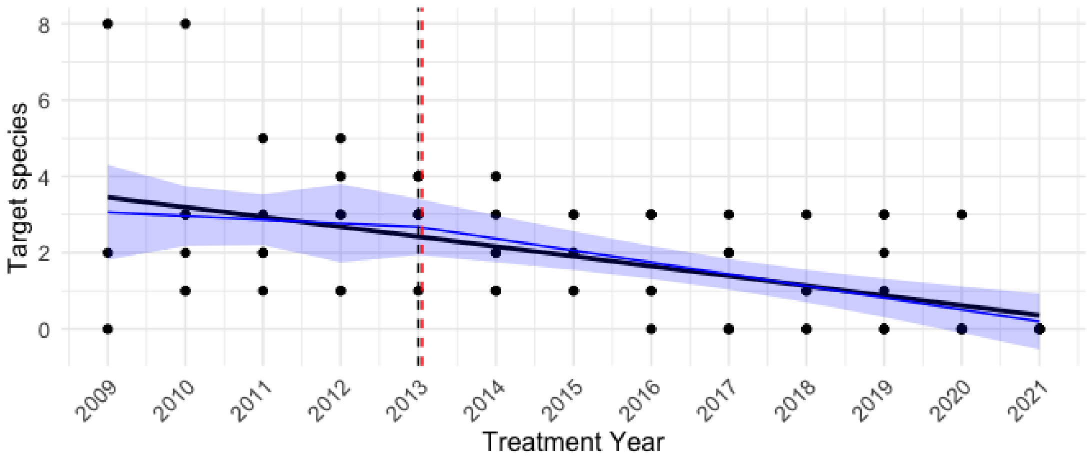

Figure 2. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 1. Summary of model fit.

Model	R-squared	AIC	dAIC
Linear model	0.29	274.10	0.00
Single breakpoint	0.30	277.15	3.05
Two breakpoints	0.31	280.92	6.82
Three breakpoints	NA	NA	NA

3.2 *Bauera microphylla/rubioides* species complex

In Task 1B, *Bauera microphylla/rubioides* species complex was identified as a species group that was more common prior to impact, compared with after impact (i.e., see Table 3, page 8, Task 1B). Figure 3 shows the number of times *Bauera microphylla/rubioides* species complex was detected at each transect within swamp S15A(2), slowly trending to a very low number of detection events by 2021.

The best model (see Table 2) had 1 breakpoint and was plotted against the underlying data and fitted linear regression model (Figure 4). Estimates of the breakpoint analysis slope parameters are given in Table 3. Until 2017, there was a statistically significant increase in the number of detection events of this species, after which there has been a statistically significant decline.

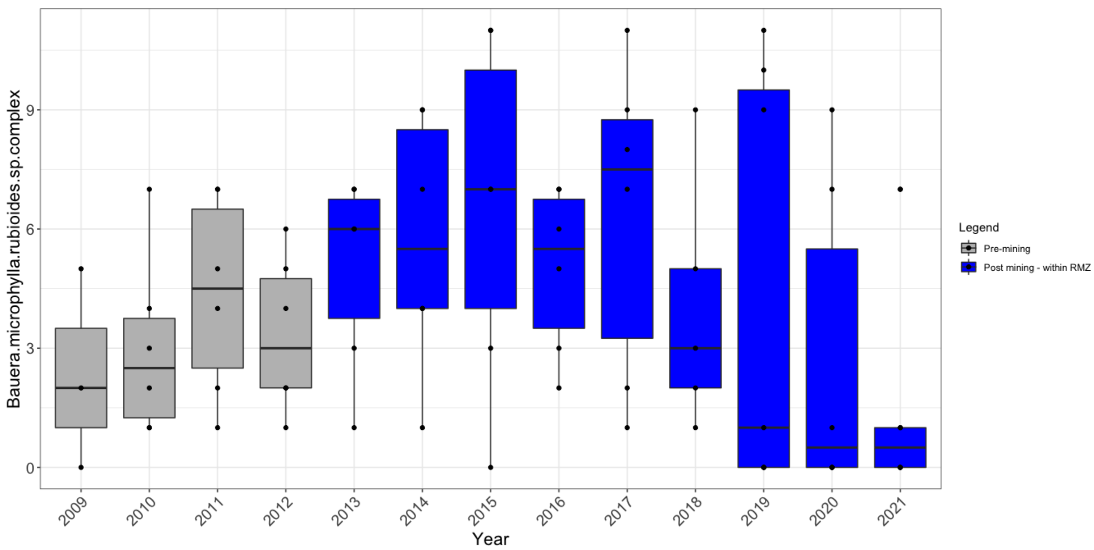

Figure 3. Boxplot of Bauera microphylla/rubioides *species complex detection events for each transect at impact swamp S15A(2). The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.*

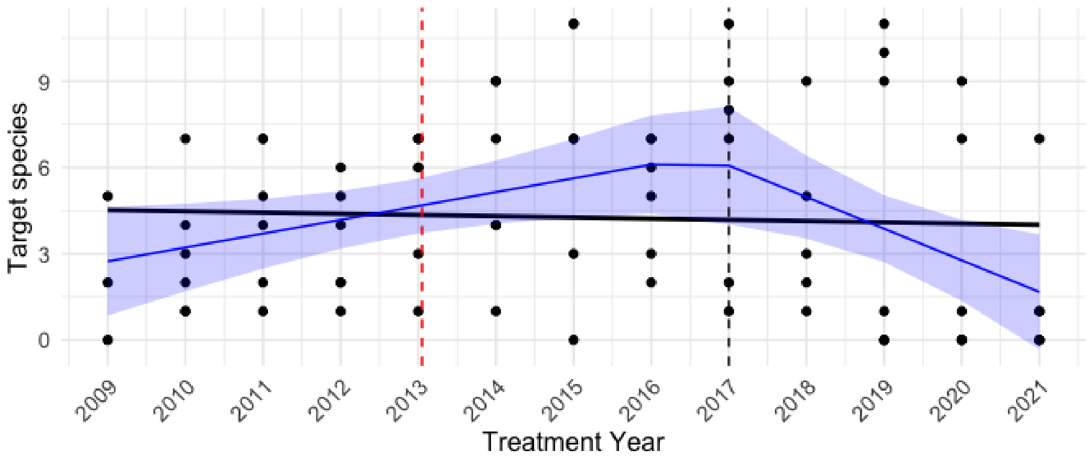

Figure 4. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 2. Summary of model fit.

Model	R-squared	AIC	dAIC
Single breakpoint	0.15	392.76	0.00
Two breakpoints	0.16	396.03	3.27
Linear model	0.00	400.96	8.20
Three breakpoints	NA	NA	NA

Table 3. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	0.48	0.22	0.05	0.92
Slope 2	-1.10	0.42	-1.93	-0.27

4 Results - Swamp S15B

4.1 *Leptospermum juniperinum*

Leptospermum juniperinum was identified by Niche as a species of interest at swamp S15B. The boxplot of *L. juniperinum* data (Figure 5) shows that from 2007 onwards the number of detection events of this species has steadily declined.

The model with the lowest AIC (see Table 4) had 1 breakpoint and was plotted against the underlying data and fitted linear regression model (Figure 6). Estimates of the breakpoint analysis slope parameters are given in Table 5. The initial increase in detection events between 2003 and 2004 was statistically significant, as was the subsequent decline.

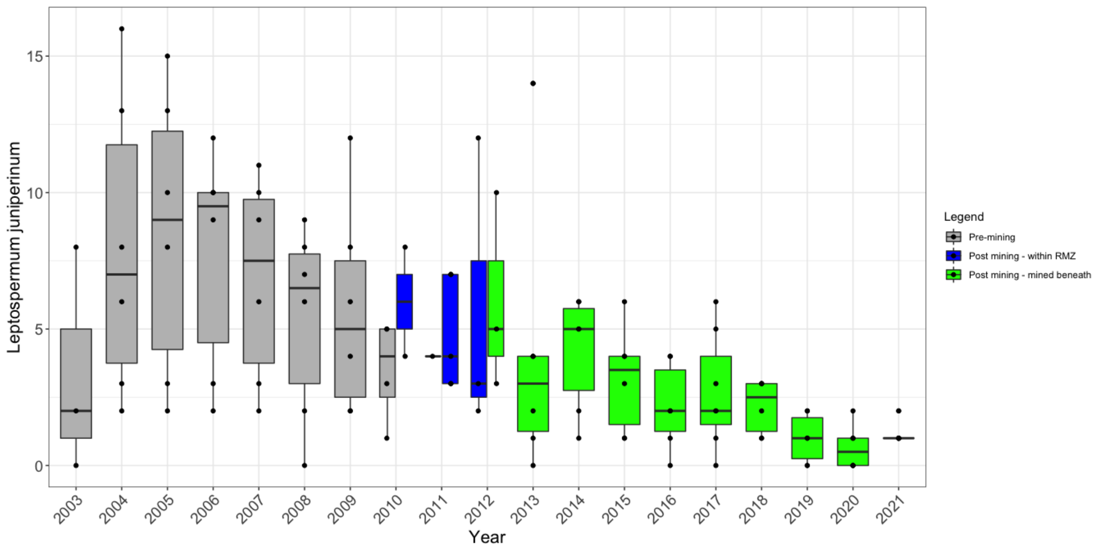

Figure 5. Boxplot of Leptospermum juniperinum *detection events for each transect at impact swamp S15B. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.*

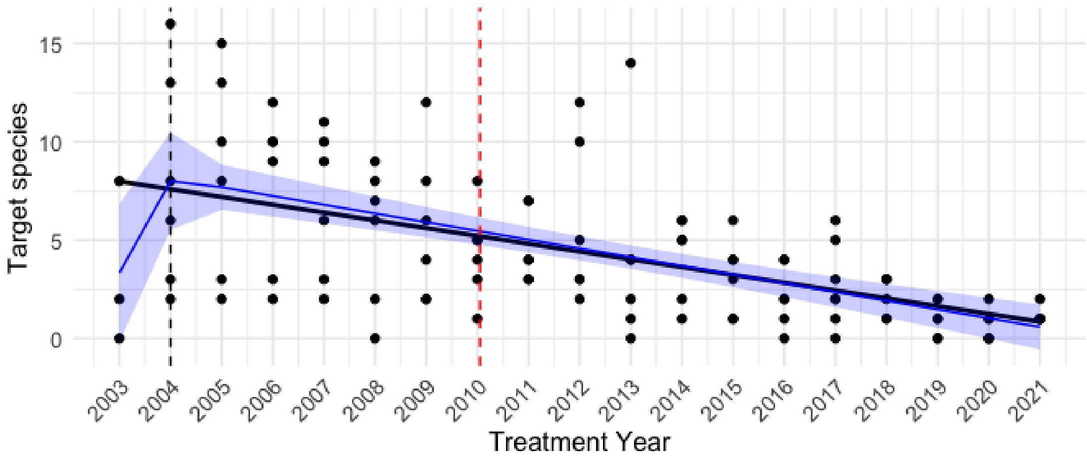

Figure 6. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 4. Summary of model fit.

Model	R-squared	AIC	dAIC
Single breakpoint	0.36	574.72	0.00
Two breakpoints	0.37	577.70	2.98
Linear model	0.32	578.48	3.76
Three breakpoints	NA	NA	NA

Table 5. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	4.67	2.17	0.37	8.96
Slope 2	-0.44	0.06	-0.57	-0.32

4.2 *Epacris obtusifolia*

In Task 1B, *Epacris obtusifolia* was identified as a species that was more common prior to impact, compared with after impact (i.e., see Table 9, page 14, Task 1B). The boxplot (Figure 7) shows that from 2005 the number of detection events of this species has steadily declined and has been only one detection of this species since 2019.

The best model (see Table 6) had 3 breakpoints and was plotted against the underlying data and fitted linear regression model (Figure 8). However, note the model selection uncertainty was high, with the difference in AIC of the next best model (i.e., the linear model) of 1.9 (that is, these models are essentially equivalent). Estimates of the breakpoint analysis slope parameters are given in Table 7. All segments were found to be statistically different from 0, excluding the last segment where the number of detection events has remained approximately stable.

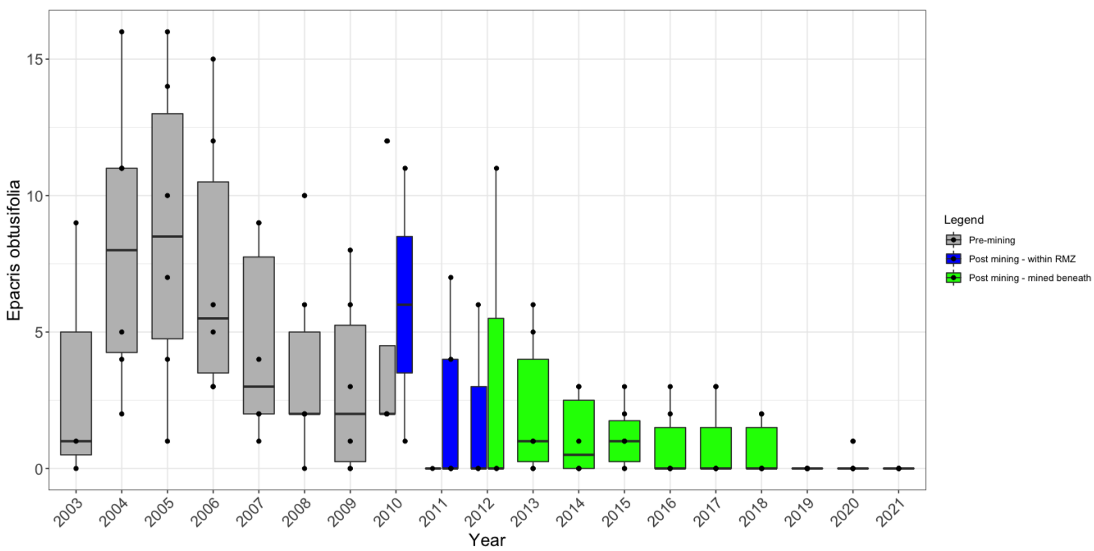

Figure 7. Boxplot of Epacris obtusifolia *detection events for each transect at impact swamp S15B. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.*

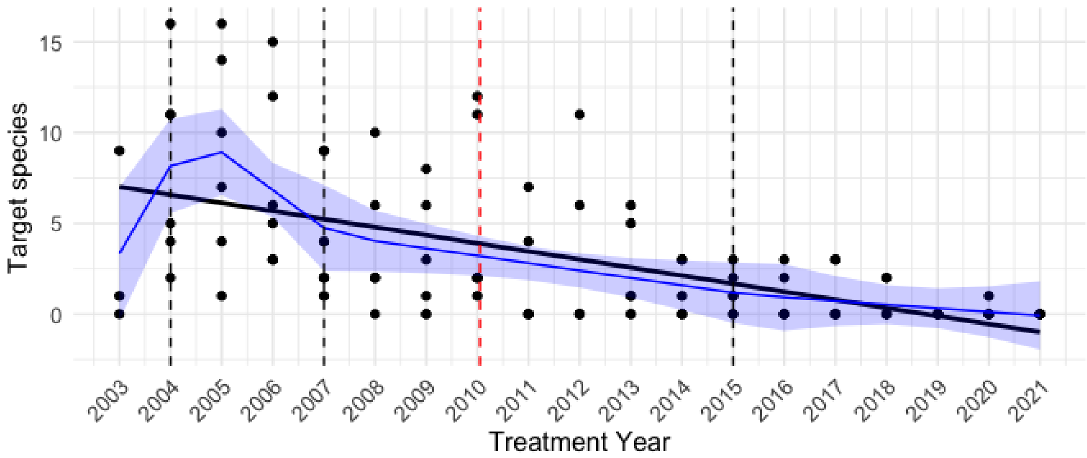

Figure 8. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 6. Summary of model fit.

Model	R-squared	AIC	dAIC
Three breakpoints	0.42	588.46	0.0
Linear model	0.34	590.36	1.9
Single breakpoint	0.36	591.66	3.2
Two breakpoints	NA	NA	NA

Table 7. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	4.83	2.27	0.34	9.33
Slope 2	-2.08	0.93	-3.92	-0.25
Slope 3	-0.41	0.20	-0.81	-0.01
Slope 4	-0.20	0.31	-0.81	0.41

5 Results - Swamp S11

5.1 *Almaleea paludosa*

In Task 1B, *Almaleea paludosa* was identified as a species that was more common prior to impact, compared with after impact (i.e., see Table 14, page 22, Task 1B). The boxplot shows the number of detection events for this species rapidly declined from 2006 to 2012, and by 2020 it was no longer detected at this swamp (Figure 9).

The best model (see Table 8) had 2 breakpoints and was plotted against the underlying data and fitted linear regression model (Figure 10). Estimates of the breakpoint analysis slope parameters are given in Table 9. The period of decline between 2006 and 2011 was found to be significantly significant, after which the number of detection events for this species has been approximately stable.

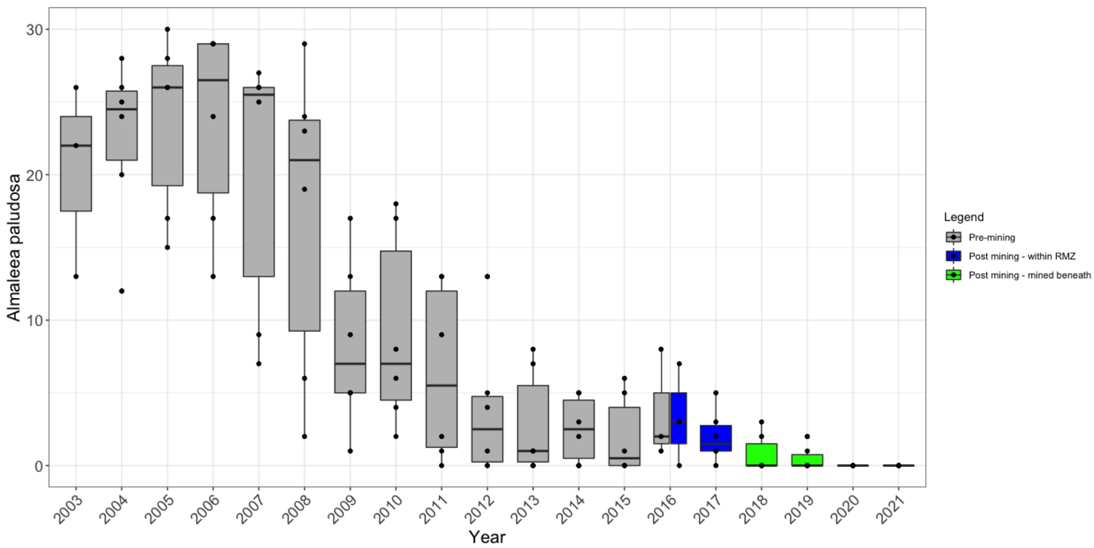

Figure 9. Boxplot of the Almaleea paludosa *detection events for each transect at impact swamp S11. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.*

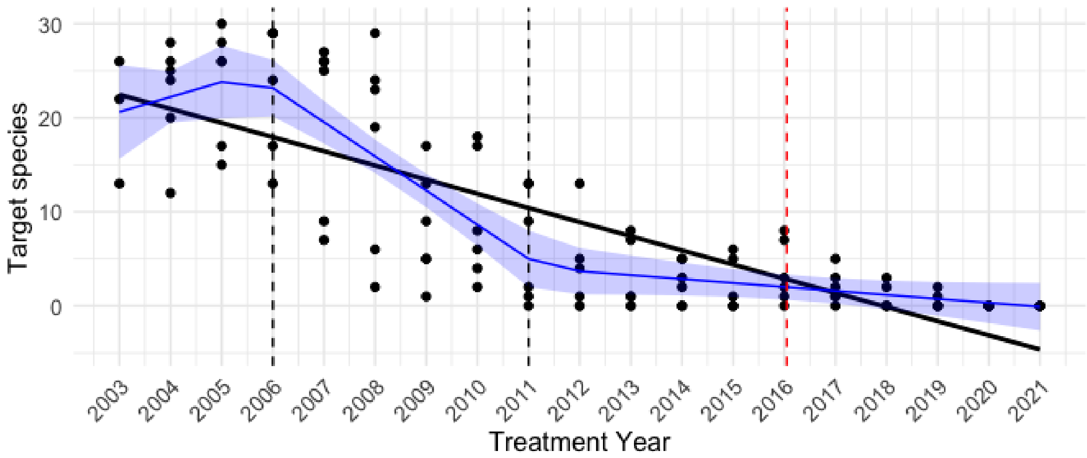

Figure 10. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 8. Summary of model fit.

Model	R-squared	AIC	dAIC
Two breakpoints	0.75	680.69	0.00
Single breakpoint	0.72	689.29	8.60
Linear model	0.64	711.77	31.08
Three breakpoints	NA	NA	NA

Table 9. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	1.60	1.78	-1.93	5.12
Slope 2	-3.63	0.50	-4.63	-2.64
Slope 3	-0.42	0.24	-0.89	0.05

5.2 *Boronia parviflora*

In Task 1B, *Boronia parviflora* was identified as a species that was more common prior to impact, compared with after impact (i.e., see Table 14, page 22, Task 1B). The boxplot shows the number of detection events for this species rapidly declined from approximately 2010, such that by 2021 it was no longer detected at this swamp (Figure 11).

The best model (see Table 10) had 2 breakpoints and was plotted against the underlying data and fitted linear regression model (Figure 12). Estimates of the breakpoint analysis slope parameters are given in Table 11. The period of decline between 2009 and 2013 was found to be statistically significantly, after which the trend in number of detection events was approximately stable.

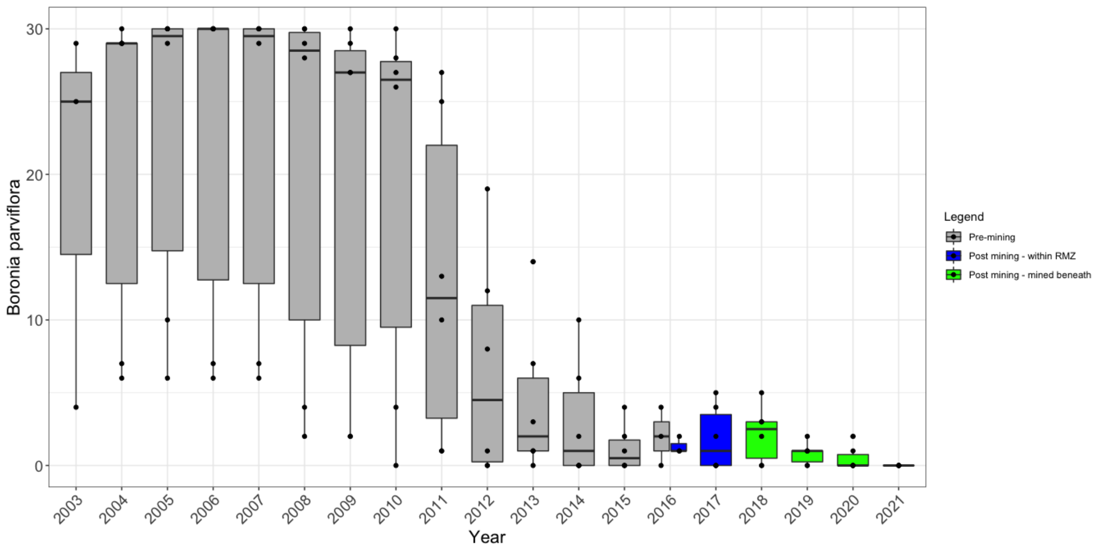

Figure 11. Boxplot of Boronia parviflora *detection events for each transect at impact swamp S11. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.*

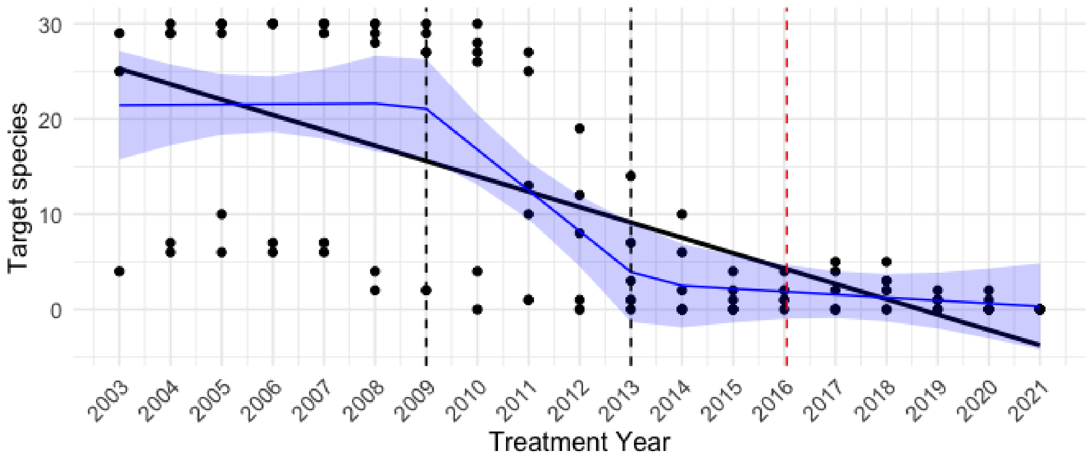

Figure 12. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 10. Summary of model fit.

Model	R-squared	AIC	dAIC
Two breakpoints	0.56	786.89	0.00
Three breakpoints	0.56	789.93	3.04
Single breakpoint	0.51	793.85	6.96
Linear model	0.49	794.36	7.47

Table 11. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	0.03	0.91	-1.77	1.84
Slope 2	-4.28	1.08	-6.42	-2.15
Slope 3	-0.31	0.54	-1.38	0.76

6 Results - Swamp S13

6.1 *Dillwynia floribunda retorta* species complex

In Task 1B, *Dillwynia floribunda retorta* species complex was identified as a species group that was more common prior to impact, compared with after impact (i.e., see Table 24, page 31, Task 1B). The boxplot (Figure 13) shows that prior to impact, the number of detection events of this species complex was variable, but since impact, the number of detection events has been declining. In addition, between-transect variability at this swamp seems high, with some transects seemingly recording more of this target species while others appear to be consistently lower (this pattern is more obvious in Figure 14).

The best model (see Table 12) was the linear model (i.e., no breakpoints, Figure 14). Although the decline in detection events is statistically significant, note the variation in the data explained by all the fitted models is very low (i.e., R^2 values in Table 12 are all < 0.2). This is probably due to high between-transect variability mentioned above.

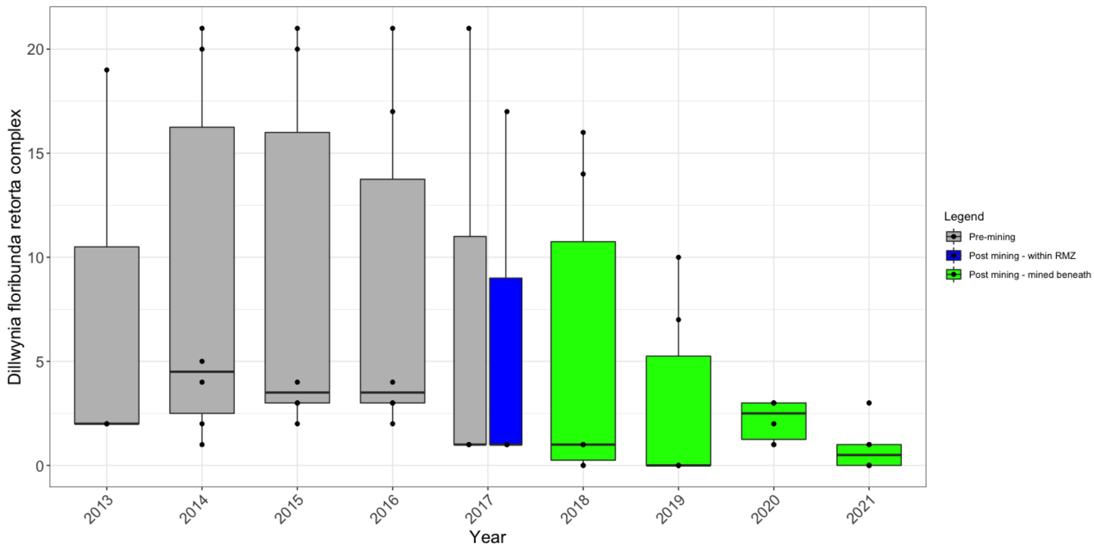

Figure 13. Boxplot of the Dillwynia floribunda retorta *complex detection events for each transect at impact swamp S13. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.*

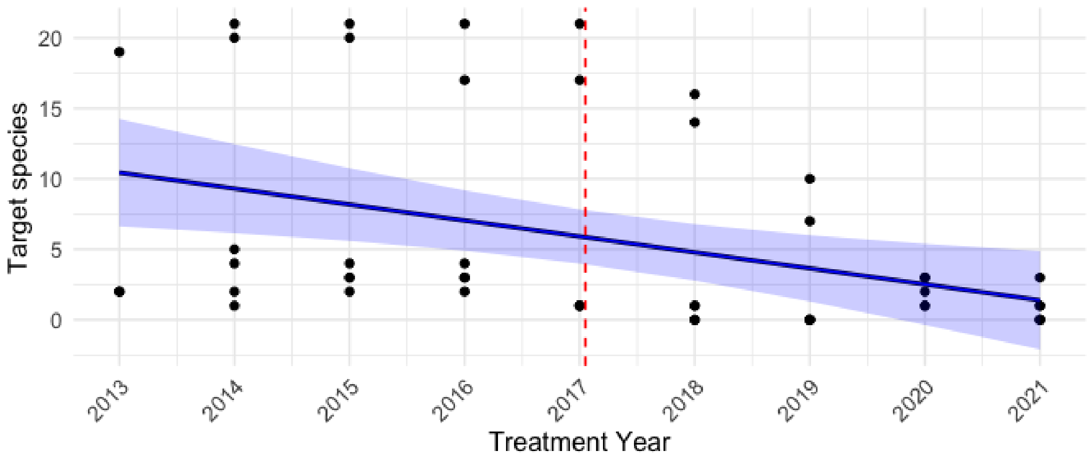

Figure 14. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 12. Summary of model fit.

Model	R-squared	AIC	dAIC
Linear model	0.15	344.13	0.00
Single breakpoint	0.17	347.08	2.95
Two breakpoints	0.17	351.01	6.88
Three breakpoints	0.17	354.96	10.83

6.2 *Xyris* species complex

Xyris species complex was identified by Niche as a species group of interest. The boxplot (Figure 15) shows that the number of detection events of this species complex was relatively stable until 2019, after which they increased sharply.

The best model (see Table 13) had a single breakpoint at 2018 (Figure 16). Estimates of the breakpoint analysis slope parameters are given in Table 14. The increase in detection events of this target species since 2018 is statistically significantly.

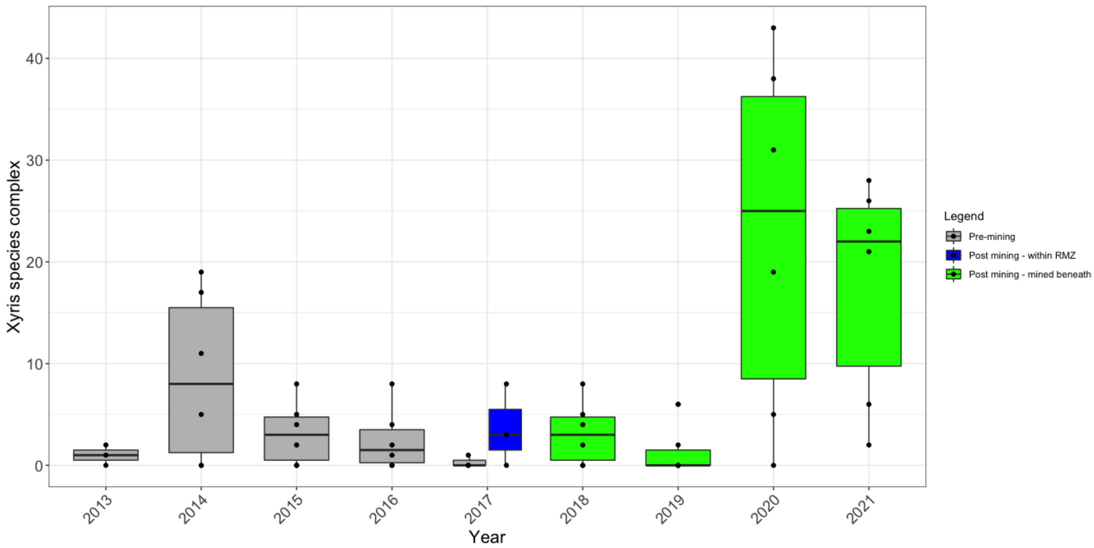

Figure 15. Boxplot of the Xyris *species complex detection events for each transect at impact swamp S13. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.*

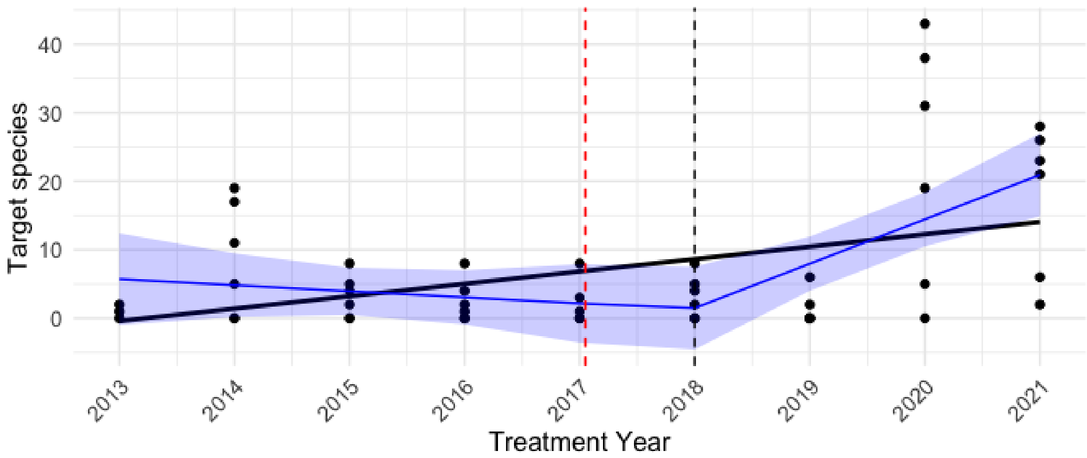

Figure 16. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 13. Summary of model fit.

Model	R-squared	AIC	dAIC
Single breakpoint	0.36	372.36	0.00
Linear model	0.18	380.70	8.34
Two breakpoints	NA	NA	NA
Three breakpoints	NA	NA	NA

Table 14. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	-0.89	1.29	-3.48	1.70
Slope 2	6.48	1.61	3.25	9.71

7 Results - Swamp S1B

7.1 *Epacris obtusifolia*

Epacris obtusifolia was identified in Task 1B as being more common before impact, compared with after impact (i.e., see Table 34, page 41, Task 1B). The boxplot (Figure 17) shows that prior to 2016, detection events of the species were relatively common but from 2017 it has barely been detected at this swamp.

The best model was a linear model (Table 15), which was a significantly linear decline in the number of detection events, and this model is plotted against the next best model (according to AIC model selection) which had 1 breakpoint (Figure 18).

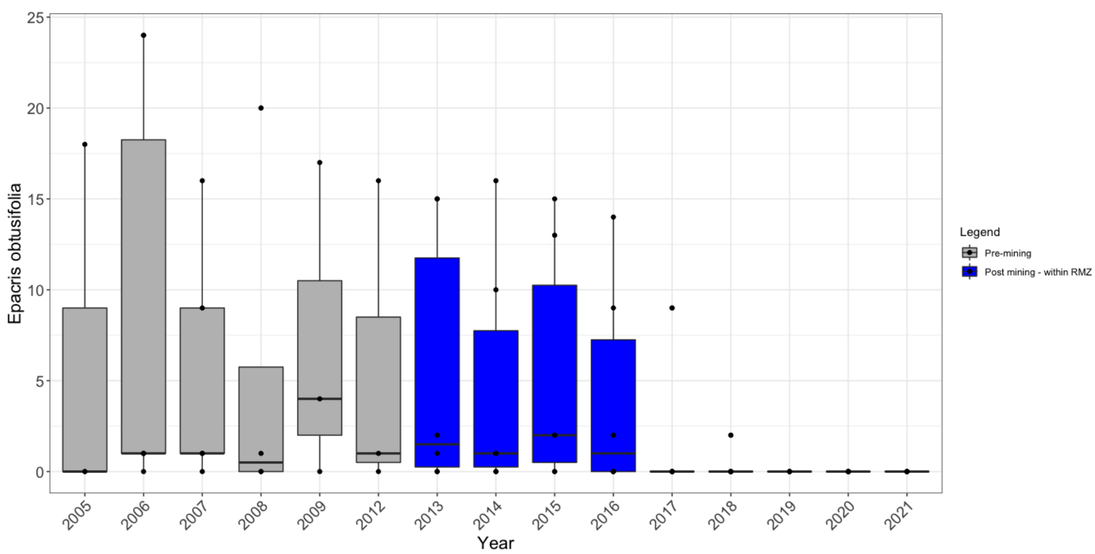

Figure 17. Boxplot of Epacris obtusifolia *detection events for each transect at impact swamp S1B. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.*

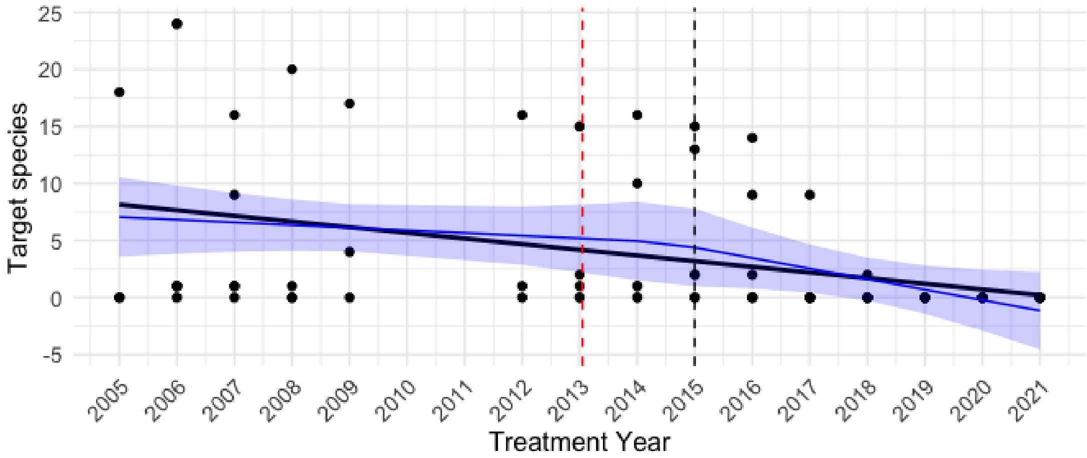

Figure 18. Best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 15. Summary of model fit.

Model	R-squared	AIC	dAIC
Linear model	0.14	508.01	0.00
Single breakpoint	0.16	510.41	2.40
Two breakpoints	0.17	513.45	5.44
Three breakpoints	NA	NA	NA

7.2 *Mitrasacme polymorpha/pilosa* species complex

Mitrasacme polymorpha/pilosa species complex was identified in Task 1B as being more common before impact, compared with after impact (i.e., see Table 34, page 41, Task 1B). The boxplot (Figure 19) shows that prior to impact, the number of detection events of this species were variable; however, since 2017 detection events have been very uncommon (mostly 0).

The best model had a single breakpoint (Table 18); however, model selection uncertainty was very high (i.e., all models fitted had a difference in AIC of less than 2 from the best fitting model) and are plotted in Figure 20. Estimates of the breakpoint analysis slope parameters are given in Table 19. There was a statistically significant decline in the number of detection events from 2008 onwards (Table 19).

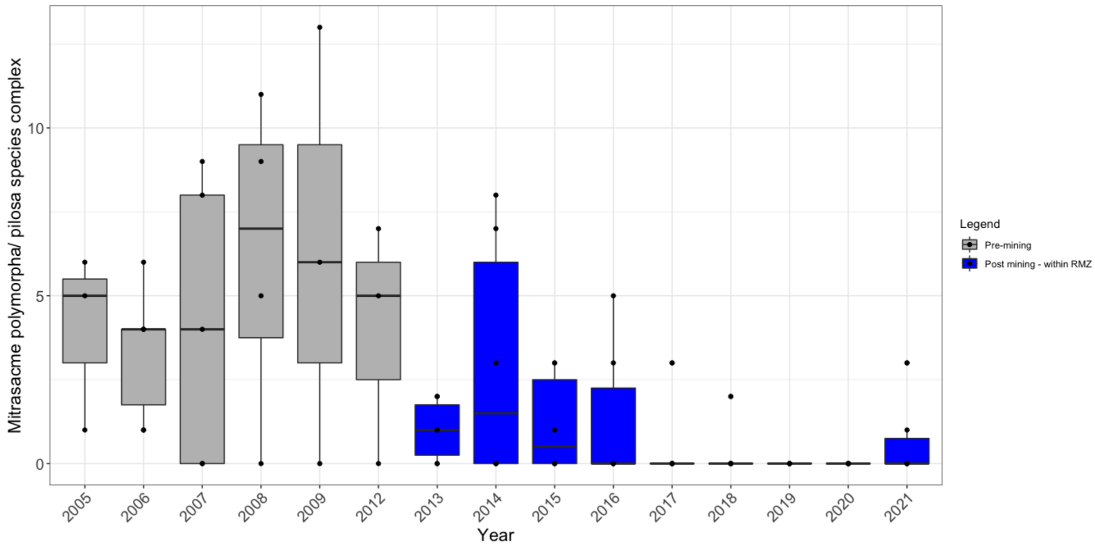

Figure 19. Boxplot of the Mitrasacme polymorpha/pilosa *species complex detection events for each transect at impact swamp S1B. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.*

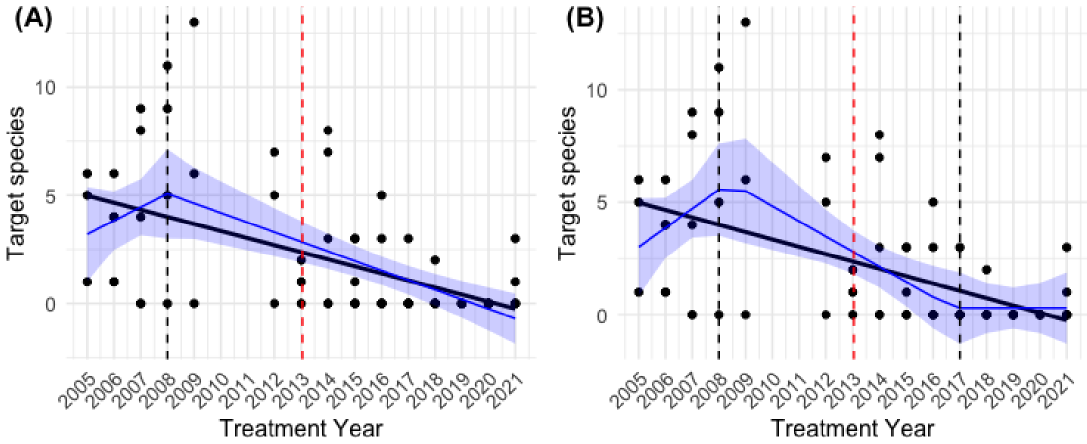

Figure 20. (A) Best breakpoint analysis model and (B) third-best breakpoint analysis model (blue line, 95% confidence limits shown by shading) plotted against data. Linear regression (second-best model) shown by black line. Breakpoints indicated by black vertical dashed lines. Red dashed line indicates impact year (shifted forward 0.05 years for visual clarity).

Table 18. Summary of model fit.

Model	R-squared	AIC	dAIC
Single breakpoint	0.33	371.84	0.00
Linear model	0.29	372.16	0.32
Two breakpoints	0.36	372.25	0.41
Three breakpoints	NA	NA	NA

Table 19. Best breakpoint analysis model slope parameters and 95% confidence intervals (CIs).

Slope	Estimate	Standard error	lower CI	upper CI
Slope 1	0.62	0.59	-0.55	1.79
Slope 2	-0.44	0.10	-0.65	-0.24

8 References

Analytical Edge (2021). *Task 1B - Analysis of flora species composition at impact swamps within the Dendrobium region, Data collected up to, and including, 2020*. Unpublished report submitted to Niche.

Buckland S.T., Burnham K.P., Augustin N.H. (1997). Model Selection: An Integral Part of Inference. *Biometrics 5*3:603–618.

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics* 6, 65–70.

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Task 3 - Investigation of differences in seasonal monitoring at swamps within the Dendrobium region

Data collected up to and including 2021

Final

31 March 2022

Project History and Version Control

Date	Amendments	Person
9 March 2022	Received revised data from Sian Griffiths (Niche).	JP
30 March 2022	Draft report submitted to Sian Griffiths (Niche).	JP
31 March 2022	Final report submitted to Sian Griffiths (Niche).	JP

Table of Contents

1 Data Summary

On 9 March 2022, The Analytical Edge (hereafter, TAE) received a revised data set from Sian Griffiths (Niche) via e-mail. It contained data collected during flora swamp monitoring within the Dendrobium region up to and including 2021 (*'dendrobium_flora_annual_monitoring-2022-02-24_DW Edit.xlsx'*, 18.7 MB). Many species names and complexes had been revised since the previous analysis.

All data relating to swamp S1 were omitted from the analysis.

Errors:

(1) A total of 78 records were missing species-level information (29 and 49 records in 2020 and 2021, respectively). Also, 12 records were referred to as either 'QUADRAT IS DEAD' or 'QUADRAT DEAD'. These were excluded from the analysis. These errors were referred to Sian for correction in the parent database.

(2) For impact sites S11 and S15A(2) when PrePost=Pre (i.e., prior to impact), the treatment was listed as 'control'. These records were changed manually to 'impact' sites, and referred to Sian for correction in the parent database.

(3) Swamp11-V1 in spring 2021 was incorrectly labelled Swamp1-V1 in the data set. These records were changed manually and referred to Sian for correction in the parent database.

(4) One species complex (*Blandfordia Burchardia Caladenia Haemodorum Microtis Thelymitra* species complex) occasionally had an additional space after the record (i.e., '*Blandfordia Burchardia Caladenia Haemodorum Microtis Thelymitra* species complex'). These records were changed manually and referred to Sian for correction in the parent database.

Disclaimer: Excluding the corrections mentioned above, this data file is assumed to be error-free. Any further errors detected by Niche may invalidate the results and conclusions made in this report and will require the analysis to be re-run under the proviso of new contract agreements.

2 Methods

The aim of this task was to investigate if any seasonal differences occur at monitored swamps (Table 1, i.e., spring versus autumn monitoring).

All analyses were conducted in R (v. 4.1.2, R Core Team 2022).

Table 1. Monitored swamps classified by whether they are impact or control swamps.

Impact Swamps	Control swamps
S15A(2)	S86
S15B	S87
S11	S88
S13	S15A(1)
S14	S22
S1A	S33
S1B	
S5	
S23	

3 Results

3.1 Differences in total species richness

Boxplots of total species richness for each control and impact swamp, contrasted by season, are provided in Figure 1 and Figure 2, respectively. From these two figures, there is no strong visual differences in TSR data collected between spring and autumn for any swamp (regardless of treatment type, being control or impact).

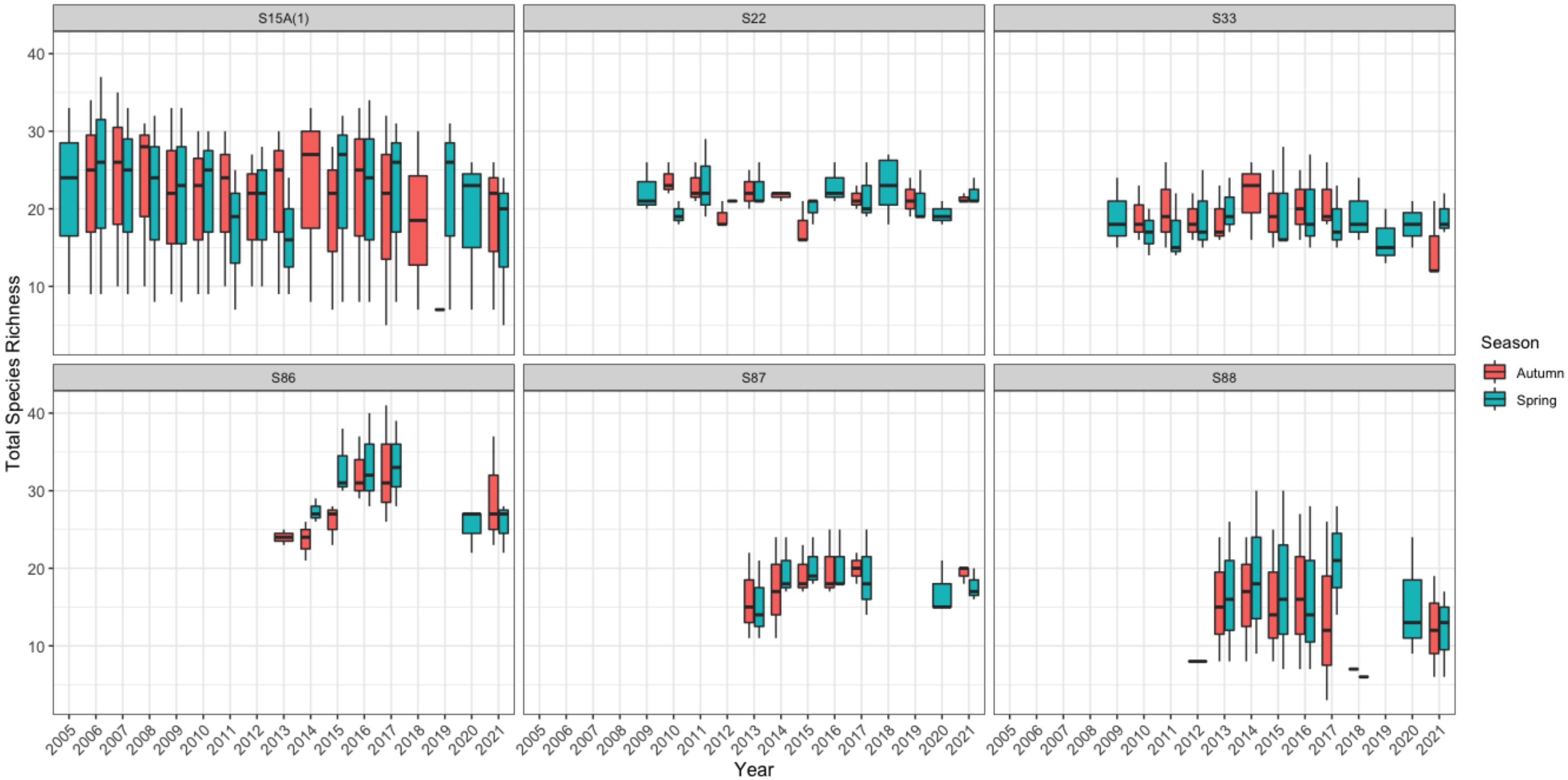


Figure 1: Boxplot of the total species richness for each transect at each control swamp, contrasted by season. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

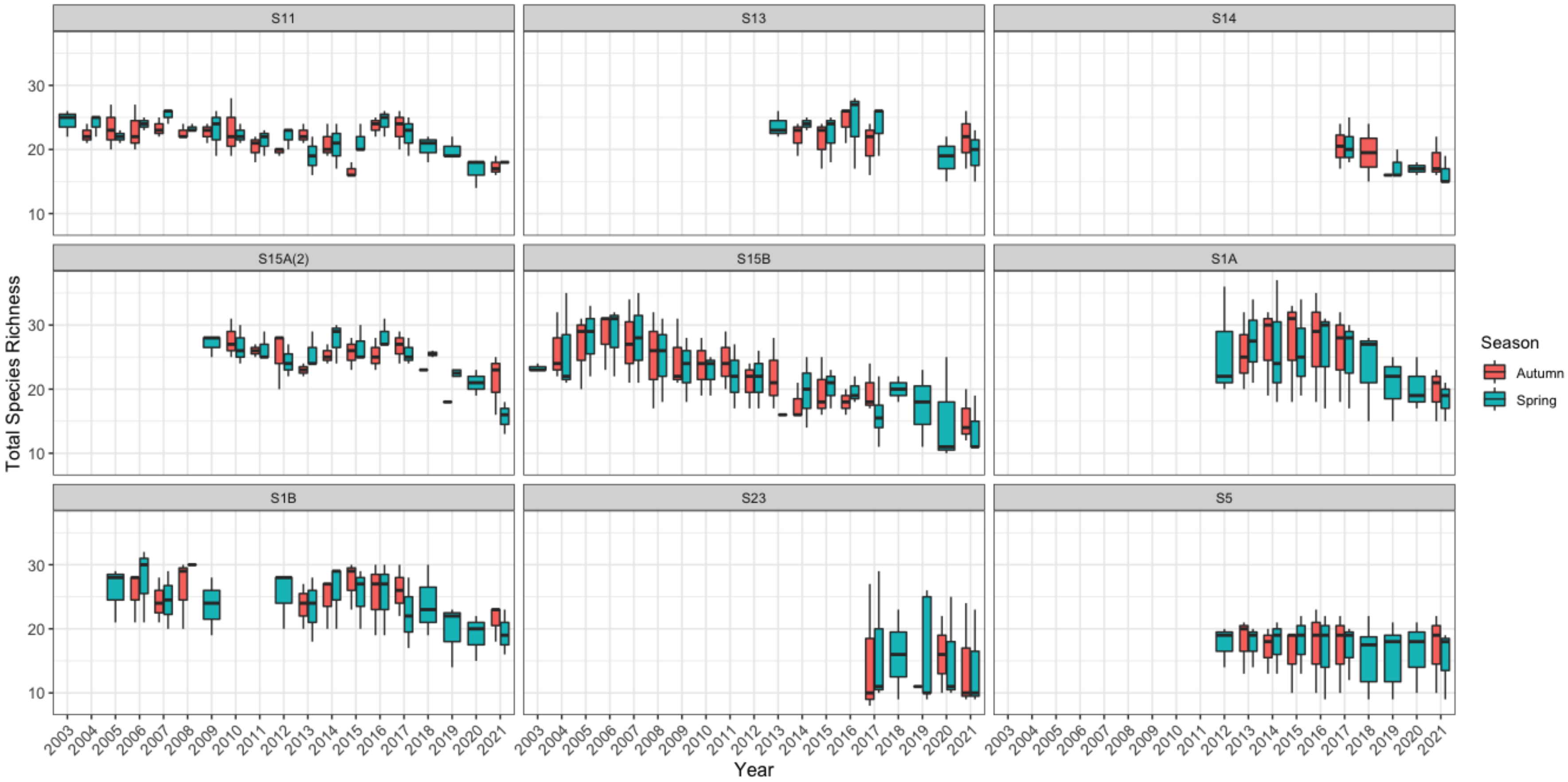


Figure 2: Boxplot of the total species richness for each transect at each impact swamp, contrasted by season. The solid line within the boxes is the median (i.e., the 50th percentile), the margins of the box are the interquartile range (IQR, i.e., the 25th and 75th percentiles), and the whiskers of the boxplot cover 1.5 times the IQR of the data.

3.2 Unique species detected in each season, per swamp

At every swamp, there was a subset of species that were detected in only one of the two seasons visited. Typically, more species are detected in spring and fewer species are detected only in autumn (and not in spring).

3.2.1 S15A(2)

At swamp S15A(2), 62 unique species were detected in autumn, and 64 unique species were detected in spring monitoring. 4 species detected in spring monitoring were *never* detected in autumn, but only 2 species were detected in autumn monitoring and never in spring (Table 2).

Table 2. Unique species detected in only one season at swamp S15A(2).

Species	Autumn	Spring
Epacris paludosa	0	1
Gompholobium minus pinnatum complex	0	1
Leptospermum squarrosum	0	12
Schizaea bifida	0	2
Banksia spinulosa var. spinulosa	3	0
Tetrarrhena juncea	1	0

3.2.2 S15B

At swamp S15B, 61 unique species were detected in autumn, and 57 unique species were detected in spring monitoring. 3 species detected in spring monitoring were *never* detected in autumn, yet 7 species were detected in autumn monitoring and never in spring (Table 3).

Table 3. Unique species detected in only one season at swamp S15B.

Species	Autumn	Spring
Acianthus species complex	0	6
Genoplesium species complex	0	1
Hakea teretifolia/ sericea sp complex	0	1
Allocasuarina littoralis	1	0
Almaleea paludosa	1	0
Baumea acuta	1	0
Goodenia hedercacea/ heterophylla Sp_ complex	1	0
Hakea dactyloides/ salicifolia Sp_ complex	1	0
Pseuderantherum variable/ brunoniella sp complex	1	0
Symphionema paludosum	1	0

3.2.3 S11

At swamp S11, 53 unique species were detected in autumn, and 60 unique species were detected in spring monitoring. 8 species detected in spring monitoring were *never* detected in autumn, but only 1 species was detected in autumn monitoring and never in spring (Table 4).

Table 4. Unique species detected in only one season at swamp S11.

Species	Autumn	Spring
Acacia terminalis	0	2
Baloskion gracile	0	1
Lepyrodia cryptica	0	46
Lomandra cylindrica/ filiformis/ micrantha sp complex	0	2
Lycopodiella lateralis	0	2
Melaleuca thymifolia	0	1
Mitrasacme polymorpha/ pilosa species complex	0	3
Utricularia species complex	0	6
Baumea acuta	4	0

3.2.4 S13

At swamp S13, 50 unique species were detected in autumn, and 54 unique species were detected in spring monitoring. 6 species detected in spring monitoring were *never* detected in autumn, but only 2 species were detected in autumn monitoring and never in spring (Table 5).

Table 5. Unique species detected in only one season at swamp S13.

Species	Autumn	Spring
Callistemon subulatus	0	1
Dianella caerulea complex	0	3
Epacris microphylla	0	1
Gymnoschoenus sphaerocephalus	0	2
Patersonia species complex	0	1
Thysanotus juncifolius	0	4
Callistemon citrinus	1	0
Grevillea sphacelata	5	0

3.2.5 S14

At swamp S14, 35 unique species were detected in autumn, and 36 unique species were detected in spring monitoring. 4 species detected in spring monitoring were *never* detected in autumn, and 3 species were detected in autumn monitoring and never in spring (Table 6).

Table 6. Unique species detected in only one season at swamp S14.

Species	Autumn	Spring
Acacia rubida	0	9
Drosera binata	0	175
Epacris paludosa	0	1
Monotaxis linifolia	0	1
Lepidosperma filiforme/ urophorum complex	1	0
Lepidosperma neesii/ Ptilothrix deusta complex	3	0
Selaginella uliginosa	1	0

3.2.6 S1A

At swamp S1A, 62 unique species were detected in autumn, and 63 unique species were detected in spring monitoring. 4 species detected in spring monitoring were *never* detected in autumn, and 3 species were detected in autumn monitoring and never in spring (Table 7).

Table 7. Unique species detected in only one season at swamp S1A.

Species	Autumn	Spring
Banksia marginata	0	1
Lomandra cylindrica/ filiformis/ micrantha sp complex	0	6
Patersonia species complex	0	3
Tetraria capillaris	0	2
Epacris paludosa	1	0
Hibbertia riparia species complex	4	0
Tetrarrhena juncea	2	0

3.2.7 S1B

At swamp S1B, 60 unique species were detected in autumn, and 60 unique species were detected in spring monitoring. 4 species detected in spring monitoring were *never* detected in autumn, and 4 different species were detected in autumn monitoring and never in spring (Table 8).

Table 8. Unique species detected in only one season at swamp S1B.

Species	Autumn	Spring
Amperea xiphoclada	0	2
Hakea teretifolia/ sericea sp complex	0	5
Melaleuca thymifolia	0	13
Thysanotus juncifolius	0	1
Comesperma defoliatum	3	0
Comesperma sphaerocarpum	1	0
Grevillea sphacelata	31	0
Lagenifera stipitata	1	0

3.2.8 S5

At swamp S5, 42 unique species were detected in autumn, and 44 unique species were detected in spring monitoring. 3 species detected in spring monitoring were *never* detected in autumn, but only 1 species was detected in autumn monitoring and never in spring (Table 9).

Table 9. Unique species detected in only one season at swamp S5.

Species	Autumn	Spring
Acacia rubida	0	1
Dampiera purpurea	0	9
Patersonia species complex	0	1
Cryptandra ericoides	13	0

3.2.9 S23

At swamp S23, 38 unique species were detected in autumn, and 46 unique species were detected in spring monitoring. 8 species detected in spring monitoring were *never* detected in autumn and there was no species detected in autumn monitoring and not in spring (Table 10).

Table 10. Unique species detected in only one season at swamp S23.

Species	Autumn	Spring
Baeckea linifolia	0	1
Bossiaea scolopendria	0	1
Hibbertia riparia species complex	0	2
Leptospermum rotundifolium	0	15
Micrantheum ericoides	0	1
Schizaea bifida	0	1
Tetraria capillaris	0	6
Thysanotus juncifolius	0	2

3.2.10 S86

At swamp S86, 66 unique species were detected in autumn, and 72 unique species were detected in spring monitoring. 13 species detected in spring monitoring were *never* detected in autumn, but only 7 species were detected in autumn monitoring and never in spring (Table 11).

Table 11. Unique species detected in only one season at swamp S86.

Species	Autumn	Spring
Banksia marginata	0	14
Comesperma ericinum f. A	0	1
Conospermum tenuifolium	0	1
Dodonaea camfieldii	0	3
Epacris paludosa	0	3
Eurychorda complanata	0	1
Goodenia hedercacea/ heterophylla Sp_ complex	0	5
Hybanthus monopetalus	0	1
Olax stricta	0	1
Orchidaceae indeterminate	0	1
Persoonia levis	0	1
Pultenaea divaricata	0	31
Schoenus brevifolius/ lepidosperma sp complex	0	8
Allocasuarina littoralis	1	0
Bossiaea heterophylla	1	0
Brachyloma Monotoca Lissanthe Leucopogon complex	1	0
Drosera peltata	5	0
Epacris microphylla	1	0
Epacris obtusifolia	2	0
Persoonia lanceolata	1	0

3.2.11 S87

At swamp S87, 41 unique species were detected in autumn, and 39 unique species were detected in spring monitoring. 4 species detected in spring monitoring were *never* detected in autumn, yet only 6 species were detected in autumn monitoring and never in spring (Table 12).

Table 12. Unique species detected in only one season at swamp S87.

Species	Autumn	Spring
Adiantum aethiopicum	0	37
Calochilus campestris	0	3
Hakea dactyloides/ salicifolia Sp_ complex	0	1
Lachnagrostis filiformis	0	1
Comesperma defoliatum	3	0
Comesperma sphaerocarpum	2	0
Genoplesium species complex	9	0
Hakea teretifolia/ sericea sp complex	1	0
Pterostylis parviflora	2	0
Tetraria capillaris	1	0

3.2.12 S88

At swamp S88, 36 unique species were detected in autumn, and 40 unique species were detected in spring monitoring. 5 species detected in spring monitoring were *never* detected in autumn, but only 1 species was detected in autumn monitoring and never in spring (Table 13).

Table 13. Unique species detected in only one season at swamp S88.

Species	Autumn	Spring
Blandfordia Burchardia Caladenia Haemodorum Microtis Thelymitra species complex	0	2
Drosera peltata	0	3
Drosera spatulata	0	1
Gahnia Sp_ complex	0	3
Panicum simile	0	4
Tetrarrhena juncea	30	0

3.2.13 S15A(1)

At swamp S15A(1), 51 unique species were detected in autumn, and 52 unique species were detected in spring monitoring. 4 species detected in spring monitoring were *never* detected in autumn, and 3 species were detected in autumn monitoring and never in spring (Table 14).

Table 14. Unique species detected in only one season at swamp S15A(1).

Species	Autumn	Spring
Baumea acuta	0	12
Brachyloma Monotoca Lissanthe Leucopogon complex	0	8
Lomandra cylindrica/ filiformis/ micrantha sp complex	0	1
Tetrarrhena juncea	0	17
Fleshy lily	3	0
Lepidosperma filiforme/ urophorum complex	1	0
Thysanotus juncifolius	5	0

3.2.14 S22

At swamp S22, 43 unique species were detected in autumn, and 45 unique species were detected in spring monitoring. 6 species detected in spring monitoring were *never* detected in autumn, but only 4 species were detected in autumn monitoring and never in spring (Table 15).

Table 15. Unique species detected in only one season at swamp S22.

Species	Autumn	Spring
Banksia ericifolia	0	2
Epacris paludosa	0	18
Gleichenia dicarpa/ microphylla sp complex	0	2
Stylidium sp_ complex	0	1
Thysanotus juncifolius	0	1
Utricularia species complex	0	2
Actinotus minor	1	0
Baumea acuta	1	0
Boronia parviflora	8	0
Omphacomeria acerba	1	0

3.2.15 S33

At swamp S33, 41 unique species were detected in autumn, and 43 unique species were detected in spring monitoring. 6 species detected in spring monitoring were *never* detected in autumn, and 4 species were detected in autumn monitoring and never in spring (Table 16).

Table 16. Unique species detected in only one season at swamp S33.

Species	Autumn	Spring
Blandfordia Burchardia Caladenia Haemodorum Microtis Thelymitra species complex	0	1
Entolasia species complex	0	1
Gonocarpus sp_ complex	0	1
Lepidosperma neesii/ Ptilothrix deusta complex	0	6
Persoonia levis	0	2
Pittosporum undulatum	0	1
Actinotus minor	1	0
Baumea acuta	1	0
Cyclosorus interruptus	1	0
Mitrasacme polymorpha/ pilosa species complex	3	0

3.3 Species composition

As per Task 1B, multivariate generalized linear models were fit to impact-swamp specific data to investigate seasonal differences in species composition. No seasonal differences between swamps were detected for all impact swamps.

Table 17. The total number of unique species, proportion of species detected only once and the output of the full model for each impact swamp monitored in 2020.

Site	ANOVA test of full model				
	##	Res.Df	Df.diff	Dev	Pr(>Dev)
S15A(2)	## prepost	73	1	110.1676	0.114
	## season	71	2	114.1324	0.573
	## prepost:season	70	1	33.5505	0.848
	##	Res.Df	Df.diff	Dev	Pr(>Dev)
S15B	## prepost	110	1	457.76891	0.001
	## season	107	3	159.99260	0.425
	## prepost:season	106	1	33.05054	0.795
	##	Res.Df	Df.diff	Dev	Pr(>Dev)
S11	## prepost	108	1	238.47657	0.001
	## season	106	2	66.15247	0.982
	## prepost:season	105	1	25.84045	0.860
	##	Res.Df	Df.diff	Dev	Pr(>Dev)
S13	## prepost	49	1	113.88036	0.087
	## season	46	3	121.22811	0.948
	## prepost:season	45	1	38.02618	0.608
	##	Res.Df	Df.diff	Dev	Pr(>Dev)
S14	## prepost	29	1	61.81977	0.068
	## season	26	3	97.84020	0.567
	## prepost:season	24	2	41.79814	0.428
	##	Res.Df	Df.diff	Dev	Pr(>Dev)
S1A	## prepost	55	1	48.35067	0.688
	## season	52	3	161.84377	0.786
	## prepost:season	51	1	52.17521	0.392
	##	Res.Df	Df.diff	Dev	Pr(>Dev)
S1B	## prepost	76	1	294.17440	0.001
	## season	74	2	120.68732	0.468
	## prepost:season	73	1	13.92142	0.986
	##	Res.Df	Df.diff	Dev	Pr(>Dev)
S5	## prepost	55	1	31.978556	0.632
	## season	53	2	54.700126	0.909
	## prepost:season	52	1	9.553214	1.000
	##	Res.Df	Df.diff	Dev	Pr(>Dev)
S14	## prepost	29	1	61.81977	0.068
	## season	26	3	97.84020	0.567
	## prepost:season	24	2	41.79814	0.428
	##	Res.Df	Df.diff	Dev	Pr(>Dev)
S23	## prepost	26	1	29.60985	0.670
	## season	23	3	81.75128	0.908
	## prepost:season	22	1	13.07138	0.954

4 Conclusions

No seasonal differences were detected in total species richness (Section 2) or species composition (Section 4). When inspecting individual species, most species were more readily detected in spring compared to autumn. However, the removal of autumn surveying would mean species detected only in autumn could potentially be missed (this ranged between a single species and up to seven unique species at individual swamps, see Section 3).

5 References

Holm, S. (1979). A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics 6, 65–70.

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL *https://www.R-project.org/*.

Analytical Edge (2021). *Analysis of flora species composition at impact swamps within the Dendrobium region, Data collected up to, and including, 2020*. Unpublished report submitted to Niche.

Annex 4 Littlejohn's Tree Frog detection data (2007 – 2021)

Table 53: Littlejohn's Tree Frog detection data, including treatments as applied in the current (2021) iteration of the program

Transect	Life stage	Transect distance (m) 2006-2019	Transect distance (m) 2020-2021	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Control																			
DC8	Adults	410	432.0865478								5	6	17	8	8	1	8	8	0
DC8	Eggmass	410	432.0865478								2	1	0	228	7	49	24	0	0
DC8	Tadpoles	410	432.0865478								12	20	39	21	50	0	100	4	4
ND1	Adults	730	742.4585914						23	0	4	15	7	15	17	24	9	21	2
ND1	Eggmass	730	742.4585914						0	0	1	0	36	110	0	36	70	15	119
ND1	Tadpoles	730	742.4585914						15	2	22	1	5	596	105	0	380	1054	69
SC7(1)	Adults	460	473.782904	21	27	0	0	0	1	7	7	3	7	4	19	2	17	20	5
SC7(1)	Eggmass	460	473.782904	0	2	0	0	0	0	0	55	75	45	33	8	0	23	6	57
SC7(1)	Tadpoles	460	473.782904	0	10	1	47	5	0	0	25	15	0	264	35	208	125	241	111
SC7(2)	Adults	420	435.6663668			0	6	7	6	11	6	7	15	18	19	2	2	0	2
SC7(2)	Eggmass	420	435.6663668			20	0	21	0	4	44	10	93	22	0	0	8	0	1
SC7(2)	Tadpoles	420	435.6663668			15	47	603	40	70	262	96	80	3	144	21	60	373	191
SC7A	Adults	440	453.4875994	12	0	0	6	7	29	23	15	4	22	14	19	0	7	5	3
SC7A	Eggmass	440	453.4875994	0	0	15	0	41	2	0	9	147	167	56	25	4	23	0	44
SC7A	Tadpoles	440	453.4875994	0	10	75	194	864	145	271	67	275	127	1987	162	32	519	634	525
SC8	Adults	300	315.4989824		2	1	2	3	0	4	0	3	1	2	1	0	4	9	1
SC8	Eggmass	300	315.4989824							4	7	1	9	6	0	7	9	0	10
SC8	Tadpoles	300	315.4989824						100	4	82	211	260	1058	74	2	2	190	6
WC10	Adults	330	346.441049					15	5	22	7	30	13	44	9	1	110	27	4
WC10	Eggmass	330	346.441049					21	0	2	138	16	95	30	10	2	38	59	120

Transect	Life stage	Transect distance (m) 2006-2019	Transect distance (m) 2020-2021	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
WC10	Tadpoles	330	346.441049					208	30	59	46	42	21	40	63	61	684	488	149
WC11	Adults	160	176.2467235					1	5	4	2	7	4	3	0	0	2	6	2
WC11	Eggmass	160	176.2467235					1	4	0	17	0	22	2	38	0	5	2	6
WC11	Tadpoles	160	176.2467235					128	39	2	80	68	7	356	210	0	841	45	38
Impact																			
6CDL	Adults	70	88.93301694				0	0	1	4	0	0	1	0	0	0	0	1	0
6CDL	Eggmass	70	88.93301694				0	0	0	9	39	0	13	10	4	0	0	0	2
6CDL	Tadpoles	70	88.93301694				200	0	38	5	347	180	149	1093	120	43	50	422	765
DC1	Adults	630	641.9570287								3	1	2	9	2	1	2	6	0
DC1	Eggmass	630	641.9570287								0	0	7	11	0	0	1	6	10
DC1	Tadpoles	630	641.9570287								0	0	0	15	4	12	4	108	6
DC13	Adults	610	640.9076152					8	12	9	2	0	2	5	5	0	0	4	0
DC13	Eggmass	610	640.9076152					11	0	4	0	0	30	56	8	0	0	17	13
DC13	Tadpoles	610	640.9076152					23	4	19	0	9	36	1079	27	0	9	46	169
LA2	Adults	840	593.1953127												3	1	19	7	2
LA2	Eggmass	840	593.1953127												70	0	16	1	0
LA2	Tadpoles	840	593.1953127												73	1	353	241	0
LA4A	Adults	190	208.9022708		1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
LA4A	Eggmass	190	208.9022708		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LA4A	Tadpoles	190	208.9022708		0	0	0	0	0	0	0	0	0	0	0	0	0	3	2
SC10(1)	Adults	530	538.6362013	9	19	0	0	10	0	1	4	16	8	18	15	31	15	25	19
SC10(1)	Eggmass	530	538.6362013	0	0	0	0	0	0	0	10	6	65	2	7	46	23	4	0

Transect	Life stage	Transect distance (m) 2006-2019	Transect distance (m) 2020-2021	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
SC10(1)	Tadpoles	530	538.6362013	7	0	4	0	5	0	3	0	3	0	0	4	142	27	0	0
SC10(2)	Adults	940	950.1081192	21	19	30	26	23	56	4	30	26	13	20	23	39	9	41	11
SC10(2)	Eggmass	940	950.1081192	0	0	0	4	9	3	6	1	3	29	101	104	194	66	30	92
SC10(2)	Tadpoles	940	950.1081192	0	0	16	81	16	13	58	77	164	22	963	89	91	862	292	138
SC10C	Adults	460	480.7039394	9	20	0	11	7	15	1	0	0	4	4	0	5	0	1	0
SC10C	Eggmass	460	480.7039394	0	0	0	0	3	0	11	0	0	28	1	0	2	0	0	0
SC10C	Tadpoles	460	480.7039394	0	2	10	17	44	9	20	27	4	0	0	0	0	0	0	0
WC15	Adults	460	477.6414963						5	2	7	10	10	40	9	7	7	0	1
WC15	Eggmass	460	477.6414963						1	0	0	0	13	8	38	2	0	0	0
WC15	Tadpoles	460	477.6414963						0	4	1	1	36	27	46	28	2	200	0
WC17	Adults	160	177.0954574						5	0	1	0	0	2	3	0	4	0	0
WC17	Eggmass	160	177.0954574						3	0	2	0	0	0	0	0	0	0	0
WC17	Tadpoles	160	177.0954574						87	0	1	0	0	0	120	0	2	125	63
WC21	Adults	1380	1399.216363								2	1	0	13	4	8	9	6	3
WC21	Eggmass	1380	1399.216363								0	0	4	15	25	13	4	0	2
WC21	Tadpoles	1380	1399.216363								0	0	148	719	112	38	100	157	95
Pre mining																			
ND2	Adults	110	123.326404					0	0	3	0	0	0	1	0	0	0	20	0
ND2	Eggmass	110	123.326404					0	0	0	0	0	0	0	0	0	0	0	0
ND2	Tadpoles	110	123.326404					0	0	0	0	0	0	0	0	0	0	86.999995	8
NDC	Adults	540	554.8333096		3	9	2	2	8	3	3	9	10	10	4	0	13	23	6

Transect	Life stage	Transect distance (m) 2006-2019	Transect distance (m) 2020-2021	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
NDC	Eggmass	540	554.8333096		0	0	0	1	1	0	0	0	0	0	0	0	0	0	1
NDC	Tadpoles	540	554.8333096		0	0	0	1	0	8	0	0	11	32	29	403	9	46	19

Annex 5 Statistical analysis – Littlejohn's Treefrog (Littlejohn's Tree Frog)

Pool characteristics and trends recorded across Dendrobium Area 3

The results below are the raw outputs from the statistical analysis for Dendrobium Area 3 examining distances to longwalls and the presence of flocculant.

Table 54: Analysis of deviance for negative binomial GLM's fitted to the count of frogs, as a function of Longwall (Distance to Longwall), and Size of pool (4 sizes).

Life stage	ANOVA	DF	Deviance Residual	Residual DF	Residual Deviance	p-value
Adults	Longwall	1	2.403	193	76.749	0.121
	Size	3	8.575	190	68.174	**0.036**
	Longwall:Size	3	0.1	187	68.073	0.992
Tadpoles	Longwall	1	0	193	226.217	1
	Size	3	0	190	271.241	1
	Longwall:Size	3	201.97	187	69.27	**<.0001**
Eggmass	Longwall	1	0.746	193	52.31	0.388
	Size	3	4.03	190	48.279	0.258
	Longwall:Size	3	0.728	187	47.552	0.867

Table 55: Analysis of deviance for negative binomial GLM's fitted to the count of frogs, as a function of flocculant, and treatment.

Life stage	ANOVA	DF	Deviance Residual	Residual DF	Residual Deviance	p-value
Adults	Flocculant	1	7.98	320	121.27	**0.005**
	Treatment	1	0.48	319	120.79	0.489
	Flocculant:Treatment	1	1.17	318	119.62	0.279
Tadpoles	Flocculant	1	1.75	320	162.97	0.186
	Treatment	1	0.00	319	276.12	1.000
	Flocculant:Treatment	1	114.37	318	161.74	**<2e-16**
Eggmass	Flocculant	1	4.21	320	165.27	**0.040**
	Treatment	1	10.98	319	154.30	**0.001**
	Flocculant:Treatment	1	0.03	318	154.26	0.861

Dendrobium Area 3A

The results below are the output and raw data from the statistical analysis for Dendrobium Area 3A.

Table 56: ANOVA table of linear models for Adults, Tadpoles, Eggmasses, comparing counts over 2020-2021 between Control and Impact sites.

Life stage	ANOVA	Numerator DF	Denominator DF	F-value	p-value
Adults	(Intercept)	1	10	7.55	0.02

Life stage	ANOVA	Numerator DF	Denominator DF	F-value	p-value
	Treatment	1	10	0.72	0.51
	year	1	10	12.53	**0.005**
	Treatment:year	1	10	0.65	0.542
Tadpoles	(Intercept)	1	20	26.10	**<.001**
	Treatment	1	20	4.24	0.05
	year	1	20	4.47	**0.047**
	Treatment:year	1	20	0.94	0.344
Eggmass	(Intercept)	1	20	6.24	**0.02**
	Treatment	1	20	1.57	0.23
	year	1	20	1.63	0.22
	Treatment:year	1	20	0.61	0.55

Pool characteristics

Table 57: Analysis of deviance for GLM fitted to the count of frogs, as predicted by Treatment (Control and Impact) and Size of pool (4 sizes).

Life stage	ANOVA	DF	Deviance Residual	Residual DF	Residual Deviance	p-value
Adults	Pool Size	3	13.68	207	113.18	**0.003**
	Treatment	1	2.86	206	110.31	0.091
	Pool Size: Treatment	3	6.80	203	103.51	0.079
Tadpoles	Pool Size	3	9.21	207	147.76	**0.027**
	Treatment	1	0.00	206	154.78	1.000
	Pool Size: Treatment	3	22.49	203	132.30	**<.001**
Eggmass	Pool Size	3	9.19	207	138.77	**0.027**
	Treatment	1	3.30	206	135.47	0.069
	Pool Size: Treatment	3	2.72	203	132.75	0.437

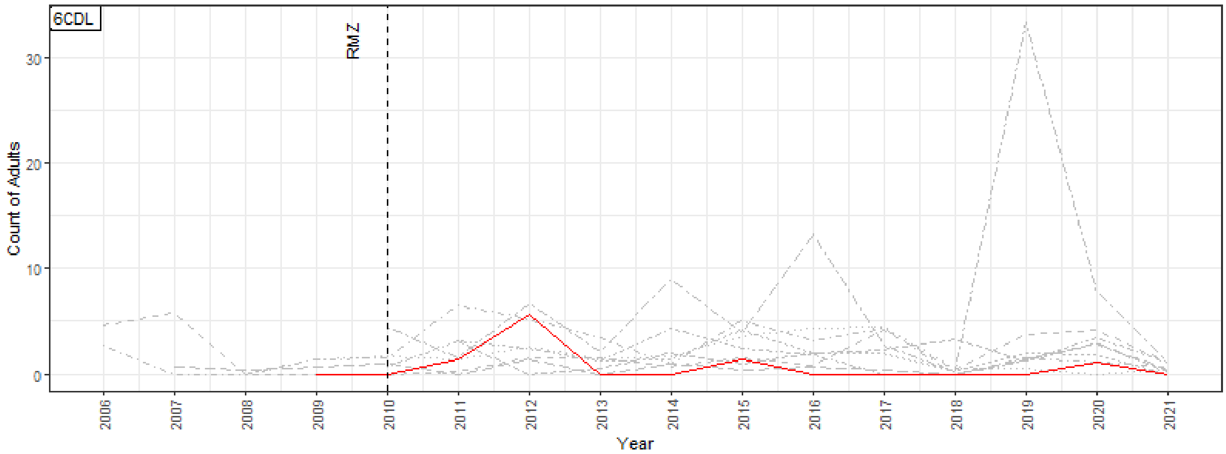
6CDL

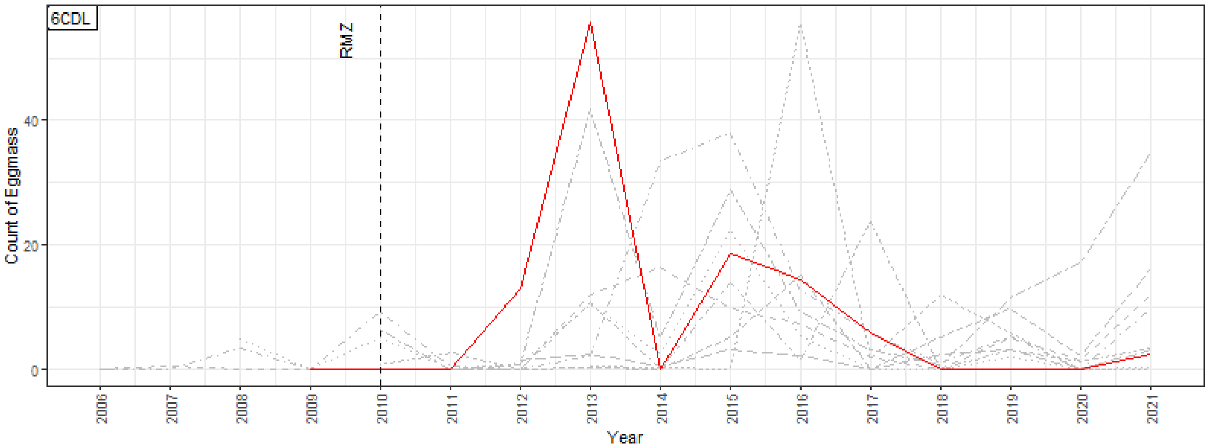
Table 58: ANOVA results for 6CDL

6CDL	ANOVA	DF	F-value	p-value
Adults	(Intercept)	1.00	11.31	<.0001*
	Mine_status	2.00	25.98	<.0001*
Tadpoles	(Intercept)	1.00	11.48	<.0001*
	Mine_status	3.00	6.48	<.0001*
Eggs	(Intercept)	1.00	61.95	<.0001*
	Mine_status	2.00	1.24	0.29

Table 59: Tukey HSD test for 6CDL

6CDL	Comparison	Estimate	Standard Error	Z-value	p-value
Adults	Pre-CONTROL = 0	-15.10	2.48	-6.09	<.0001*
	RMZ - CONTROL = 0	-14.29	2.00	-7.15	<.0001*
	RMZ - Pre = 0	0.81	1.59	0.51	0.86
Tadpoles	Pre-CONTROL = 0	-13.46	3.66	-3.68	<.0001*
	RMZ - CONTROL = 0	-16.70	4.32	-3.87	<.0001*
	RMZ - Pre = 0	-3.24	3.24	-1.00	0.74
Eggs	Pre-CONTROL = 0	-15.10	15.03	-1.00	0.55
	RMZ - CONTROL = 0	-5.98	4.72	-1.27	0.39
	RMZ - Pre = 0	9.12	15.52	0.59	0.81





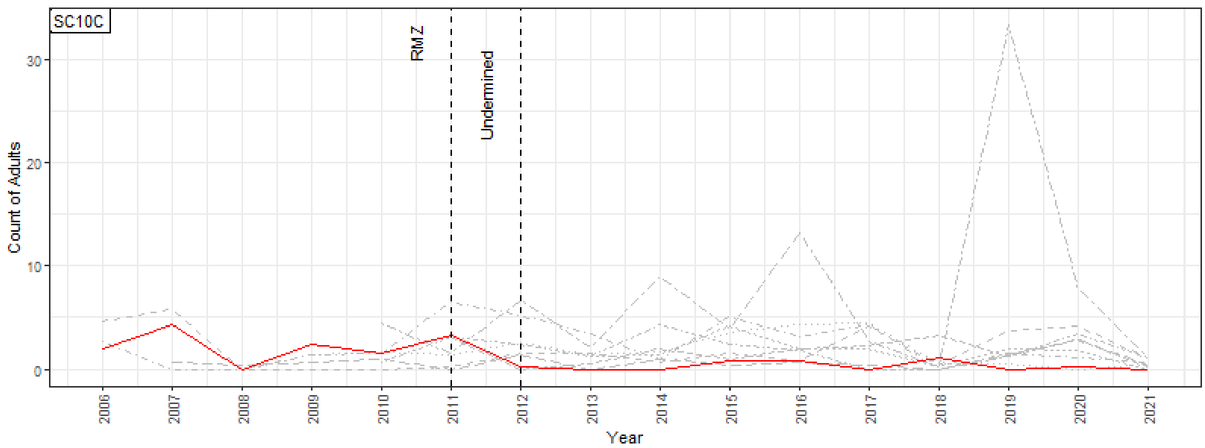
SC10C

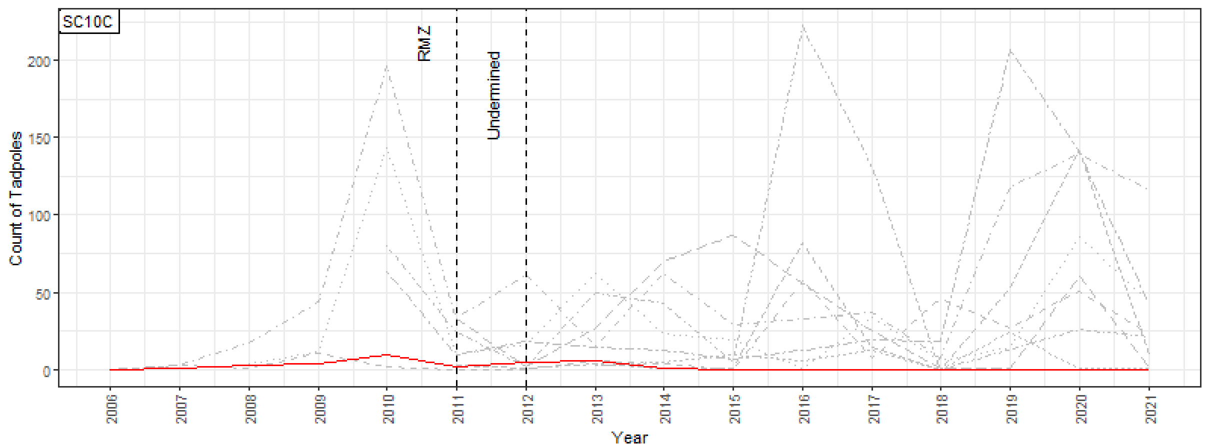
Table 60: ANOVA results for SC10C

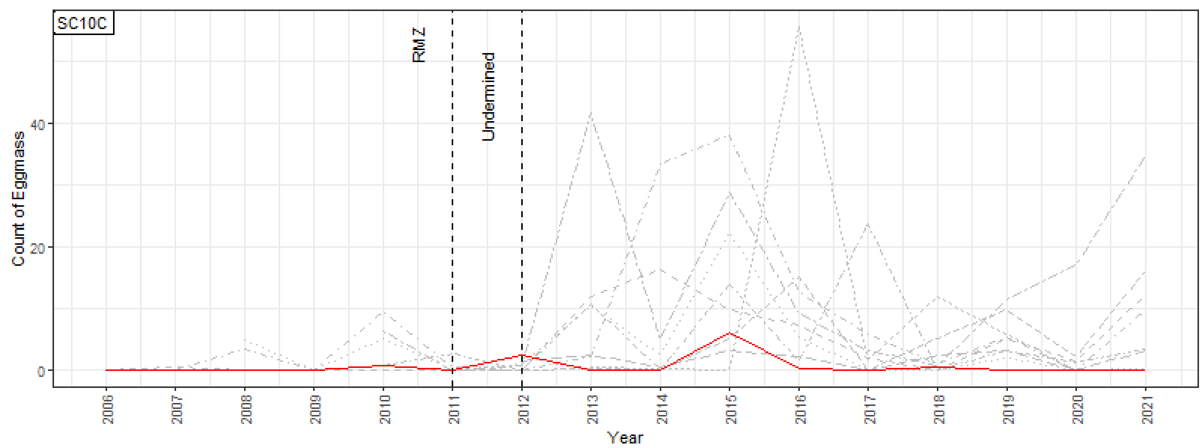
SC10C	ANOVA	DF	F-value	p-value
Adults	(Intercept)	1.00	33.13	<.0001*
	Mine_status	3.00	23.85	<.0001*
Tadpoles	(Intercept)	1.00	27.59	<.0001*
	Mine_status	3.00	14.38	<.0001*
Eggs	(Intercept)	1.00	10.05	<.0001*
	Mine_status	3.00	18.04	<.0001*

Table 61: Tukey HSD test for SC10C

SC10C	Comparison	Estimate	Standard Error	Z-value	p-value
Adults	Pre-CONTROL = 0	-12.07	1.86	-6.50	<.0001*
	RMZ - CONTROL = 0	-10.85	2.01	-5.40	<.0001*
	Mined under - CONTROL = 0	-13.78	1.84	-7.51	<.0001*
	RMZ - Pre = 0	1.22	0.94	1.30	0.53
	Mined under - Pre = 0	-1.72	0.47	-3.66	<.0001*
	Mined under - RMZ = 0	-2.94	0.90	-3.27	<.0001*
Tadpoles	Pre-CONTROL = 0	-10.93	2.14	-5.11	<.0001*
	RMZ - CONTROL = 0	-12.15	3.12	-3.90	<.0001*
	Mined under - CONTROL = 0	-13.00	1.98	-6.55	<.0001*
	RMZ - Pre = 0	-1.22	2.78	-0.44	0.97
	Mined under - Pre = 0	-2.07	1.39	-1.49	0.43
	Mined under - RMZ = 0	-0.85	2.66	-0.32	0.99
Eggs	Pre-CONTROL = 0	-13.98	1.93	-7.23	<.0001*
	RMZ - CONTROL = 0	-14.11	2.35	-6.01	<.0001*
	Mined under - CONTROL = 0	-13.20	1.88	-7.03	<.0001*
	RMZ - Pre = 0	-0.13	1.63	-0.08	1.00
	Mined under - Pre = 0	0.78	0.82	0.96	0.76
	Mined under - RMZ = 0	0.91	1.56	0.59	0.93







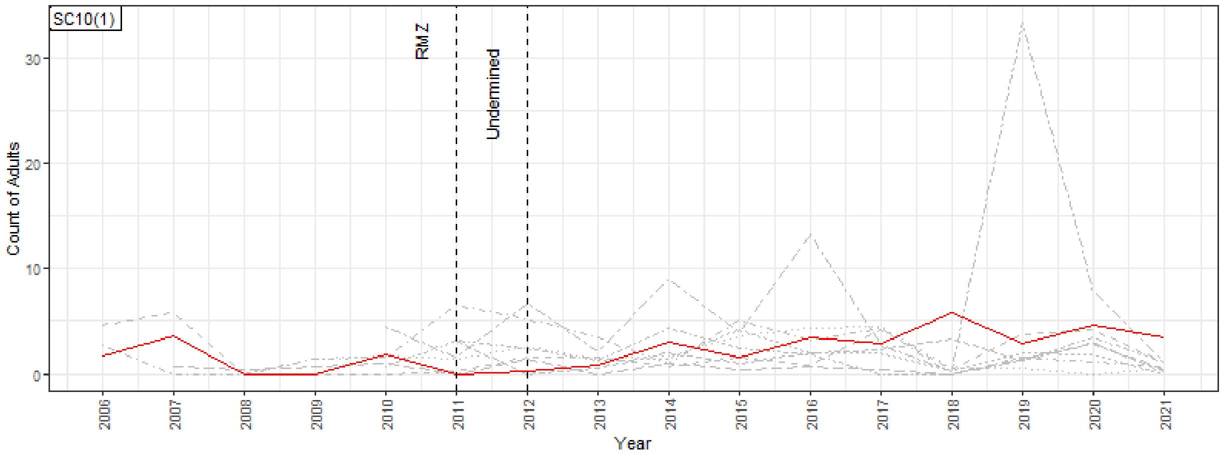
SC10(1)

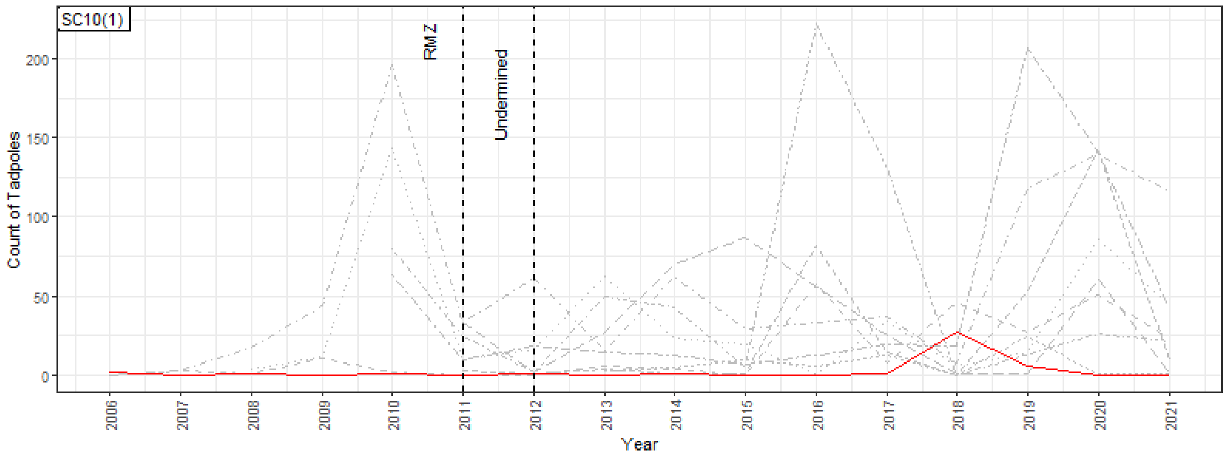
Table 62: ANOVA results for SC10(1)

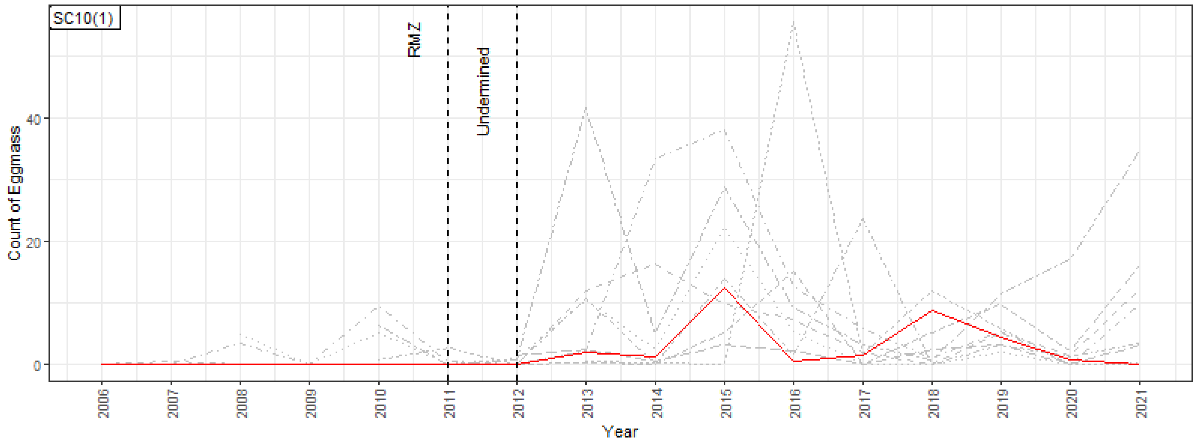
SC10(1)	ANOVA	DF	F-value	p-value
Adults	(Intercept)	1.00	55.04	<.0001*
	Mine_status	3.00	15.48	<.0001*
Tadpoles	(Intercept)	1.00	11.48	<.0001*
	Mine_status	3.00	6.48	<.0001*
Eggs	(Intercept)	1.00	28.41	<.0001*
	Mine_status	3.00	13.82	<.0001*

Table 63: Tukey HSD test for SC10(1)

SC10(1)	Comparison	Estimate	Standard Error	Z-value	p-value
Adults	Pre-CONTROL = 0	-12.67	1.93	-6.55	<.0001*
	RMZ - CONTROL = 0	-14.11	2.35	-6.00	<.0001*
	Mined under - CONTROL = 0	-11.25	1.88	-6.00	<.0001*
	RMZ - Pre = 0	-1.43	1.64	-0.88	0.80
	Mined under - Pre = 0	1.42	0.82	1.74	0.28
	Mined under - RMZ = 0	2.85	1.57	1.82	0.24
Tadpoles	Pre-CONTROL = 0	-13.46	3.66	-3.68	<.0001*
	RMZ - CONTROL = 0	-16.70	4.32	-3.87	<.0001*
	Mined under - CONTROL = 0	-16.87	4.32	-3.91	<.0001*
	RMZ - Pre = 0	-3.24	3.24	-1.00	0.74
	Mined under - Pre = 0	-3.41	3.24	-1.05	0.71
	Mined under - RMZ = 0	-0.17	3.97	-0.04	1.00
Eggs	Pre-CONTROL = 0	-14.11	2.30	-6.14	<.0001*
	RMZ - CONTROL = 0	-14.11	3.64	-3.88	<.0001*
	Mined under - CONTROL = 0	-11.03	2.07	-5.33	<.0001*
	RMZ - Pre = 0	0.00	3.46	0.00	1.00
	Mined under - Pre = 0	3.07	1.73	1.78	0.27
	Mined under - RMZ = 0	3.07	3.31	0.93	0.78







SC10(2)

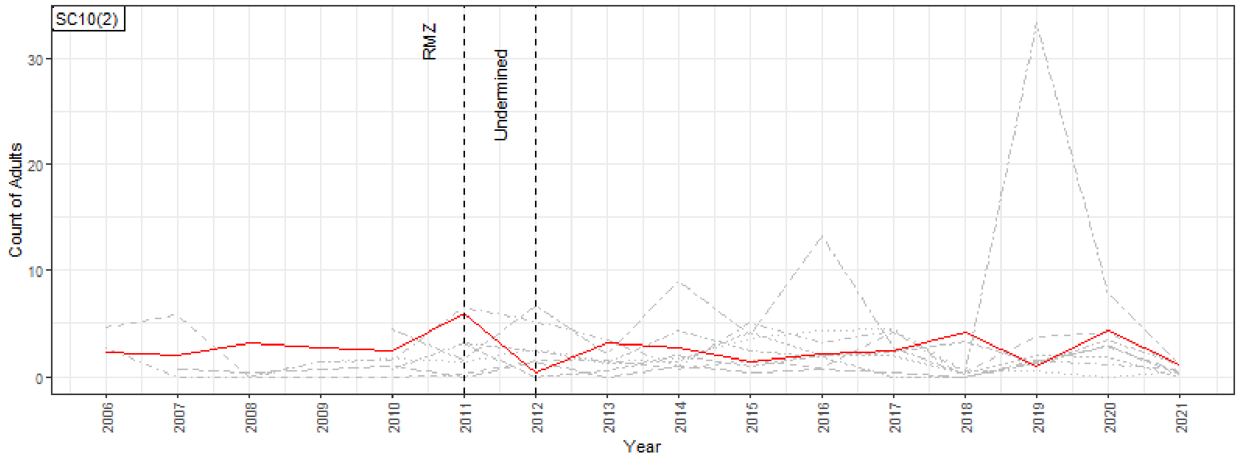
Table 64: ANOVA results for SC10(2)

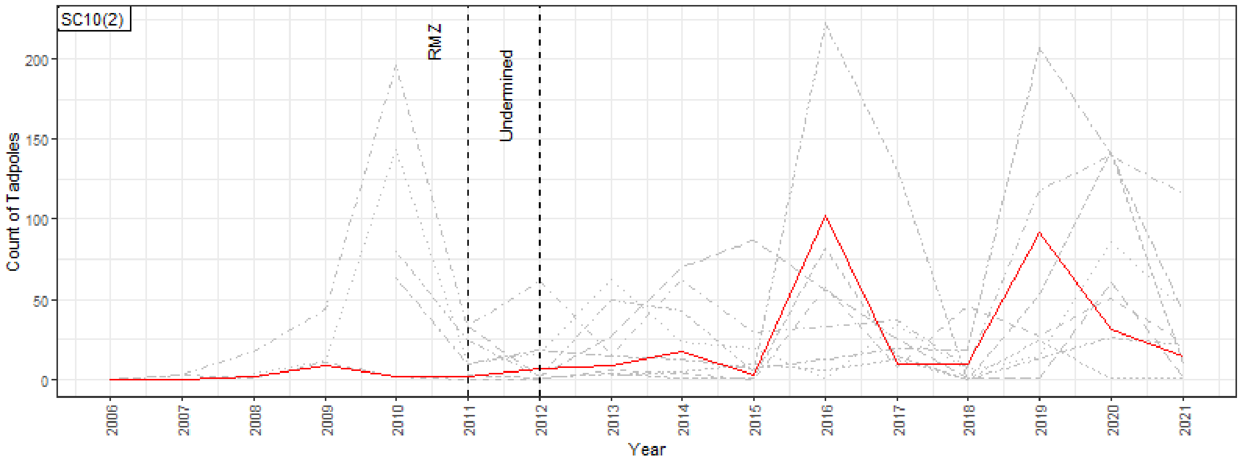
SC10(2)	ANOVA	DF	F-value	p-value
Adults	(Intercept)	1.00	67.50	<.0001*
	Mine_status	3.00	1.35	0.26
Tadpoles	(Intercept)	1.00	67.50	<.0001*
	Mine_status	3.00	1.35	0.26
Eggs	(Intercept)	1.00	52.15	<.0001*
	Mine_status	3.00	8.77	<.0001*

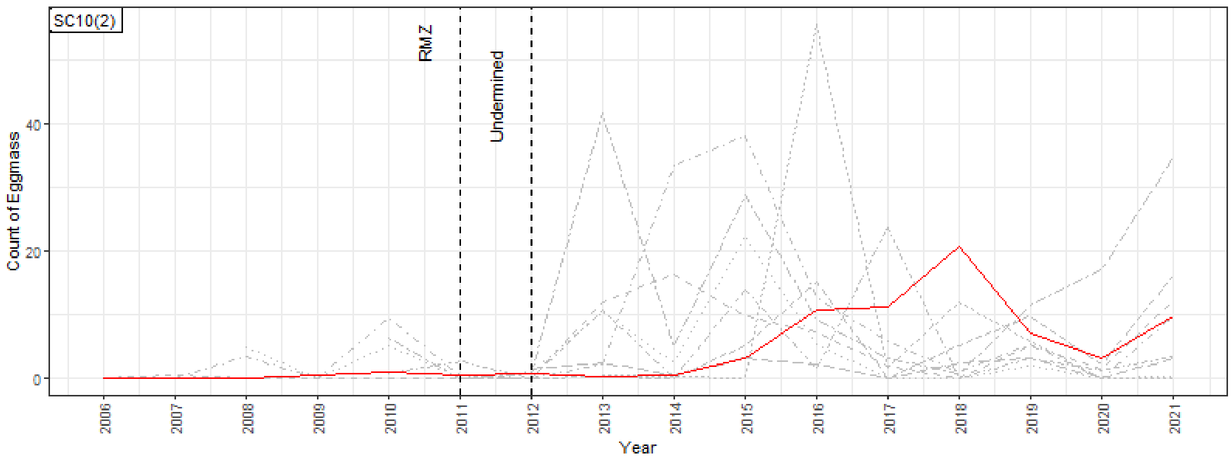
Table 65: Tukey HSD test for SC10(2)

SC10(2)	Comparison	Estimate	Standard Error	Z-value	p-value
Adults	Pre-CONTROL = 0	-11.58	1.87	-6.18	<.0001*
	RMZ - CONTROL = 0	-8.15	2.09	-3.90	<.0001*
	Mined under - CONTROL = 0	-11.82	1.85	-6.41	<.0001*
	RMZ - Pre = 0	3.43	1.13	3.03	0.01*
	Mined under - Pre = 0	-0.24	0.57	-0.42	0.97
	Mined under - RMZ = 0	-3.67	1.08	-3.38	0.00*
Tadpoles	Pre-CONTROL = 0	-11.70	12.53	-0.93	0.76
	RMZ - CONTROL = 0	-12.73	27.78	-0.46	0.96
	Mined under - CONTROL = 0	15.16	8.95	1.69	0.30
	RMZ - Pre = 0	-1.02	30.37	-0.03	1.00
	Mined under - Pre = 0	26.87	15.18	1.77	0.26
	Mined under - RMZ = 0	27.89	29.08	0.96	0.75
Eggs	Pre-CONTROL = 0	-13.83	2.86	-4.84	<.0001*
	RMZ - CONTROL = 0	-13.79	5.27	-2.62	0.04*
	Mined under - CONTROL = 0	-7.46	2.40	-3.12	0.01*
	RMZ - Pre = 0	0.04	5.41	0.01	1.00

SC10(2)	Comparison	Estimate	Standard Error	Z-value	p-value
	Mined under - Pre = 0	6.37	2.71	2.35	0.08
	Mined under - RMZ = 0	6.33	5.18	1.22	0.60







WC17

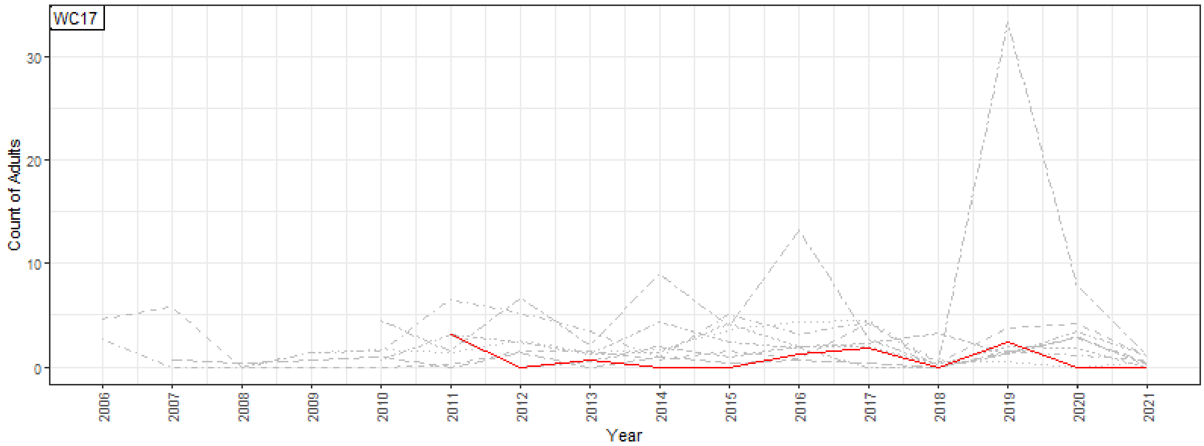
Table 66: ANOVA results for WC17

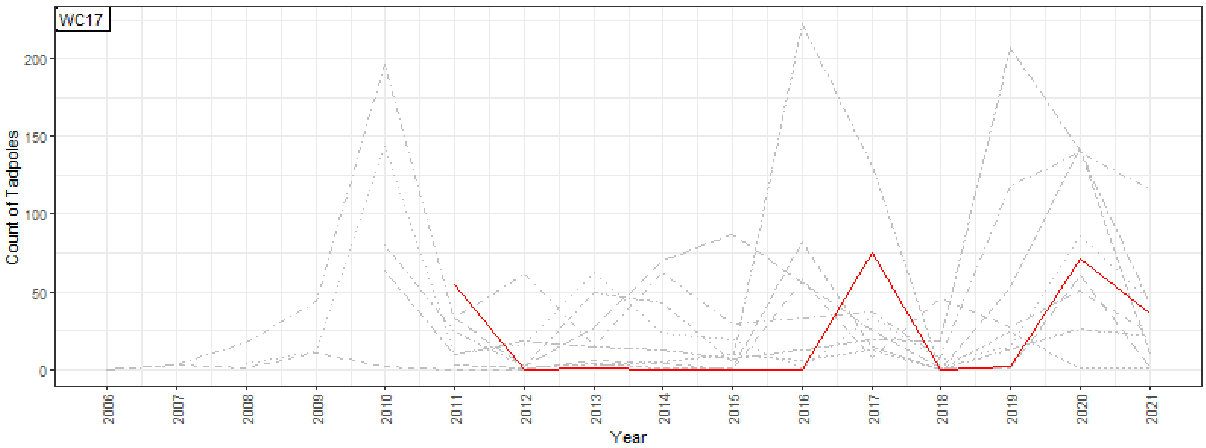
WC17	ANOVA	DF	F-value	p-value
Adults	(Intercept)	1.00	14.41	<.0001*

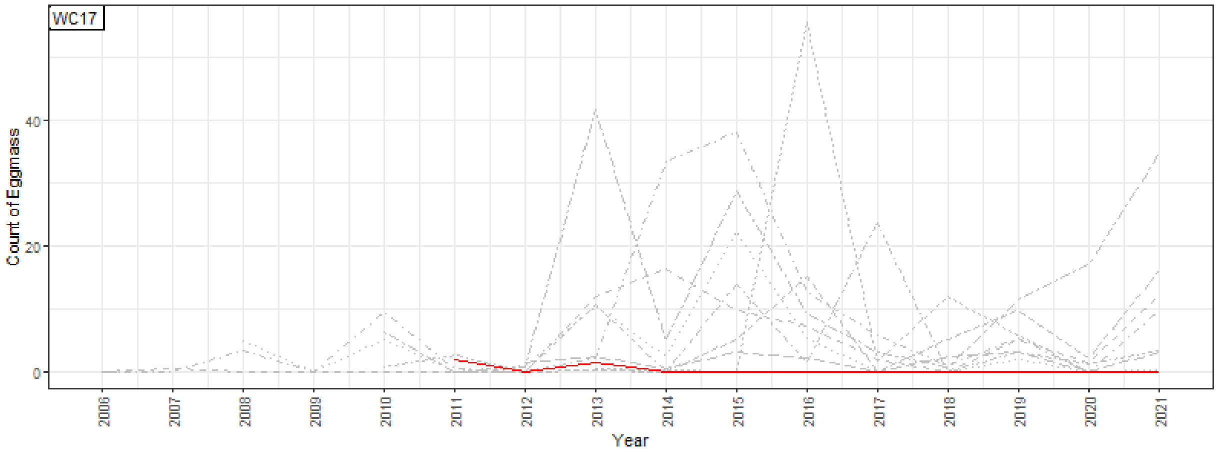
WC17	ANOVA	DF	F-value	p-value
	Mine_status	1.00	48.18	<.0001*
Tadpoles	(Intercept)	1.00	61.27	<.0001*
	Mine_status	1.00	0.62	0.43
Eggs	(Intercept)	1.00	5.02	0.03*
	Mine_status	1.00	53.42	<.0001*

Table 67: Tukey HSD test for WC17

WC17	Comparison	Estimate	Standard Error	Z-value	p-value
Adults	Mined under - CONTROL = 0	-13.49	1.94	-6.94	<.0001*
Tadpoles	Mined under - CONTROL = 0	7.24	9.19	0.79	0.43
Eggs	Mined under - CONTROL = 0	-14.06	1.92	-7.31	<.0001*







WC17
Count of Eggmass
0
20
40
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Year

Dendrobium Area 3B

The results below are the output and raw data from the statistical analysis for Dendrobium Area 3B.

Table 68: ANOVA table of linear models for Adults, Tadpoles, Eggmasses, comparing counts over 2020-2021 between Control and Impact sites

		Numerator DF	Denomiator DF	F-value	p-value
Adults	(Intercept)	1	22	17.63	<.0001
	Treatment	2	22	5.71	**0.01**
	Year	1	22	6.26	**0.02**
	Treatment:Year	2	22	3.33	**0.055**
Tadpoles	(Intercept)	1	22	18.94	**<.0001**
	Treatment	2	22	5.52	**0.011**
	Year	1	22	5.17	**0.033**
	Treatment:Year	2	22	0.89	0.427
Eggmasses	(Intercept)	1	22	6.81	**0.016**
	Treatment	2	22	2.81	0.082
	Year	1	22	0.26	0.616
	Treatment:Year	2	22	1.29	0.295

Pool characteristics

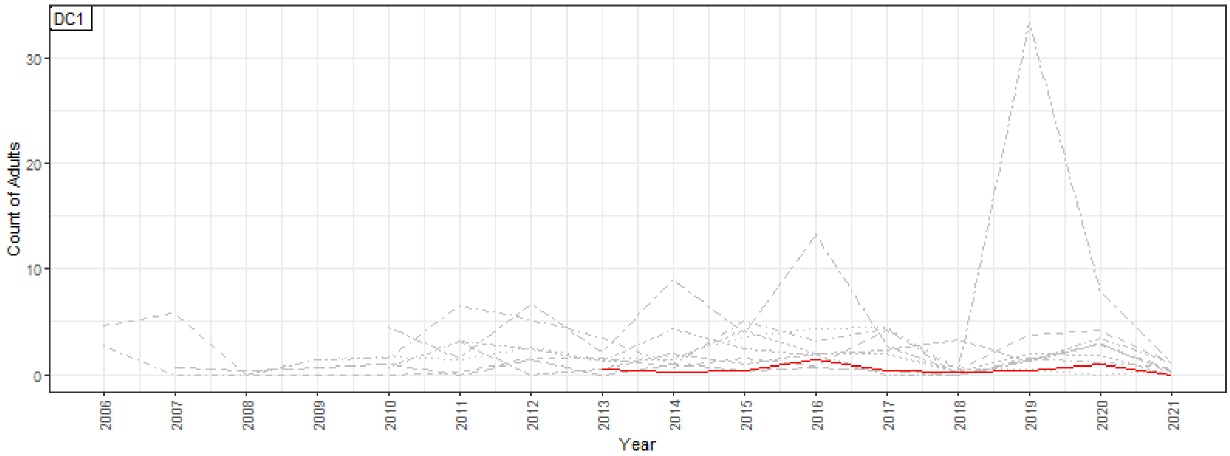
Table 69: Analysis of deviance for GLM fitted to the count of frogs, as predicted by Treatment (Control and Impact) and Size of pool (4 sizes).

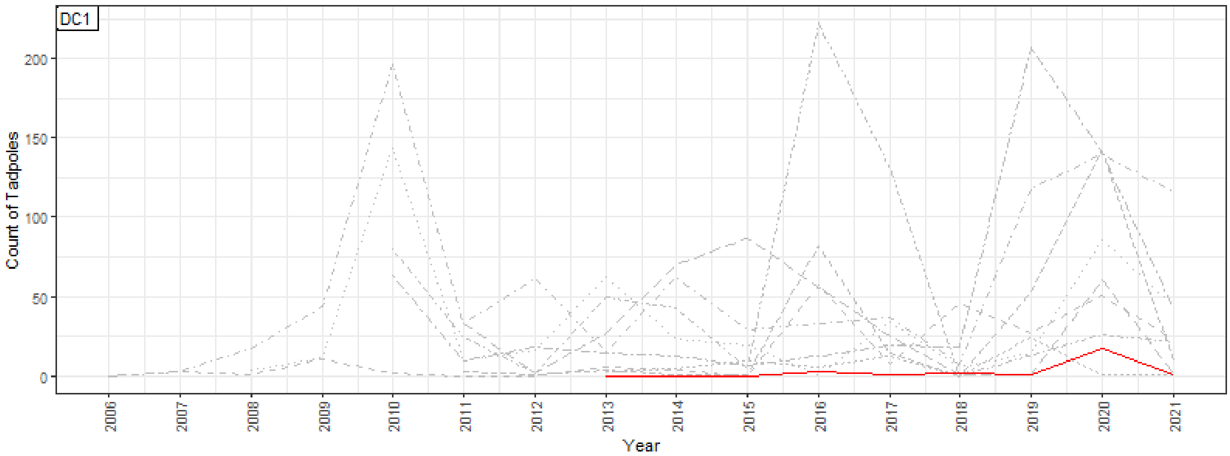
Life stage	ANOVA	DF	Deviance Residual	Residual DF	Residual Deviance	p-value
Adults	Pool Size	3	13.68	207	113.18	**0.003**
	Treatment	1	2.86	206	110.31	0.091
	Pool Size: Treatment	3	6.80	203	103.51	0.079
Tadpoles	Pool Size	3	9.21	207	147.76	**0.027**
	Treatment	1	0.00	206	154.78	1.000
	Pool Size: Treatment	3	22.49	203	132.30	**<.001**
Eggmass	Pool Size	3	9.19	207	138.77	**0.027**
	Treatment	1	3.30	206	135.47	0.069
	Pool Size: Treatment	3	2.72	203	132.75	0.437

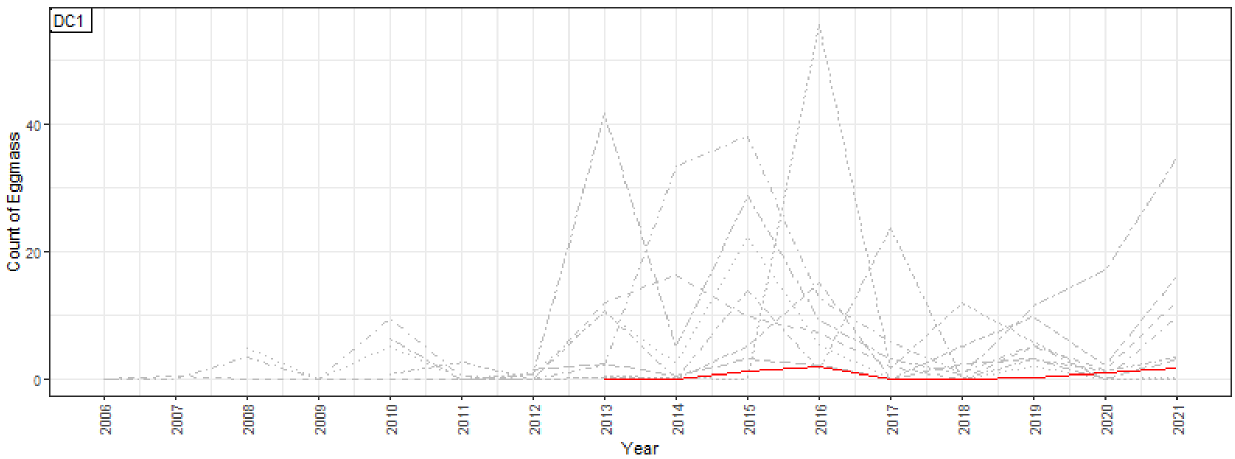
DC(1)

Table 70: ANOVA results for DC(1)

DC(1)	ANOVA	DF	F-value	p-value
Adults	(Intercept)	1.00	13.39	<.0001*
	Mine_status	1.00	47.51	<.0001*
Tadpoles	(Intercept)	1.00	30.44	<.0001*
	Mine_status	1.00	22.42	<.0001*
Eggs	(Intercept)	1.00	11.40	<.0001*
	Mine_status	1.00	46.26	<.0001*







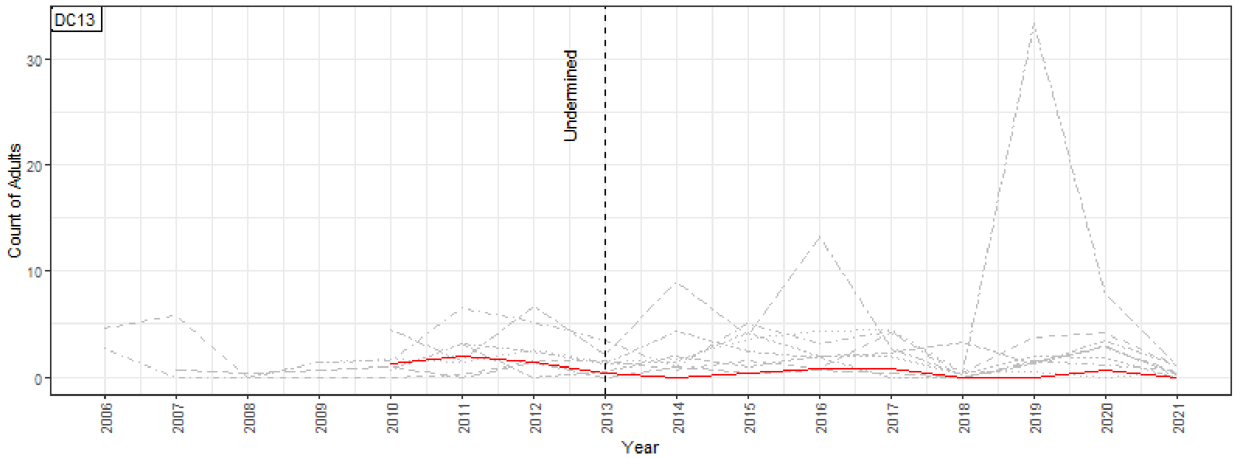
DC13

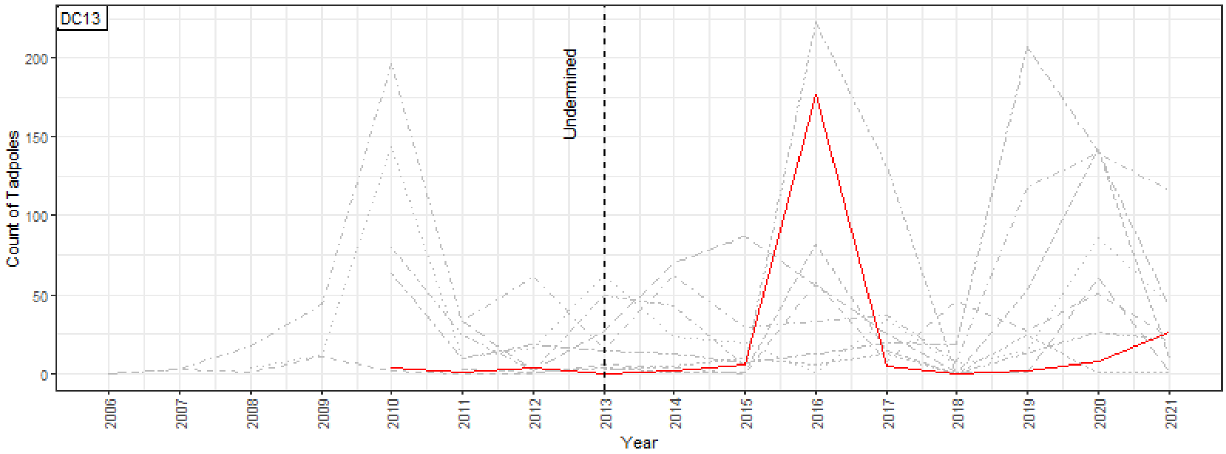
Table 71: ANOVA results for DC13

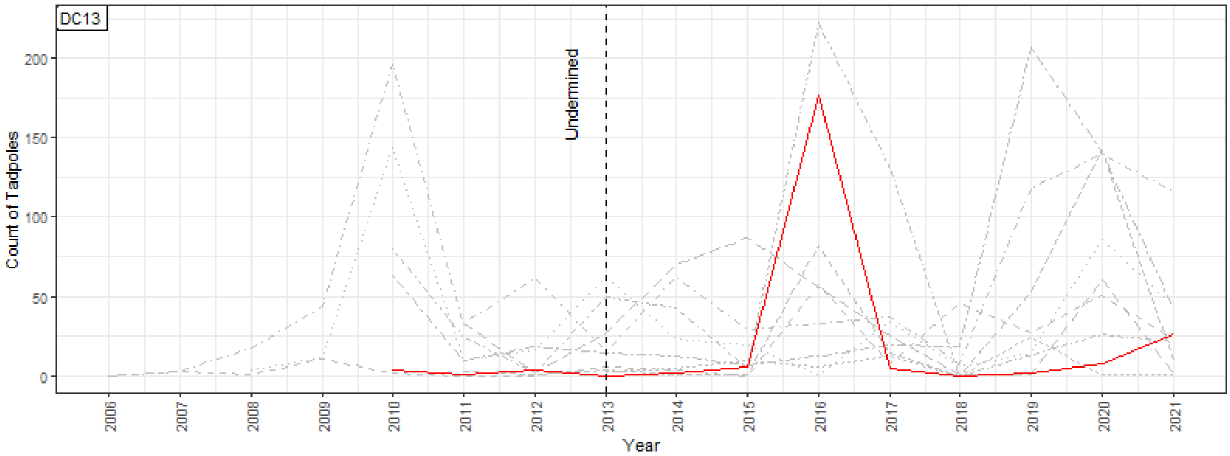
DC13	ANOVA	DF	F-value	p-value
Adults	(Intercept)	1.00	52.06	<.0001*
	Mine_status	2.00	43.98	<.0001*
Tadpoles	(Intercept)	1.00	60.37	<.0001*
	Mine_status	2.00	0.29	0.75
Eggs	(Intercept)	1.00	25.20	<.0001*
	Mine_status	2.00	20.19	<.0001*

Table 72: Tukey HSD test for DC13

DC13	Comparison	Estimate	Standard Error	Z-value	p-value
Adults	Pre-CONTROL = 0	-13.82	2.02	-6.83	<.0001*
	Mined under - CONTROL = 0	-15.08	2.02	-7.47	<.0001*
	Mined under - Pre = 0	-1.26	0.22	-5.86	<.0001*
Tadpoles	Pre-CONTROL = 0	-12.89	27.37	-0.47	0.88
	Mined under - CONTROL = 0	22.34	31.52	0.71	0.75
	Mined under - Pre = 0	-3.41	3.24	-1.05	0.71
Eggs	Pre-CONTROL = 0	-14.58	2.50	-5.83	<.0001*
	Mined under - CONTROL = 0	-13.17	2.19	-6.02	<.0001*
	Mined under - Pre = 0	1.41	1.71	0.83	0.68







LA2

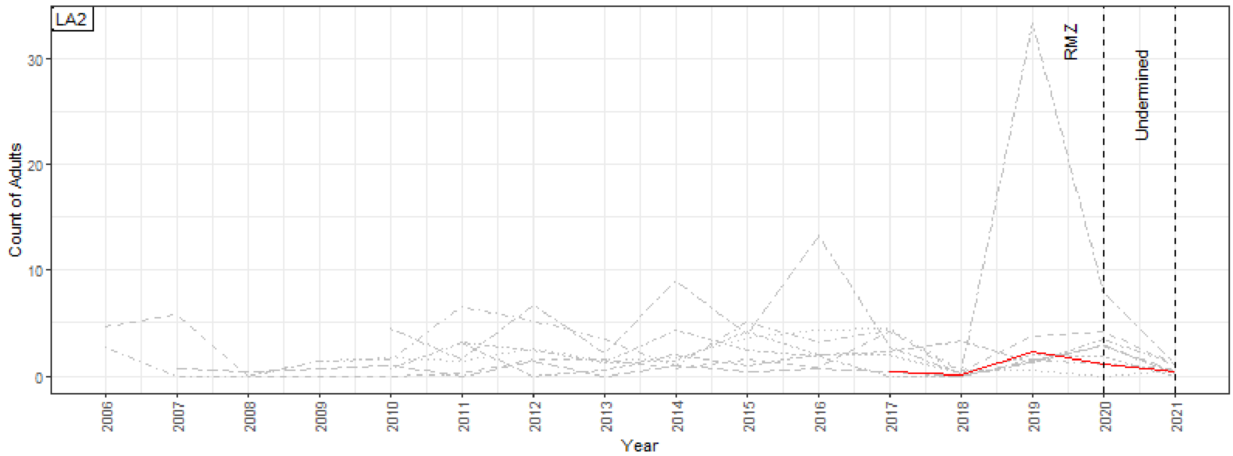
Table 73: ANOVA results for LA2

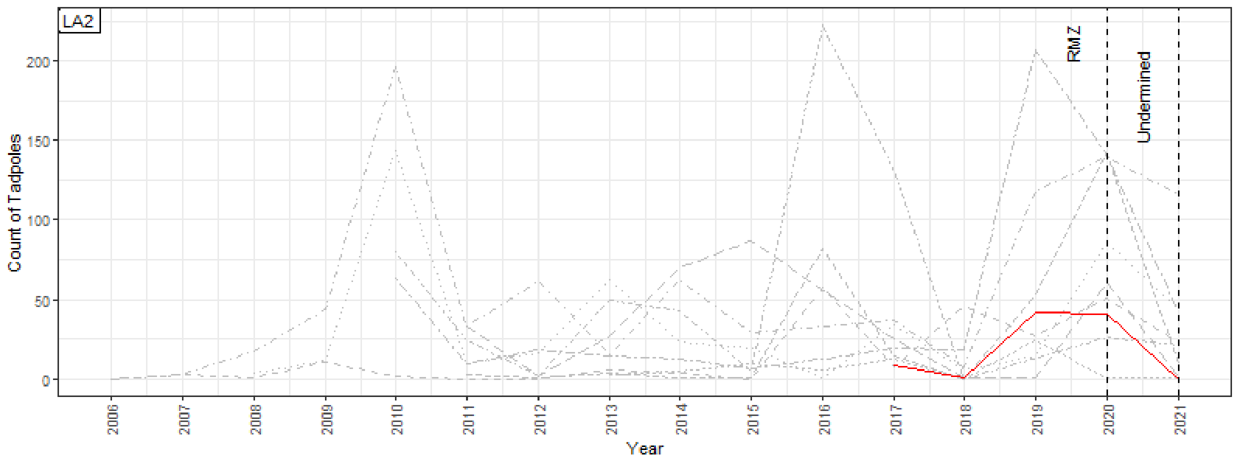
LA2	ANOVA	DF	F-value	p-value
Adults	(Intercept)	1.00	9.21	<.0001*
	Mine_status	3.00	8.10	<.0001*
Tadpoles	(Intercept)	1.00	34.70	<.0001*
	Mine_status	3.00	1.39	0.25
Eggs	(Intercept)	1.00	11.48	<.0001*
	Mine_status	3.00	6.48	<.0001*

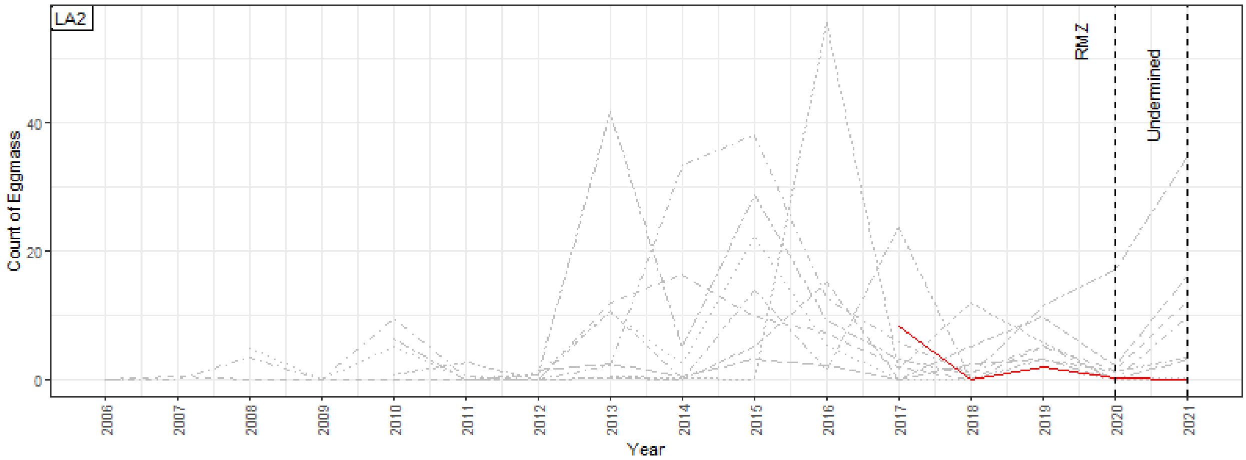
Table 74: Tukey HSD test for LA2

LA2	Comparison	Estimate	Standard Error	Z-value	p-value
Adults	Pre-CONTROL = 0	-15.96	3.31	-4.83	<.0001*
	RMZ - CONTROL = 0	-15.69	3.36	-4.66	<.0001*
	Mined under - CONTROL = 0	-16.54	3.36	-4.91	<.0001*
	RMZ - Pre = 0	0.27	0.87	0.31	0.99
	Mined under - Pre = 0	-0.58	0.87	-0.66	0.90
	Mined under - RMZ = 0	-0.84	1.07	-0.79	0.84
Tadpoles	Pre-CONTROL = 0	0.07	8.85	0.01	1.00

LA2	Comparison	Estimate	Standard Error	Z-value	p-value
	RMZ - CONTROL = 0	23.76	14.61	1.63	0.34
	Mined under - CONTROL = 0	-16.87	14.61	-1.16	0.64
	RMZ - Pre = 0	23.68	16.43	1.44	0.45
	Mined under - Pre = 0	-16.94	16.43	-1.03	0.71
	Mined under - RMZ = 0	-40.63	20.13	-2.02	0.17
Eggs	Pre-CONTROL = 0	-13.46	3.66	-3.68	<.0001*
	RMZ - CONTROL = 0	-16.70	4.32	-3.87	<.0001*
	Mined under - CONTROL = 0	-16.87	4.32	-3.91	<.0001*
	RMZ - Pre = 0	-3.24	3.24	-1.00	0.74
	Mined under - Pre = 0	-3.41	3.24	-1.05	0.71
	Mined under - RMZ = 0	-0.17	3.97	-0.04	1.00







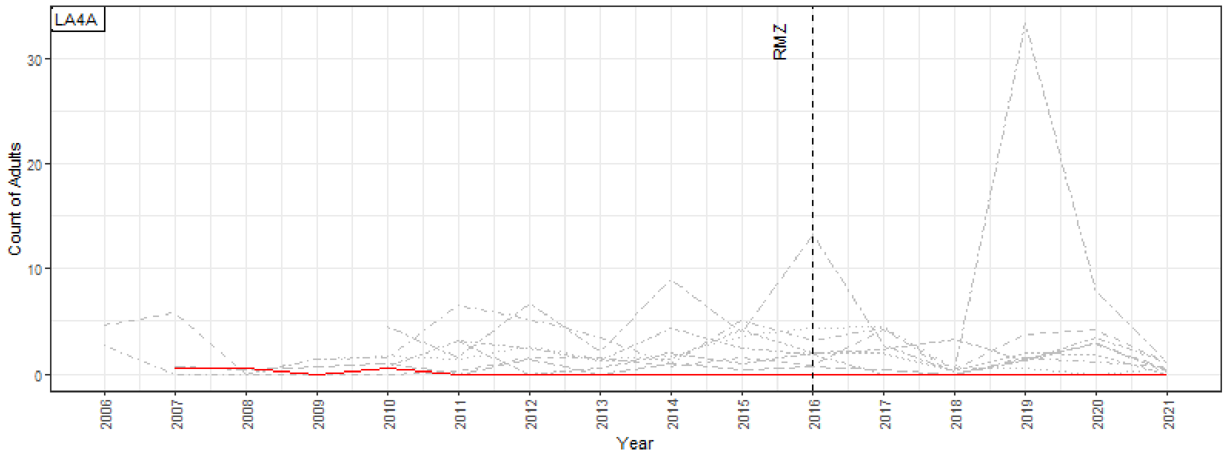
LA4A

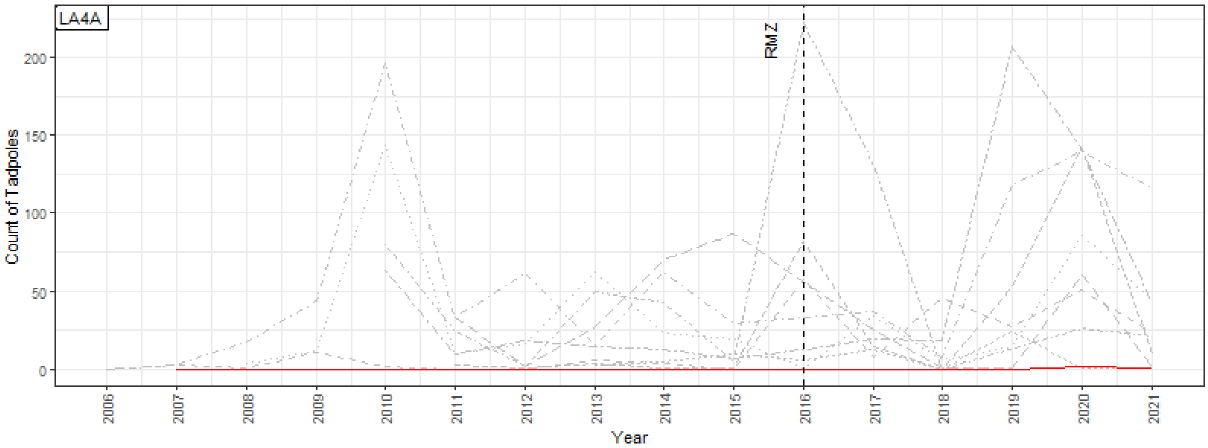
Table 75: ANOVA results for LA4A

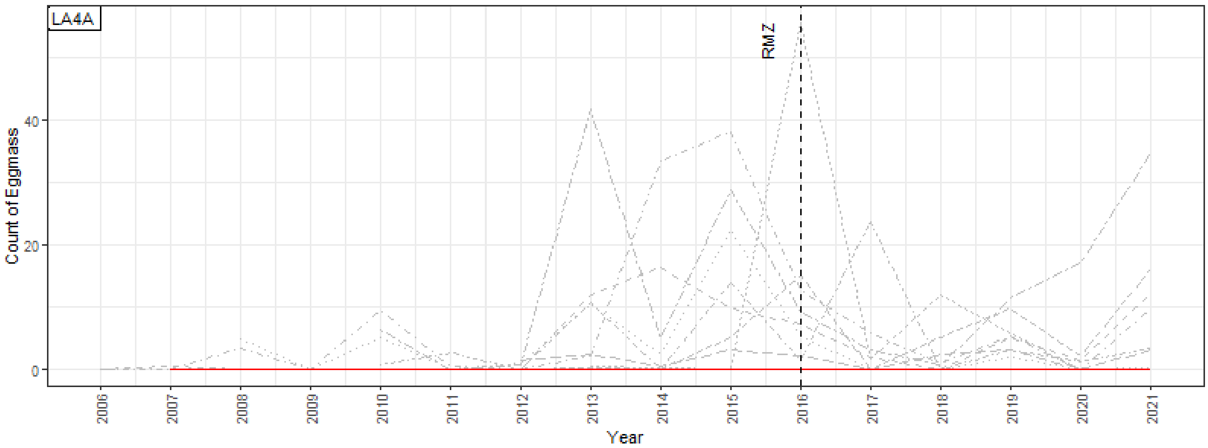
LA4A	ANOVA	DF	F-value	p-value
Adults	(Intercept)	1.00	5.38	0.02
	Mine_status	2.00	31.30	<.0001*
Tadpoles	(Intercept)	1.00	4.30	0.04*
	Mine_status	2.00	31.63	<.0001*

Table 76: Tukey HSD test for LA4A

LA4A	Comparison	Estimate	Standard Error	Z-value	p-value
Adults	Pre-CONTROL = 0	-14.19	1.85	-7.68	<.0001*
	RMZ - CONTROL = 0	-14.37	1.85	-7.77	<.0001*
	RMZ - Pre = 0	-0.18	0.10	-1.72	0.17
Tadpoles	Pre-CONTROL = 0	-14.37	1.85	-7.76	<.0001*
	RMZ - CONTROL = 0	-13.97	1.85	-7.54	<.0001*
	RMZ - Pre = 0	0.40	0.19	2.05	0.08







WC15

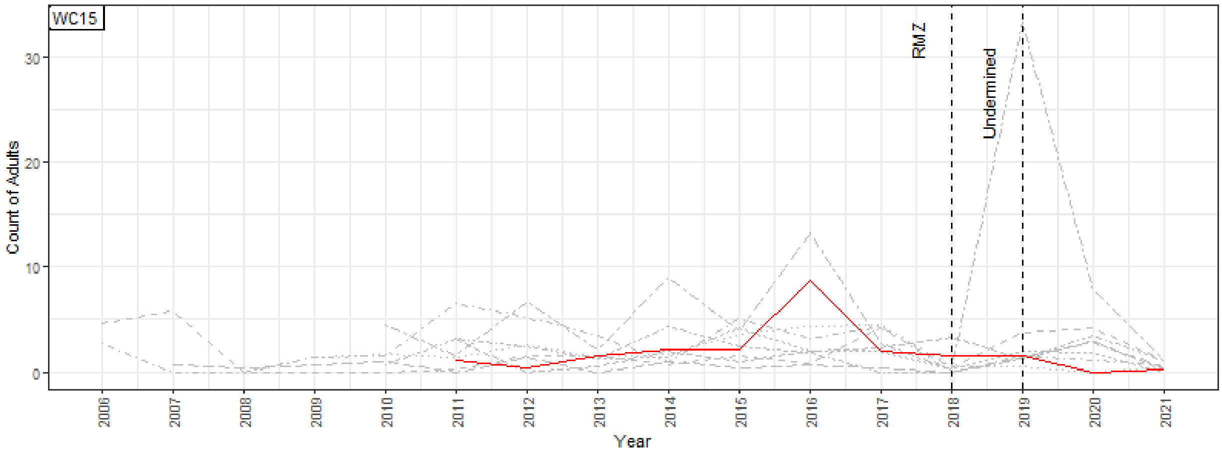
Table 77: ANOVA results for WC15

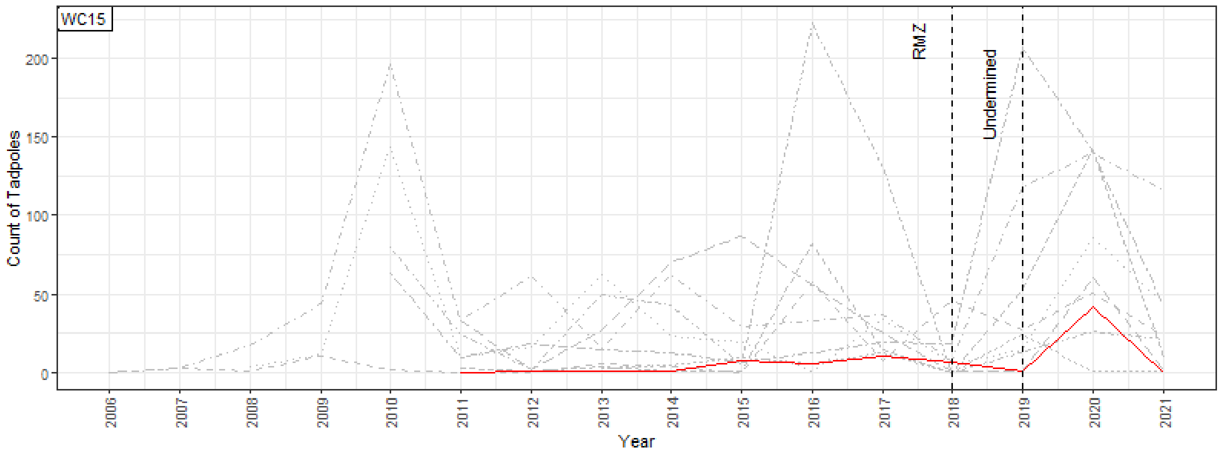
WC15	ANOVA	DF	F-value	p-value
Adults	(Intercept)	1.00	27.50	<.0001*
	Mine_status	3.00	13.20	<.0001*
Tadpoles	(Intercept)	1.00	55.78	<.0001*
	Mine_status	3.00	2.04	0.11
Eggs	(Intercept)	1.00	17.54	<.0001*
	Mine_status	3.00	14.33	<.0001*

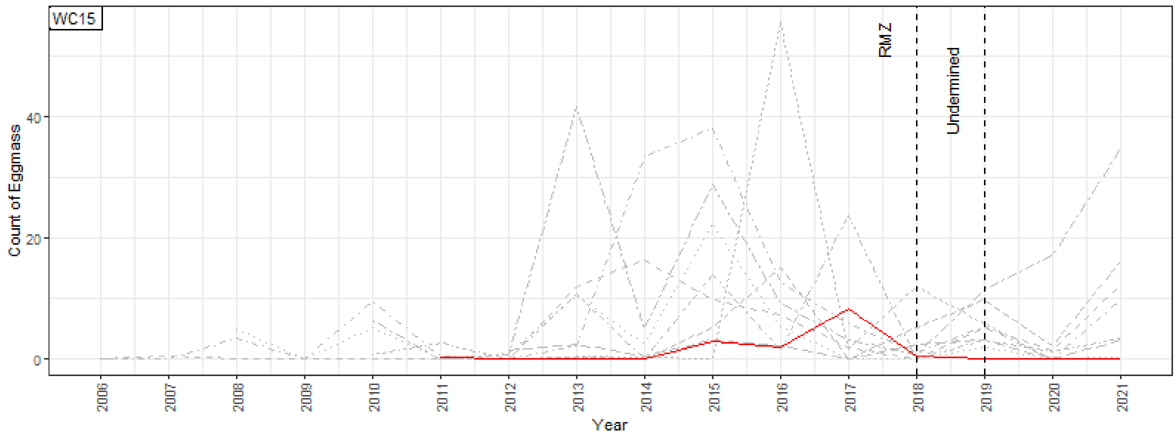
Table 78: Tukey HSD test for WC15

WC15	Comparison	Estimate	Standard Error	Z-value	p-value
Adults	Pre-CONTROL = 0	-11.77	2.08	-5.66	<.0001*
	RMZ - CONTROL = 0	-12.82	2.84	-4.51	<.0001*
	Mined under - CONTROL = 0	-13.77	2.27	-6.06	<.0001*
	RMZ - Pre = 0	-1.06	2.24	-0.47	0.96
	Mined under - Pre = 0	-2.00	1.44	-1.39	0.49
	Mined under - RMZ = 0	-0.94	2.42	-0.39	0.98
Tadpoles	Pre-CONTROL = 0	-10.77	4.51	-2.39	0.07*
	RMZ - CONTROL = 0	-8.26	10.97	-0.75	0.86

WC15	Comparison	Estimate	Standard Error	Z-value	p-value
	Mined under - CONTROL = 0	-0.24	6.53	-0.04	1.00
	RMZ - Pre = 0	2.52	11.55	0.22	1.00
	Mined under - Pre = 0	10.53	7.45	1.41	0.46
	Mined under - RMZ = 0	8.02	12.47	0.64	0.91
Eggs	Pre-CONTROL = 0	-12.48	2.10	-5.94	<.0001*
	RMZ - CONTROL = 0	-13.91	2.96	-4.70	<.0001*
	Mined under - CONTROL = 0	-14.34	2.32	-6.18	<.0001*
	RMZ - Pre = 0	-1.43	2.41	-0.59	0.93
	Mined under - Pre = 0	-1.86	1.55	-1.20	0.62
	Mined under - RMZ = 0	-0.43	2.60	-0.17	1.00



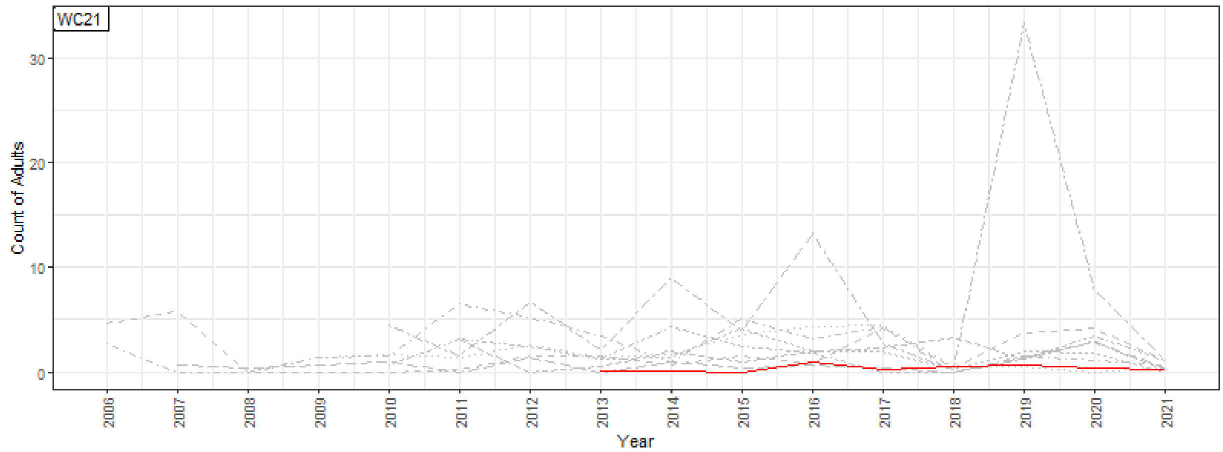


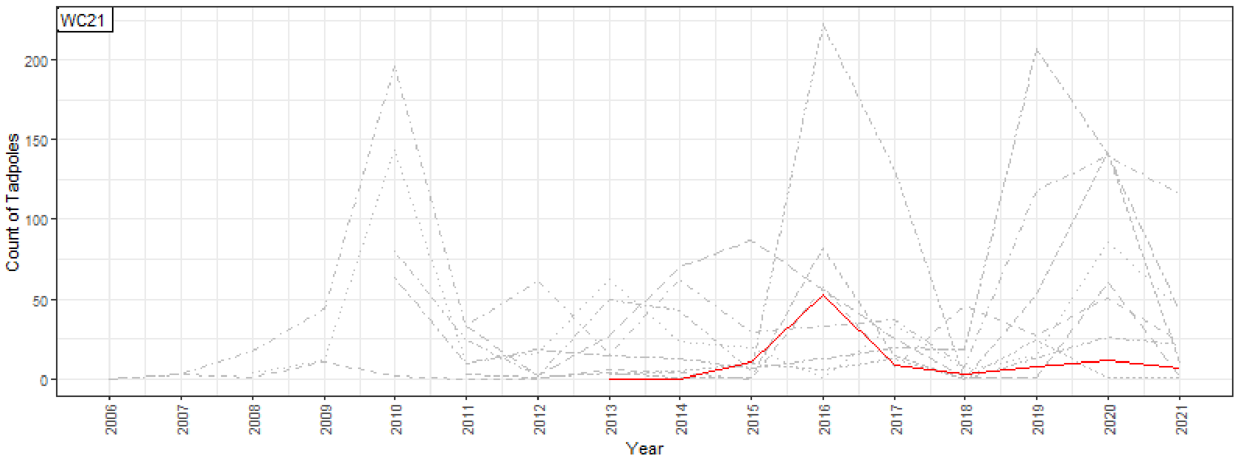


WC21

Table 79: ANOVA results for WC21

WC21	ANOVA	DF	F-value	p-value
Adults	(Intercept)	1.00	16.80	<.0001*
	Mine_status	1.00	48.15	<.0001*
Tadpoles	(Intercept)	1.00	54.51	<.0001*
	Mine_status	1.00	0.80	0.37
Eggs	(Intercept)	1.00	9.94	<.0001*
	Mine_status	1.00	47.01	<.0001*





WC21
Count of Eggmass
40
20
0
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Year

Annex 6 Photo point monitoring data

The complete photo point monitoring dataset has been provided as a separate Annex due to the large size of the document, titled: *Annex6_Dendrobium_3A_3B_PhotoPoints_20220328*.

Annex 7 Trigger Action Response Plans (IMC 2021)

Table 1.1 – Dendrobium Landscape Key Monitoring Sites

<table>
<tr><th colspan="2">Monitoring Site</th><th>Monitoring Type</th><th>Monitoring Frequency</th><th>Monitoring Parameters</th></tr>
<tr><td colspan="5">LANDSCAPE FEATURES – TARGETED SITES (Refer to Dendrobium Area 3A SMP Figures 19.2 and 19.3 and Dendrobium Area 3B Figure 18.1 for location of sites)</td></tr>
<tr><td rowspan="6">AREA 2</td><td>Cliffs
A2-CL1 (above LW4)</td><td rowspan="11">The categories of site inspection include:
1. Specific targeted monitoring sites based on potential risk
2. Re-visits to identified impact sites</td><td rowspan="11">• Two 6 monthly baseline monitoring campaigns 1 year prior to mining
• 6 monthly monitoring during mining and monthly during any substantial subsidence period
• Monitoring to continue 6 monthly for 2 years following the completion of mining</td><td rowspan="11">Baseline recording includes landform elements from the Australian Soil and Land Survey Field Handbook including:
• Slope
• Morphological type
• Dimensions
• Mode of geomorphological activity and geomorphological agent
During mining recording includes impacts to landform elements, e.g.
• Drainage
• Disturbance of site
• Erosion
• Aggradations
• Inundation
• Rock Fracturing
• Changes in runoff
• Changes in vegetation
• Rockfalls
• Soil cracking
• Slumping</td></tr>
<tr><td>Steep Slopes
A2-SL1 and A2-SL2 (above LWs 4 & 5)</td></tr>
<tr><td>Watercourses
A2-WC13 (above LWs 4 & 5)</td></tr>
<tr><td>Swamp
A2-SW1 (above LWs 4 & 5)</td></tr>
<tr><td>4WD Track
A2-FT1 (above LWs 4 & 5)</td></tr>
<tr><td>Crinanite Surface Extent
A2-CN1 & A2-CN2 (above LWs 3 & 4)</td></tr>
<tr><td rowspan="5">AREA 3A</td><td>Cliffs
A3-CL1 & A3-CL2 (above LW10)
A3-CL3 & A3-CL4 (W end of LW10)
A3-CL5 (SW end of LW9)</td></tr>
<tr><td>Steep Slopes
A3-SL1 (above LW6)
A3-SL2 (SE corner of LW6)
A3-SL3 (W end of LW7)
A3-SL4 & A3-SL5 (above LWs 7 and 8)
A3-SL6 (E end of LW8)
A3-SL7 (W end of LW9)
A3-SL8 (above LW9)
A3-SL9 (W end of LW9)</td></tr>
<tr><td>Watercourses / Swamps
A3-WC1 (above LW7 in Swamp 12)
A3-WC2 & A3-WC3 (above LWs 8, 9 and 10 in Swamps 15a and 15b)</td></tr>
<tr><td>Fire Trails
A3-FR1 (across LWs 6-10)
A3-FR2 (above LWs 6 & 7)</td></tr>
</table>

AREA 3B	**Cliffs** DA3-CF19 (E LW13) DA3-CF20 (E LW13) DA3-CF21 (E LW13) DA3-CF22 (E LW13) DA3-CF23 (E LW13) DA3-CF25 (E LW17) DA3-CF26 (E LW17) DA3-CF41 (E LW18) DA3-CF42 (E LW18) DA3-CF43 (E LW 18)	The categories of site inspection include: 1. General inspection of all active subsidence areas 2. Re-visits to identified impact sites	• Baseline monitoring campaign prior to mining • monthly monitoring during any subsidence period • Monitoring to continue 6 monthly for 2 years following the completion of mining	Baseline recording includes landform elements from the Australian Soil and Land Survey Field Handbook including: • Slope • Morphological type • Dimensions • Mode of geomorphological activity and geomorphological agent During mining recording includes impacts to landform elements, e.g. • Drainage • Disturbance of site • Erosion • Aggradations • Inundation • Rock Fracturing • Changes in runoff • Changes in vegetation • Rockfalls • Soil cracking • Slumping
	Watercourses / Swamps *Refer to DA3 Watercourse and Swamp Monitoring TARPs*			
	Fire Trails Fire Road No.6A (across LWs 10-18) Fire Road No.6N (across LW14) Fire Road No.6Q (across LW 15, 16 and 17)			
INSPECTION OF ACTIVE MINING AREA - LANDSCAPE FEATURES, VEGETATION, WATERCOURSES				
AREA 3A	All mapped cliff, steep slopes, watercourse, swamp and fire trail sites in subsidence area *Refer to Dendrobium Area 3A SMP Figure 19.3 for location of sites* General observation of active mining areas	The categories of site inspection include: 1. General inspection of all active subsidence areas 2. Re-visits to identified impact sites	• Weekly monitoring when longwall extraction is within 400m of feature	During mining recording includes impacts to: • Drainage • Disturbance of site • Erosion • Aggradations • Inundation • Rock Fracturing • Changes in runoff • Changes in vegetation • Impacts to fauna/fish • Rockfalls • Soil cracking • Slumping
AREA 3B	All mapped cliff, steep slopes, watercourse, swamp and fire trail sites in subsidence area *Refer to Dendrobium Area 3B SMP Figure 5.3, 15.1 and 18.1 for location of sites* General observation of active mining areas			

TERRESTRIAL FLORA				
AREA 2 AREA 3A AREA 3B	A number of sites located across and around Areas 2, 3A and 3B *Refer Dendrobium Area 3A SMP Figure 21.1, 21.2 and 21.3 and 3B Figure 20.1*	Observational and quantitative (transect) monitoring to identify stressed or dead vegetation including riparian and upland swamp vegetation not readily explained by natural processes. Causes may include rock/cliff falls or mass movement, gas emissions, changes in ponding and interconnectivity, and iron staining from ferruginous spring releases	• Two baseline monitoring campaigns 1 year prior to mining during autumn and spring • 6 monthly monitoring during mining in autumn and spring each year • 6 monthly monitoring post mining for two years or as otherwise required	• Vegetation communities • Vegetation condition • Changes in vegetation • Tree health • Swamp vegetation • Threatened species • Control sites
TERRESTRIAL FAUNA				
AREA 2 AREA 3A AREA 3B	A number of sites located across and around Areas 2, 3A and 3B *Refer Dendrobium Area 3A SMP Figure 21.1, 21.2 and 21.3 and 3B Figure 20.1*	Observational and quantitative (population counts) monitoring to identify alteration or loss of fauna habitat, fauna habitat assessed to be degraded without a natural cause readily apparent	• Two baseline monitoring campaigns 1 year prior to mining • 6 monthly monitoring during mining • 6 monthly monitoring post mining for two years or as otherwise required	• Species and habitat characteristics • Targeted surveys and monitoring of known populations of threatened frog species

ABORIGINAL ARCHAEOLOGY (Refer Dendrobium Area 3A SMP Figure 22.1 and Dendrobium Area 3B Figure 21.1 for location of sites)				
AREA 2	• Dendrobium 4	Observational and photographic monitoring in consultation with stakeholders	• Baseline archival recording: prior to longwall mining • First impact assessment recording: Following initial subsidence movement of the site • Sandstone shelter Aboriginal sites will be monitored during mining • Further impact assessment recording: twelve months after undermining or final subsidence movement of the site	• Re-recording of the principal components identified by Sefton (Sefton 2000) • Macro and micro recording using digital photography (Navin Officer 2003) • Detailed elevation plans of shelter walls recording structural and surface features including but not limited to the art itself, graffiti, joints , bedding planes, exfoliation scars, cracks, mineral and micro-organism growth, drip line and water seepage locations
AREA 3A	• Browns Road Site 33 (recording code 52-2-0458) • Browns Road Site 32 (recording code 52-2-1646) • Browns Road Site 20 (recording code 52-2-1647) • Sandy Creek Road 21 (recording code 52-5-0274) • Sandy Creek Road 22 (recording code 52-5-0274) • Sandy Creek Road 25 (recording code 52-5-0277) • Sandy Creek Road 26 (recording code 52-5-0278) • DM13 (New recording) • DM15 (New recording) • DM20 (New recording) • DM23 (New recording)			

AREA 3B	• Donalds Castle Creek Site 1; Cordeaux Catchment Area (recording code 52-2-1562) • Browns Road Site 8 (recording code 52-2-1623) • Browns Road Site 11 (recording code 52-2-1626) • Browns Road Site 12 (recording code 52-2-1627) • Browns Road Site 13 (recording code 52-2-1628) • Upper Avon 35 (recording code 52-2-1771) • Upper Avon 36 (recording code 52-2-1772) • Upper Avon 37 (recording code 52-2-1773) • Upper Avon 38 (recording code 52-2-1774) • Upper Avon 39 (recording code 52-2-1775) • Upper Avon 40 (recording code 52-2-1776) • Upper Avon 41 (recording code 52-2-1777) • DENDROBIUM 1 (recording code 52-2-2208) • DENDROBIUM 2 (recording code 52-2-2209) • SITE 1 – DB1 (recording code 52-2-2229) • DENDROBIUM 6 (recording code 52-2-2246) • DENDROBIUM 7 (recording code 52-2-2248) • DENDROBIUM 8 (recording code 52-2-3088) • DM16 (recording code 52-2-3640) • DM17 (recording code 52-2-3641) • DM21 (recording code 52-2-3645) • DM22 (recording code 52-2-3878)	Observational and photographic monitoring in consultation with stakeholders	• Baseline archival recording: prior to longwall mining • First impact assessment recording: Following initial subsidence movement of the site • Sandstone shelter Aboriginal sites will be monitored during mining • Further impact assessment recording: twelve months after undermining or final subsidence movement of the site	• Re-recording of the principal components identified by Sefton (Sefton 2000) • Macro and micro recording using digital photography (Navin Officer 2003) • Detailed elevation plans of shelter walls recording structural and surface features including but not limited to the art itself, graffiti, joints , bedding planes, exfoliation scars, cracks, mineral and micro-organism growth, drip line and water seepage locations

Table 1.2 – Dendrobium Landscape Impacts, Triggers and Response

<table>
<tr><th>Monitoring</th><th>Trigger</th><th>Action</th></tr>
<tr><td colspan="3">LANDSCAPE FEATURES</td></tr>
<tr><td rowspan="3"><u>AREA 2</u>
Cliffs
A2-CL1 (above LW4)
Steep Slopes
A2-SL1 and A2-SL2 (above LWs 4 & 5)
Watercourses
A2-WC10 and A2-WC11 (above LW3)
A2-WC13 & A2-WC16 (above LWs 4 & 5)
Swamp
A2-SW1 (above LWs 4 & 5)
4WD Track
A2-FT1 (above LWs 4 & 5)
Crinanite Surface Extent
A2-CN1 & A2-CN2 (above LWs 3 & 4)

<u>AREA 3A</u>
Cliffs
All mapped cliff sites in subsidence area (Refer to Dendrobium Area 3A SMP Figures 19.3 for location of sites)
Steep Slopes
All mapped steep slopes in subsidence area Refer to Dendrobium Area 3A SMP Figures 19.3 for location of sites
Watercourses/ Swamps
All mapped watercourse and swamps in subsidence area
Refer to Dendrobium Area 3A SMP Figure 19.3
Fire Trails
All mapped fire trails in subsidence area
Refer to Dendrobium Area 3A SMP Figure 19.3

<u>AREA 3B</u>
Cliffs
All mapped cliff sites in subsidence area
Refer to Dendrobium Area 3B SMP Figures 18.1 for location of sites</td>
<td>Level 1 *
• Rock fall from a cliff which is left mostly intact (<10% length), resulting in insignificant ground disturbance
• Surface movement or rock displacement with negligible soil surface exposed
• Crack at the surface, which should not result in any significant erosion or further ground movement
• Crack in a fire trail which should not result in erosion or impede access
• Crack or fracture up to 100mm width
• Crack or fracture up to 10m length
• Erosion in a localised area which would be expected to naturally stabilise without CMA and within the period of monitoring</td>
<td>• Continue monitoring program
• Report impacts to key stakeholders
• Summarise impacts and Report in the End of Panel Report and AEMR</td></tr>
<tr><td>Level 2 *
• Rock fall or overhang collapse at a cliff site, where characteristics of the cliff have changed, and there has been significant ground disturbance
• Surface movement or rock displacement that has exposed significant areas of soil
• A crack at the surface, which could result in significant erosion or movement at the surface
• A crack at the surface with potential risk to safety and/or fauna entrapment
• A crack in the fire trail, which could result in significant erosion or impede vehicle access
• Crack or fracture between 100 and 300mm width
• Crack or fracture between 10 and 50m length
• Significant erosion at any location, which is not likely to naturally stabilise within the period of monitoring, or is located in a sensitive area e.g. swamps, creek, lake shore, and may result in increased sediment transport to Cordeaux Dam, or has been previously identified as Level 1, but is not likely to naturally stabilise within the monitoring period</td>
<td>• Actions as stated for Level 1
• Review monitoring frequency
• Notify relevant technical specialists and seek advice on any CMA required
• Provide safety signage and barricades as appropriate
• Implement approved repairs to ensure safety and serviceability on fire trails
• Implement agreed CMAs as approved

Note: CMAs are to be proposed based on appropriate management of environmental and other consequences of impacts i.e. cracking at the surface with insignificant consequences may not require specific CMAs other than ongoing monitoring to confirm there are no ongoing impacts</td></tr>
<tr><td>Level 3 *
• Major cliff collapse where the characteristics of the cliff change significantly and there is significant ground disturbance that is unlikely to naturally stabilise within the monitoring period</td>
<td>• Actions as stated for Level 2
• Immediately notify DoPI, DPIM, SCA, resource managers and relevant technical specialists and seek advice on any CMA required
• Site visits with stakeholders if required</td></tr>
</table>

Table 1.2 – Dendrobium Landscape Impacts, Triggers and Response

Monitoring	Trigger	Action
	• Crack or fracture over 300mm width • Crack or fracture over 50m length • Mass movement of a slope causing large areas of exposed soil with potential for further movement	• Review monitoring program and modify if necessary within 1 month • Implement increased monitoring if required within 2 weeks • Develop site CMA in consultation with key stakeholders within 1 month, (pending stakeholder availability) and seek approvals • Completion of works following approvals • Issue CMA report within 1 month of works completion • Conduct initial follow up monitoring & reporting within 2 months of CMA completion • Review the relevant TARP and Management Plan in consultation with key stakeholders *Note: CMAs are to be proposed based on appropriate management of environmental and other consequences of impacts i.e. cracking at the surface with insignificant consequences may not require specific CMAs other than ongoing monitoring to confirm there are no ongoing impacts*
Sandy Creek Waterfall	***Exceeding Prediction*** • Rock fall at Sandy Creek Waterfall or from its overhang • Structural integrity of the waterfall, its overhang and its pool are impacted • More than negligible cracking within 30 m of the waterfall • More than negligible diversion of water from the lip of the waterfall	• Actions as stated for Level 3 • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation
TERRESTRIAL FLORA AND FAUNA		
A number of sites located across and around Areas 2, 3A and 3B *Refer Dendrobium Area 3A SMP Figure 21.1, 21.2 and 21.3 and Dendrobium Area 3B Figure 20.1 for location of sites* General observation of active mining areas	***Level 1 **** • Vegetation impacted by mining (by rockfalls, soil slippage, gas emissions) that is likely to naturally regenerate within the monitoring period	• Continue monitoring program • Report impacts to key stakeholders • Summarise impacts and Report in the End of Panel Report and AEMR
	Level 2 * • Vegetation impacted by mining (by rockfalls, soil slippage, gas emissions) that is unlikely to naturally regenerate within the monitoring period • Statistically significant difference between Before After Control Impact sites as a result of mining	• Actions as stated for Level 1 • Review monitoring frequency • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved

Table 1.2 – Dendrobium Landscape Impacts, Triggers and Response

Monitoring	Trigger	Action
	Level 3 * • Vegetation impacted by mining that is not responding to CMAs	• Actions as stated for Level 2 • Immediately notify OEH, DoPI, DPI, SCA, other resource managers and relevant technical specialists and seek advice on any CMA required • Site visits with stakeholders if required • Review monitoring program and modify if necessary within 1 month • Implement increased monitoring if required within 2 weeks • Develop site CMA in consultation with key stakeholders within 1 month, (pending stakeholder availability) and seek approvals • Completion of works following approvals • Issue CMA report within 1 month of works completion • Conduct initial follow up monitoring & reporting within 2 months of CMA completion • Review the relevant TARP and Management Plan in consultation with key stakeholders
ABORIGINAL ARCHAEOLOGY		
Area 2 (1 site): Dendrobium 4 **Area 3A (11 total):** • Browns Road Site 33 (recording code 52-2-0458) • Browns Road Site 32 (recording code 52-2-1646) • Browns Road Site 20 (recording code 52-2-1647) • Sandy Creek Road 21 (recording code 52-5-0273) • Sandy Creek Road 22 (recording code 52-5-0274) • Sandy Creek Road 25 (recording code 52-5-0277) • Sandy Creek Road 26 (recording code 52-5-0278) • DM13 (New Recording) • The site DM15 (New Recording) • The site DM20 (New Recording) • The site DM23 (New Recording)	***Level 1 **** • Change in shelter conditions not attributable to natural weathering or preservation – mineral growth or micro-organism growth (as observed by comparing pre-mining photographs with post-subsidence/mining photographs) • Changes external to the shelter that affect the site context (e.g. ground cracking, boulder slumping, rock and/or tree falls)	• Continue monitoring program • Condition assessment and photographic record • Notify relevant specialists and key stakeholders (e.g. Aboriginal community groups) • Summarise impacts and Report in the End of Panel Report and AEMR
	Level 2 * • Change in shelter conditions not attributable to natural weathering or preservation – change in drip line or seepage, cracking or exfoliation of overhang or shelter, movement or opening of existing planes and joints at panel, block fall within shelter or overhang, shelter or overhang collapse	• Actions as stated for Level 1 • Modify monitoring program if necessary • Consider development of site management plan to mitigate effects in consultation with Registered Aboriginal Groups and the Landowner (SCA)
	Level 3 * • Level 2 impacts at greater frequency than predicted • Level 2 impacts attributable to mining remote from the mining area	• Actions as stated for Level 2 • Immediately notify OEH, DoPI, DPI, SCA, other resource managers and relevant technical specialists and seek advice on any CMA required • Site visits with stakeholders if required • Review monitoring program and modify if necessary within 1 month • Implement increased monitoring if required within 2 weeks • Develop site CMA in consultation with key stakeholders within 1 month, (pending stakeholder availability) and seek approvals • Completion of works following approvals

Area3B (25 total): • Donalds Castle Creek Site 1; Cordeaux Catchment Area (recording code 52-2-1562) • Browns Road Site 8 (recording code 52-2-1623) • Browns Road Site 11 (recording code 52-2-1626) • Browns Road Site 12 (recording code 52-2-1627) • Browns Road Site 13 (recording code 52-2-1628) • Upper Avon 35 (recording code 52-2-1771) • Upper Avon 36 (recording code 52-2-1772) • Upper Avon 37 (recording code 52-2-1773) • Upper Avon 38 (recording code 52-2-1774) • Upper Avon 39 (recording code 52-2-1775) • Upper Avon 40 (recording code 52-2-1776) • Upper Avon 41 (recording code 52-2-1777) • DENDROBIUM 1 (recording code 52-2-2208) • DENDROBIUM 2 (recording code 52-2-2209) • SITE 1 – DB1 (recording code 52-2-2229) • DENDROBIUM 6 (recording code 52-2-2246) • DENDROBIUM 7 (recording code 52-2-2248) • DENDROBIUM 8 (recording code 52-2-3088) • DM16 (recording code 52-2-3640) • DM17 (recording code 52-2-3641) • DM21 (recording code 52-2-3645) • DM22 (recording code 52-2-3878)		• Issue CMA report within 1 month of works completion • Conduct initial follow up monitoring & reporting within 2 months of CMA completion • Review the relevant TARP and Management Plan in consultation with key stakeholders

* These may be revised in consultation with DoPI and DPI and other key stakeholders following analysis of natural variability within the pre-mining baseline data. These TARPs relate to Dendrobium Area 3B and impacts resulting from mining in Areas 1, 2 and 3A were managed under previous TARPs.

Office of Environment and Heritage (OEH)

Department of Planning and Infrastructure (DoPI)

Department of Primary Industries: including Division of Resources and Energy, Office of Water, Fisheries (DPI)

Sydney Catchment Authority (SCA)

Performance Measures	***Potential Impacts***	***Performance Triggers***	***Management Strategies***	***Offsets***	***Other Actions***
Negligible erosion of the surface of the swamp	Gully erosion or similar	*Level 1:* The increase in length of erosion within a swamp (compared to its pre-mining length) is **2%** of the swamp length or area; and/or Erosion in a localised area (not associated with cracking or fracturing) which would be expected to naturally stabilise without CMA and within the period of monitoring. *Level 2*: The increase in length of erosion within a swamp (compared to its pre-mining length) is **3%** of the swamp length or area; and/or Soil surface crack that causes erosion that is likely to stabilise within the monitoring period without intervention; and/or Gully knickpoint forms or an existing gully knickpoint becomes active. *Level 3:* The increase in length of erosion within a swamp (compared to its pre-mining length) is **4%** of the swamp length or area; and/or Soil surface crack that causes erosion that is unlikely to stabilise within the monitoring period without intervention. *Exceeding Prediction* Mining results in the total length of erosion within a swamp (compared to its pre-mining length) to increase **>5%** of the length or area of the swamp compared to any increase in total erosion length in a reference swamp (ie increase in length or area of erosion in an impact swamp less any increase in length or area in erosion in a reference swamp is **>5%**).	a) upfront mine planning b) erosion monitoring (ie ALS, observation) c) coir logs d) knickpoint control e) water spreading f) weeding g) fire management h) reporting i) investigation and review j) update future predictions	Offset required **immediately**, if no remediation considered practicable. Offset required **2 years** following remediation, if it is ineffective. This period can be extended to **5 years**, with the agreement of the Secretary.	
Minor changes in the size of the swamps **Minor changes** in the ecosystem functionality of the swamps **No significant change** to the composition or distribution of	Swamp vegetation changes: - Swamp size - Species richness, distribution, composition and diversity - Vegetation sub-communities	**Swamp Size** *Level 1:* A trending decline in the extent of an upland swamp (combined area of groundwater dependent communities) for two consecutive monitoring periods, greater than observed in the Control Group, and exceeding the standard error (SE) of the Control Group. *Level 2:* A trending decline in the extent of an upland swamp (combined area of groundwater dependent communities) for three consecutive monitoring periods, greater than observed in the Control Group, and exceeding the SE of the Control Group. *Level 3:* A trending decline in the extent of an upland swamp (combined area of groundwater dependent communities) for four consecutive monitoring periods, greater than observed in the Control Group, and	a) upfront mine planning b) vegetation monitoring c) water spreading d) seeding/planting e) weeding f) fauna monitoring g) fire management h) grouting of controlling of controlling	Offset required **immediately**, if no remediation considered practicable. Offset required **5 years** following remediation, if it is ineffective. This period can be extended to **10 years**, with	Monitoring period for swamp size is related to capture of Lidar data at the end of each longwall ~ 1 year Triggers for groundwater decline result in increased intensity and

species within the swamps		exceeding the SE of the Control Group. *<u>Exceeding Prediction:</u>* Mining results in a trending decline in the extent of an upland swamp (combined area of groundwater dependent communities) for five consecutive monitoring periods, greater than observed in the Control Group, and exceeding the SE of the Control Group. **Ecosystem Functionality** *<u>Level 1:</u>* A trending decline in the extent of any individual groundwater dependent community within a swamp for two consecutive monitoring periods, greater than observed in the Control Group, and exceeding the SE of the Control Group. *<u>Level 2:</u>* A trending decline in the extent of any groundwater dependent community within a swamp for three consecutive monitoring periods, greater than observed in the Control Group, and exceeding the SE of the Control Group.. *<u>Level 3:</u>* A trending decline in the extent of any groundwater dependent community within a swamp for four consecutive monitoring periods, greater than observed in the Control Group, and exceeding the SE of the Control Group.. *<u>Exceeding Prediction:</u>* Mining results in a trending decline in the extent of a groundwater dependent community within a swamp for five consecutive monitoring periods, greater than observed in the Control Group, and exceeding the SE of the Control Group. **Species Composition and Distribution** *<u>Level 1:</u>* A **2%** (or otherwise statistically significant) decline in species richness or diversity during a period of stability or increase in species richness/diversity in reference swamps for **two** consecutive years; and/or *<u>Level 2:</u>* A **5%** (or otherwise statistically significant) decline in species richness or diversity during a period of stability or increase in species richness/diversity in reference swamps for **three** consecutive years. *<u>Level 3:</u>* An **8%** (or otherwise statistically significant) decline in species richness or diversity during a period of stability or increase in species richness/diversity in reference swamps for **four** consecutive years.	rockbars and bedrock base and/or use of other remediation techniques i) reporting j) investigation and review k) update future predictions	the agreement of the Secretary.	frequency of vegetation monitoring

		Exceeding Prediction: Mining results in a **>10%** (or otherwise statistically significant) decline in species richness or diversity during a period of stability or increase in species richness/diversity in reference swamps for **five** consecutive years.			
Maintenance or restoration of the structural integrity of the bedrock base of any significant permanent pool or controlling rockbar within the swamps	Subsidence impacts (ie cracking) on bedrock base or controlling rockbar	*Level 1:* Fracturing observed in the bedrock base of any significant permanent pool which results in observable loss of surface water of **10%** compared to baseline for the pool (in addition to any decrease in reference pools). *Level 2:* Fracturing observed in the bedrock base of any significant permanent pool which results in observable loss of surface water of **20%** compared to baseline for the pool (in addition to any decrease in reference pools). *Level 3:* Fracturing observed in the bedrock base of any significant permanent pool which results in observable loss of surface water of **20%** compared to baseline for the pool for **>20%** of the time over a period of **1** year (in addition to any decrease in reference pools). *Exceeding Prediction* Structural integrity of the bedrock base of any significant permanent pool or controlling rockbar cannot be restored, ie pool water level within the swamp after CMAs continues to be **>20%** lower than baseline for **>20%** of the time over a period of **1** year.	a) upfront mine planning b) subsidence monitoring c) surface water monitoring d) groundwater monitoring e) grouting of controlling of controlling rockbars and bedrock base and/or use of other remediation techniques f) CMAs g) reporting h) investigation and review i) update future predictions	Offset required **immediately**, if no remediation considered practicable. Offset required **2 years** following remediation, if it is ineffective. This period can be extended to **5 years**, with the agreement of the Secretary.	
Minor changes in the ecosystem functionality of the swamps	Falls in surface or near-surface groundwater levels in swamps *NB. Not linked specifically to a PM and would not be considered a breach if predictions were exceeded.*	*Level 1:* Groundwater level lower than baseline level at any monitoring site within a swamp (in comparison to reference swamps); and/or Rate of groundwater level reduction exceeds rate of groundwater level reduction during baseline period at any monitoring site (measured as average mm/day during the recession curve). *Level 2:* Groundwater level lower than baseline level at **50%** of monitoring sites (within 400 m of mining) within a swamp (in comparison to reference swamps); and/or Rate of groundwater level reduction exceeds rate of groundwater level reduction during baseline period at a **50%** of monitoring sites (within 400m of mining) within the swamp.	a) upfront mine planning b) groundwater monitoring c) implementation of swamp research program d) weeding e) fire management f) reporting g) update future predictions		Triggers for groundwater decline result in increased intensity and frequency of vegetation monitoring and/or further investigations of subsidence impacts on bedrock base and rockbars

		Level 3: Groundwater level lower than baseline level at **>80%** of monitoring sites (within 400m of mining) within a swamp (in comparison to reference swamps); and/or Rate of groundwater level reduction exceeds rate of groundwater level reduction during baseline period at **>80%** of monitoring sites (within 400 m of mining) within the swamp.			
Minor changes in the ecosystem functionality of the swamps	Falls in soil moisture levels in swamps *NB. Not linked specifically to a PM and would not be considered a breach if predictions were exceeded.*	*Level 1:* Soil moisture level lower than baseline level at **any** monitoring sites (within 400 m of mining) within a swamp (in comparison to reference swamps). *Level 2:* Soil moisture level lower than baseline level at **50%** of monitoring sites (within 400m of mining) within a swamp (in comparison to reference swamps). *Level 3:* Soil moisture level lower than baseline level at **>80%** of monitoring sites (within 400m of mining) within a swamp (in comparison to reference swamps).	a) upfront mine planning b) soil moisture monitoring c) water spreading d) weeding e) fire management f) reporting g) update future predictions		Triggers of soil moisture decline result in increased intensity and frequency of vegetation monitoring and/or further investigations of subsidence impacts on bedrock base and rockbars

Table 1.1 – Dendrobium Area 3 Watercourse Monitoring

Watercourse monitoring within Dendrobium Area 3 will be installed ahead of mining to achieve 2 years baseline data (subject to timing and approval timeframes of any request to install additional monitoring). Monitoring will be conducted throughout the mining period and for at least 2 years following active subsidence. A review of the continuation and potentially extending post mining monitoring will be carried out in consultation with DPIE, WaterNSW and other relevant agencies where required. Where impacts are observed, the monitoring period will be extended and this will be reported in Impact Assessment Reports and End of Panel Reports. For Level 2 and 3 Triggers and for impacts exceeding prediction this review will be conducted in consultation with key agencies. The location of monitoring sites is indicated on Figures 2-1 to 2-57.

<table>
<tr><th colspan="2">MONITORING SITE</th><th>SITE TYPE</th><th>MONITORING FREQUENCY</th><th>PARAMETERS</th></tr>
<tr><td colspan="5">OBSERVATIONAL-MONITORING</td></tr>
<tr><td>AREA 3A</td><td>Sandy Creek and tributaries (including SC7 and SC10)
Refer to Figure 2-1</td><td rowspan="2">Observation and photo point monitoring:
• Sites based on an assessment of risk
• Streams and swamps
• Pools and rockbars
• Previously observed impacts that warrant follow-up inspection</td><td rowspan="2">• Monthly 2 years pre- and post-mining, weekly when longwall is within 400 m of monitoring site
• Reference sites 6 monthly</td><td rowspan="2">Visual signs of impacts to creeks and drainage lines (i.e. cracking, vegetation changes, increased erosion, changes in water colour, soil moisture etc.) determined by comparing baseline photos with photos during the mining period

Key water quality parameters in pools analysed to identify any changes resulting from mining

Pool water levels to identify any changes resulting from mining</td></tr>
<tr><td>AREA 3B</td><td>Impact Sites:
• Native Dog, Wongawilli and Donalds Castle Creeks, WC21, WC18, WC16, WC15, WC12, WC9, WC8, WC7, WC6, LA5, LA4, LA3, LA2, ND1 and DC13
• Swamps 5, 10, 11, 13, 14, 23, 35a, 35b, 1a, 1b, 8, 3 and 4
Refer to Figures 2-2 to 2-11 and 2-25 to 2-32

Reference Sites:
• Wongawilli Creek, Sandy Creek, LC5, WC11, SC9A, SC10A, NDC1, DC10 and D10
• Swamps 2, 7, 15a, 22, 24, 25, 33, 84, 85, 86, 87 and 88
Refer to Figures 2-12 to 2-25, 2-28 to 2-30 and 2-33 to 2-35</td></tr>
<tr><td colspan="5">WATER QUALITY</td></tr>
</table>

AREA 3A	**Wongawilli Creek** WWU1, WWU4, WC_Pool 46, WWM2, WC_Pool 43b and Wongawilli Creek (FR6) **Sandy Creek** SCk_Rockbar 5 (Sandy Creek adjacent to LW7) *Refer to Figure 2-1*	• Grab sample • Field water quality	• Monthly monitoring pre, during and post mining for two years	Manual Field Testing: • Field pH, Temp, EC, DO and ORP • Lab. analytes (incl. lab check of pH, lab. check of EC, DOC, Na, K, Ca, Mg, Filt. SO4, Cl, T. Alk., Total Fe, Mn, Al, Filt. Cu, Ni, Zn, Si)
AREA 3B	**Wongawilli Creek** WWU1 (Wongawilli Creek headwaters) WWU4 (Wongawilli Creek upstream) WC_Pool 51 (Wongawilli Creek downstream of WC7) WC Pool 49 (Wongawilli Creek adjacent to LW15) WC_Pool 46 (Wongawilli Creek adjacent to LW12) WWM2 (Wongawilli Creek adjacent to LW11) WC_Pool 43b (Wongawilli Creek downstream of LW9) Wongawilli Creek (FR6) (Wongawilli Creek downstream) WC21_Pool 5 (Wongawilli Creek tributary downstream of mining) WC21 Pools 30 and 53 (Wongawilli Creek tributaries over mining) WC15_Pool 28 (Wongawilli Creek tributary downstream of mining) WC15_Pool 9 (Wongawilli Creek tributary downstream of mining) WC15_Pool 2 (Wongawilli Creek tributary downstream of mining)WC7_Pool 1(Wongawilli Creek tributary downstream of mining) **Lake Avon** LA4_S1, LA4_S2, LA5_S1, LA5_S2, LA3 Pool 4, LA2 Pool 5 and LA_1 (Lake Avon tributaries downstream of mining) NDC4 (Native Dog Creek downstream of mining) NDC1 (Native Dog Creek upstream of Area 3B) **Donalds Castle Creek** Donalds Castle Creek (FR6) (Donalds Castle Creek lower) DCL3 (Donalds Castle Creek @ Cordeaux River)			

	DC_Pool 22 (Donalds Castle Creek downstream of mining) DC13_Pool 2b (Donalds Castle Creek tributary downstream of mining) **Lake Cordeaux** *LC5_S1 (Reference Site)* *Refer to Figure 2-35*			
WATER FLOW				
Ref Sites	**O'Hares Creek** [NSW govt site] 213200 (O'Hares Creek @ Wedderburn) **Wongawilli Creek** WWU (Wongawilli Creek upstream)	• Some data (for reference sites) is provided by WaterNSW		Other reference sites may be used depending on data availability and quality (e.g. Woronora River 2132101 and Bomaderry Creek 215016)
AREA 3A	**Wongawilli Creek** WWU (Wongawilli Creek upstream) WWL_A (Wongawilli Creek downstream) **Sandy Creek** SCL2(Sandy Creek at downstream) SC10S1 and SC10CS1 (Sandy Creek tributary) *Refer to Figures 2-35 and 2-36*	• Pressure transducer with data logger.	• Continuous 1-hour logging intervals	Automatic pool water level measurements which are converted to flows by calculation of rating curves using measured creek cross sections/measured flows at the monitoring point. Hydrological changes are assessed by comparing pre- and post-mining observed flows from impact or assessment sites to flow data from similar reference sites (that are not impacted by mining).
AREA 3B	**Wongawilli Creek** WWU (Wongawilli Creek upstream) WWL_A (Wongawilli Creek downstream) WC21S1 (Wongawilli Creek tributary downstream of mining) WC15S1 (Wongawilli Creek tributary downstream of mining) WC12S1 (Wongawilli Creek tributary downstream of mining) **Donalds Castle Creek** DCU (Donalds Castle Creek @ FR6) DC13S1 (Donalds Castle Creek tributary downstream of mining) DCS2 (Donalds Castle Creek downstream of mining) **Lake Avon** LA4S1 (Lake Avon tributary downstream of mining) LA3S1 (Lake Avon tributary downstream of mining) LA2S1 (Lake Avon tributary downstream of mining)			

	NDTS1 (Lake Avon Tributary downstream of mining) **Lake Cordeaux** LC5S1 (Reference Site) *Refer to Figures 2-35 and 2-36*			
AQUATIC ECOLOGY				
AREA 3A	Sandy Creek Catchment: Sites 8, 9, 10, 11, 12 and 13 *Refer to Figure 2-57*	• Quantitative and observational monitoring	• Two baseline monitoring campaigns prior to mining during autumn and spring • Monitoring during mining in autumn and spring • Monitoring post mining for two years or as otherwise required • Monitoring targets sites as mining progresses through the domain	Macroinvertebrate sampling and assessment using the AUSRIVAS protocol and quantitative sampling using artificial collectors In consideration of Adams Emerald Dragonfly, Giant Dragonfly and Sydney Hawk Dragonfly, individuals of the genus Austrocorduliidae and Gomphomacromiidae, Petalura are identified to species level if possible Fish are sampled by visual observations and dip netting in Area 3A, and sampled using a back-pack electrofisher and baited traps in Area 3B
AREA 3B	**Impact Sites:** Sites 2, 3, 4, X4, X5 and X6 (Wongawilli Creek) Sites X2 and X3 (WC21) Site X1 (Donalds Castle Creek) **Reference Sites:** Site 1 (Wongawilli Creek – until LW15) Site 5 (Wongawilli Creek) Site 14 (Donalds Castle Creek) Site 6 (WC21) Site 7 (Sandy Creek) Sites 15 and 16 (Kentish Creek) *Refer to Figure 2-57*			
TERRESTRIAL FAUNA – THREATENED FROG SPECIES				
AREA 3B	**Impact Sites:** DC13 (Donalds Castle Creek tributary) DC(1) (Donalds Castle Creek) WC15 and 21 (Wongawilli Creek tributaries) LA4A (Lake Avon tributary) ND1 (Native Dog Creek tributary) *Refer to Figures 2-42 to 2-47* **Reference Sites:** WC10 and 11 (Wongawilli Creek tributaries) SC6, SC7-1, SC7-2, SC7A and SC8 (Sandy Creek tributaries) DC8 (Donalds Castle Creek tributary) NDC (Native Dog Creek) *Refer to Figures 2-48 to 2-56*	• Standardised transects in potential breeding habitat for two threatened frog species, Littlejohn's Tree Frog and Giant Burrowing Frog	• Surveys are undertaken in optimal periods over the season (i.e. when frogs are calling and/or active at known sites)	Frog surveys are conducted along creeks with a focus on features susceptible to impacts e.g. breeding pools. Potential breeding habitat for Littlejohn's Tree Frog and Giant Burrowing Frog will be targeted. Standardised transects have been established to record numbers of individuals recorded at each site from one year to the next. Tadpole counts will also be undertaken as part of the breeding habitat monitoring transects. These transects are surveyed by walking down the creekline and counting all amphibians seen or heard on either side of the line

Table 1.2 – Dendrobium Area 3B Watercourse Impacts, Triggers and Response

OBSERVATIONAL-MONITORING		
Wongawilli Creek, Donalds Castle Creek and WC-WF54 **Relevant Performance Measure(s):** • Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences • Waterfall WC-WF54 – negligible environmental consequences	***Level 1*** • Crack or fracture up to 100mm width at its widest point with no observable loss of surface water or erosion • Crack or fracture up to 10m length with no observable loss of surface water or erosion • Erosion in a localised area (not associated with cracking or fracturing) which would be expected to naturally stabilise without CMA and within the period of monitoring • Observable release of strata gas at the surface • Observable increase in iron staining within the mining area • Observation that a pool on a subject Creek is dry • Observation that the subject Creek has ceased to flow	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, DRG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
General observation of streams in active mining areas when longwall is within 400m	***Level 2*** • Observation that a single pool on a subject Creek is dry in consecutive monitoring events • Observation that two or more pools on a subject Creek are dry in a single monitoring event • Observation that the subject Creek has ceased to flow in consecutive monitoring event	• *Actions as stated for Level 1* • Carry out Water Flow Assessment Method D • Review monitoring frequency • Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	• Crack or fracture between 100 and 300mm width at its widest point or any fracture which results in observable loss of surface water or erosion • Crack or fracture between 10 and 50m length • Soil surface crack that causes erosion that is likely to stabilise within the monitoring period without intervention • Observable increase in iron staining within the mining area continues to outside the mining area i.e. 400m from the longwall	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3 • Crack or fracture over 300mm width at its widest point • Crack or fracture over 50m length • Fracturing observed in the bedrock base of any significant permanent pool which results in observable loss of surface water • Soil surface crack that causes erosion that is unlikely to stabilise within the monitoring period without intervention	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, DRG, Water NSW • Implement additional monitoring or increase frequency if required • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, DRG, Water NSW • Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced

	• Gas release results in vegetation dieback, mortality or loss of aquatic habitat • Observable increase in iron staining within the mining area continues more than 600m from the longwall	movements and impacts are complete), including monitoring and reporting on success • Review relevant TARP and Management Plan in consultation with key agencies
	Exceeding Prediction • Structural integrity of the bedrock base of any significant permanent pool or controlling rockbar cannot be restored i.e. pool water level within the pool after CMAs continues to be lower than baseline period • Gas release results in vegetation dieback that does not revegetate • Gas release results in mortality of threatened species or ongoing loss of aquatic habitat • Iron staining and associated increases in dissolved iron resulting from the mining is observed in water at Wongawilli Creek downstream monitoring site Wongawilli Creek (FR6) • Iron staining and associated increases in dissolved iron resulting from the mining is observed in water at the Donalds Castle Creek downstream monitoring site Donalds Castle Creek (FR6) • Rock fall at WC-WF54 or its overhang • Impacts on the structural integrity of WC-WF54, its overhang or its pool	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Native Dog Creek, DC13, WC21, WC15, LA2, LA3, LA4, LA5, ND1, WC6, WC7, WC8, WC9, WC12, WC16 and WC18 General observation of streams in active mining areas when longwall is within 400m	***Level 1*** • Crack or fracture up to 100mm width at its widest point with no observable loss of surface water or erosion • Crack or fracture up to 10m length with no observable loss of surface water or erosion • Erosion in a localised area (not associated with cracking or fracturing) which would be expected to naturally stabilise without CMA and within the period of monitoring • Observable release of strata gas at the surface • Observable increase in iron staining within the mining area	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, DRG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR

<table>
<tr><td rowspan="2"></td><td>Level 2
Crack or fracture between 100 and 300mm width at its widest point or any fracture which results in observable loss of surface water or erosion
Crack or fracture between 10 and 50m length
Soil surface crack that causes erosion that is likely to stabilise within the monitoring period without intervention
Observable increase in iron staining within the mining area continues to outside the mining area i.e. 400m from the longwall</td><td>Actions as stated for Level 1
Review monitoring frequency
Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required
Implement agreed CMAs as approved (subject to agency feedback)</td></tr>
<tr><td>Level 3
Crack or fracture over 300mm width at its widest point
Crack or fracture over 50m length
Fracturing observed in the bedrock base of any significant permanent pool which results in observable loss of surface water
Soil surface crack that causes erosion that is unlikely to stabilise within the monitoring period without intervention
Gas release results in vegetation dieback, mortality or loss of aquatic habitat
Observable increase in iron staining within the mining area continues more than 600m from the longwall</td><td>Actions as stated for Level 2
Offer site visit with BCD, DPIE, DRG, Water NSW
Implement additional monitoring or increase frequency if required
Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, DRG, Water NSW
Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
Review relevant TARP and Management Plan in consultation with key agencies</td></tr>
<tr><td colspan="3">WATER QUALITY</td></tr>
<tr><td rowspan="2">Wongawilli Creek

Relevant Performance Measure(s):
Wongawilli Creek - minor environmental consequences
Wongawilli Creek (FR6)
Baseline means:
pH 5.98
EC 98.8 uS/cm
DO 89.5%</td><td>Level 1
One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:
pH 4.45
EC 154.1 uS/cm
DO 50.5%</td><td>Continue monitoring program
Submit an Impact Report to BCD, DPIE, DRG, Water NSW
Report in the End of Panel Report
Summarise actions and monitoring in AEMR</td></tr>
<tr><td>Level 2
Two non-consecutive exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:
pH 4.45
EC 154.1 uS/cm
DO 50.5%</td><td>Actions as stated for Level 1
Review monitoring frequency
Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required
Implement agreed CMAs as approved (subject to agency feedback)</td></tr>
</table>

	Level 3 • Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, DRG, Water NSW • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key agencies • Develop site CMA (subject to agency feedback). This may include: – Limestone emplacement to raise pH where it is appropriate to do so • Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • Mining results in two consecutive exceedances or three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Donalds Castle Creek **Relevant Performance Measure(s):** • Donalds Castle Creek - minor environmental consequences Donalds Castle Creek (FR6) Baseline means: • pH 5.41 • EC 116.0 uS/cm • DO 85.6%	***Level 1*** • One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, DRG Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • Two non-consecutive exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, DRG, Water NSW • Implement additional monitoring or increase frequency if required

<table>
<tr><td rowspan="2"></td><td>Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:
– pH 3.60
– EC 185.8 uS/cm
– DO 40.1%</td><td>Review relevant TARP and Management Plan in consultation with key agencies
Collect laboratory samples and analyse for:
– pH, EC, major cations, major anions, Total Fe, Mn & Al
– Filterable suite of metals
Develop site CMA (subject to agency feedback). This may include:
– Limestone emplacement to raise pH where it is appropriate to do so
Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success</td></tr>
<tr><td>Exceeding Prediction
Mining results in two consecutive exceedances or three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:
– pH 3.60
– EC 185.8 uS/cm
– DO 40.1%</td><td>Actions as stated for Level 3
Investigate reasons for the exceedance
Update future predictions based on the outcomes of the investigation
Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent</td></tr>
<tr><td rowspan="3">Lake Avon

Relevant Performance Measure(s):
Lake Avon - negligible reduction in the quality of surface water inflows to Lake Avon
Lake Avon tributary (LA4_S1)
Baseline means:
pH 5.38
EC 90.8 uS/cm
DO 89.9%</td><td>Level 1
One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:
– pH 4.90
– EC 129.8 uS/cm
– DO 69.5%</td><td>Continue monitoring program
Submit an Impact Report to BCD, DPIE, DRG, Water NSW
Report in the End of Panel Report
Summarise actions and monitoring in AEMR</td></tr>
<tr><td>Level 2
Two non-consecutive exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:
– pH 4.90
– EC 129.8 uS/cm
– DO 69.5%</td><td>Actions as stated for Level 1
Review monitoring frequency
Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required
Implement agreed CMAs as approved (subject to agency feedback)</td></tr>
<tr><td>Level 3</td><td>Actions as stated for Level 2
Offer site visit with BCD, DPIE, DRG, Water NSW
Implement additional monitoring or increase frequency if required</td></tr>
</table>

	• Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• Review relevant TARP and Management Plan in consultation with key agencies • Collect laboratory samples and analyse for: – pH, EC, major cations, major anions, Total Fe, Mn & Al – Filterable suite of metals • Develop site CMA (subject to agency feedback). This may include: – Limestone emplacement to raise pH where it is appropriate to do so – Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than baseline period • Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • Mining results in two consecutive exceedances or three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
POOL WATER LEVEL		
Wongawilli Creek and Donalds Castle Creek **Relevant Performance Measure(s):** • Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences	***Level 1*** • Single pool on a subject Creek is observed as dry	• Continue monitoring program • Carry out Water Flow Assessment Method D. • Submit letter report to DPIE, DRG and Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • Single pool on a subject Creek is observed as dry in consecutive monitoring events • Two or more pools on a subject Creek are observed as dry in a single monitoring event	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)

	Level 3 • Fracturing resulting in diversion of flow such that <10% of the pools have water levels lower than baseline period	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, DRG, Water NSW • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key agencies • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BD, DPIE, DRG, Water NSW • Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • Fracturing resulting in diversion of flow such that >10% of the pools have water levels lower than baseline period	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Waterfall WC-WF54 **Relevant Performance Measure(s):** • Waterfall WC-WF54 – negligible environmental consequences	***Exceeding Prediction*** • Fracturing in Wongawilli Creek within 30m of the waterfall which results in observable flow diversion • Fracturing in Wongawilli Creek which results in observable flow diversion from the lip of the waterfall	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent

Monitoring	Trigger	Action
SURFACE WATER FLOW		
Wongawilli Creek and Donalds Castle Creek **Lake Avon and Cordeaux River** **Relevant Performance Measure(s):**	***Level 1*** • A) Lower flow than expected (additional 10-15% of days where Q% lower than Reference Q%) • B) 5-10% increase in cease-to-flow frequency beyond natural) • C) Reduction in Q50 (10-15% beyond natural)	• Continue monitoring program. • Submit an Impact Report to BCD, DPIE, DRG, WaterNSW. • Report in the End of Panel Report. • Summarise actions and monitoring in AEMR.

• Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences • Lake Avon - negligible reduction in the quantity of surface water inflows to Lake Avon[1] • Cordeaux River - negligible reduction in the quantity of surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek[2] **Surface water flow Reference sites** (as in Table 1.1)**:** • <u>Wongawilli Creek - WWU</u> (Wongawilli Creek upstream); • <u>O'Hares Creek at Wedderburn (213200);</u> • (other such sites, if necessary, include Woronora River 2132101 and Bomaderry Creek 215016) NB. This section of the TARP contains four Water Flow Assessment Methods, labelled A, B, C and D, which are specified in detail in Watershed HydroGeo (2019). Hydrological changes are assessed by comparing pre- and post-mining observed flows from impact or assessment sites to flow data from the reference sites. *Natural variability ('NV') will be defined as the 'average' change at the selected reference sites. Triggers may occur when the apparent impact at a site (NV + x% change) could be less than maximum observed variability at one of the reference sites.*	***Level 2*** • A) Lower flow than expected (additional 15-20% of days where Q% lower than Reference Q%). • B) 10-20% increase in cease-to-flow frequency (beyond natural) • C) 15-20% reduction in Q50 (beyond natural) • D) Observation that the subject Creek has ceased to flow at spatially consecutive monitoring sites.	• *Actions as stated for Level 1* • Review monitoring frequency. • D) → carry out Water Flow Assessment Method D. • Submit letter report to DPIE, DRG and WaterNSW and seek advice on any CMA required. • Implement agreed CMAs as approved (subject to agency feedback).
	Level 3 • A) Lower flow than expected (additional >20% of days where Q% lower than Reference Q%) • B) >20% increase in cease-to-flow frequency (beyond natural) • C) >20% reduction in Q50 (beyond natural)	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, DRG, WaterNSW. • Implement additional monitoring or increase frequency if required. • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, DRG, WaterNSW. • Completion of works following approvals and at a time agreed between S32, DPIE, DRG and WaterNSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success. • Review relevant TARP and Management Plan in consultation with key agencies.
	Exceeding Prediction Measured surface water flow reduction, based on Assessment Methods C, D, to be compared against predictions made in contemporary groundwater modelling conducted to the satisfaction of the Secretary to assess whether effects that cannot be explained by natural variability "exceed prediction".	• *Actions as stated for Level 3* • Investigate reasons for the exceedance. • Update future predictions based on the outcomes of the investigation. • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent.

[1] Surface water inflows calculation = [Impacts at gauged catchments (LA1 + LA2 + LA3 + LA4 + LA6+ NDT1 + ND2) + estimated impacts at ungauged but undermined catchments (e.g. LA5)] / [total inflow to LA].
[2] Flow reduction as determined from measured at flow gauging station WWL_A.

Tributaries of Wongawilli Creek and Donalds Castle Creek and other affected watercourses not subject to performance measures **Surface water flow Reference sites** (as in Table 1.1)**:** • <u>Wongawilli Creek - WWU</u> (Wongawilli Creek upstream); • <u>O'Hares Creek and Wedderburn (213200);</u> • (other such sites, if necessary, include Woronora River 2132101 and Bomaderry Creek 215016) NB. This section of the TARP contains four Water Flow Assessment Methods, labelled A, B, C and D, which are specified in detail in Watershed HydroGeo (2019). Hydrological changes are assessed by comparing pre- and post-mining observed flows from impact or assessment sites to flow data from the reference sites. *Natural variability ('NV') will be defined as the 'average' change at the selected reference sites. Triggers may occur when the apparent impact at a site (NV + x% change) could be less than maximum observed variability at one of the reference sites.*	***Level 1*** • A) Lower flow than expected (additional 10-20% of days where Q% lower than Reference Q%) • B) 5-10% increase in cease-to-flow frequency (beyond natural) • C) 10-20% reduction in Q50 (beyond natural)	• Continue monitoring program. • Submit an Impact Report to BCD, DPIE, DRG, WaterNSW. • Report in the End of Panel Report. • Summarise actions and monitoring in AEMR.
	Level 2 • A) Lower flow than expected (additional 20-30% of days where Q% lower than Reference Q%) • B) 10-20% increase in cease-to-flow frequency (beyond natural) • C) 20-30% reduction in Q50 (beyond natural)	• *Actions as stated for Level 1* • Review monitoring frequency. • Submit letter report to DPIE, DRG and WaterNSW and seek advice on any CMA required. • Implement agreed CMAs as approved (subject to agency feedback).
	Level 3 • A) Lower flow than expected (additional >30% of days where Q% lower than Reference Q%) • B) >20% increase in cease-to-flow frequency (beyond natural) • C) >30% reduction in Q50 (beyond natural)	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, DRG, WaterNSW. • Implement additional monitoring or increase frequency if required • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, DRG, WaterNSW. • Completion of works following approvals and at a time agreed between S32, DPIE, DRG and WaterNSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success. • Review relevant TARP and Management Plan in consultation with key agencies.
AQUATIC ECOLOGY		
Pool water level, interconnectivity between pools and loss of connectivity, noticeable alteration of habitat • Wongawilli Creek catchment – 8 sites • Donalds Castle Creek catchment – 1 site	***Level 1*** • Reduction in aquatic habitat for 1 year	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, DRG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2	• *Actions as stated for Level 1*

<table>
<tr><td rowspan="2">Relevant Performance Measure(s):
• Wongawilli Creek - minor environmental consequences
• Donalds Castle Creek - minor environmental consequences</td><td>• Reduction in aquatic habitat for 2 years following the active subsidence period</td><td>• Review monitoring frequency
• Submit letter report to DPIE, BCD, DRG and Water NSW and seek advice on any CMA required
• Implement agreed CMAs as approved (subject to agency feedback)</td></tr>
<tr><td>Level 3
• Reduction in aquatic habitat for >2 years following the active subsidence period</td><td>• Actions as stated for Level 2
• Offer site visit with BCD, DPIE, DRG, Water NSW
• Implement additional monitoring or increase frequency if required
• Review relevant TARP and Management Plan in consultation with key agencies
• Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, DRG, Water NSW
• Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success</td></tr>
<tr><td colspan="3">TERRESTRIAL FAUNA – THREATENED FROG SPECIES</td></tr>
<tr><td rowspan="3">Pool water level, interconnectivity between pools and loss of connectivity, noticeable alteration of habitat
• Wongawilli Creek catchment – 2 sites
• Donalds Castle Creek catchment – 2 sites
• Lake Avon tributary – 1 site
• Native Dog tributary – 1 site
Relevant Performance Measure(s):
• Wongawilli Creek - minor environmental consequences
• Donalds Castle Creek - minor environmental consequences</td><td>Level 1
• Reduction in habitat for 1 year</td><td>• Continue monitoring program
• Submit an Impact Report to BCD, DPIE, DRG, Water NSW
• Report in the End of Panel Report
• Summarise actions and monitoring in AEMR</td></tr>
<tr><td>Level 2
• Reduction in habitat for 2 years following the active subsidence period</td><td>• Actions as stated for Level 1
• Review monitoring frequency
• Submit letter report to DPIE, BCD, DRG and Water NSW and seek advice on any CMA required
• Implement agreed CMAs as approved (subject to agency feedback)</td></tr>
<tr><td>Level 3
• Reduction in habitat for > 2 years following the active subsidence period</td><td>• Actions as stated for Level 2
• Offer site visit with BCD, DPIE, DRG, Water NSW
• Implement additional monitoring or increase frequency if required
• Review relevant TARP and Management Plan in consultation with key agencies
• Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, DRG, Water NSW
• Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced</td></tr>
</table>

		movements and impacts are complete), including monitoring and reporting on success

Department of Planning, Industry and Environment (DPIE)

Biodiversity and Conservation Division (BCD) within DPIE

Division of Resources and Geoscience within the Department (DRG) within DPIE

WaterNSW

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Port Macquarie
Illawarra
Coffs Harbour
Central Coast
Gold Coast
Canberra

Our services

Ecology and biodiversity
Terrestrial
Freshwater
Marine and coastal
Research and monitoring
Wildlife Schools and training

Heritage management
Aboriginal heritage
Historical heritage
Conservation management
Community consultation
Archaeological, built and landscape values

Environmental management and approvals
Impact assessments
Development and activity approvals
Rehabilitation
Stakeholder consultation and facilitation
Project management

Environmental offsetting
Offset strategy and assessment (NSW, QLD, Commonwealth)
Accredited BAM assessors (NSW)
Biodiversity Stewardship Site Agreements (NSW)
Offset site establishment and management
Offset brokerage
Advanced Offset establishment (QLD)