RioTinto

Mesa K Remnant Mining Project

Mesa K - Troglofauna Monitoring Plan

September 2024

RTIO-HSE-0969967
Robe River Mining Co. Pty. Ltd.
152-158 St Georges Terrace, Perth
GPO Box A42, Perth WA 6837

Disclaimer and Limitation

This Troglofauna Monitoring Plan has been prepared by Rio Tinto's Iron Ore group (Rio Tinto), on behalf of Robe River Mining Co. Pty. Limited (the Proponent), specifically for Mesa K. Neither the report nor its contents may be referred to without the express approval of Rio Tinto, unless the report has been released for referral and assessment of proposals.

Document Status						
Rev	**Document Number**	**Author**	**Reviewer/s**	**Date**	**Approved for Issue**	
					To Whom	**Date**
A	Mesa J and K EMP RTIO-HSE-0162720	Rio Tinto	Approvals, Ops Environment	2012	EPA Services	December 2012[1]
B	Mesa K Troglofauna Monitoring Plan RTIO-HSE-0969967	Rio Tinto	Approvals, Ops Environment	December 2022	DWER	December 2022 / TBC
C	Mesa K Troglofauna Monitoring Plan RTIO-HSE-0969967	Rio Tinto	Approvals, Ops Environment	October 2024	DWER	TBC

[1] Mesa J K EMP Approved December 2012.

Summary

This Troglofauna Monitoring Plan is submitted by Rio Tinto on behalf of Robe River Mining Co. Pty. Ltd. (the Proponent) in accordance with Condition 6 of Ministerial Statement (MS) 776. Table S1 below presents the environmental criteria to measure achievement of the environmental outcomes and objectives to be met through implementation of this EMP.

Table S1: Condition summary

Proposal title		**Mesa K Remnant Mining Project**
Proponent		Robe River Mining Co. Pty. Ltd.
Ministerial Statement		MS776
Purpose of this monitoring regime		This monitoring regime addresses the monitoring requirements for troglofauna during implementation of the Mesa K Remnant Mining Project and fulfils the requirements of conditions 6-1 and 6-2 of MS776 in relation to management of troglofauna.
Condition 6-1		The proponent shall implement the proposal to avoid disturbance of areas where troglofauna taxa represented by only one individual have been recorded (as shown in Figure 4 attached and delineated by AMG coordinates listed in Schedule 2).
Condition 6-2		The proponent shall establish a monitoring regime to the requirements of the Minister for the Environment on the advice of the Environmental Protection Authority to demonstrate the effectiveness of the disturbance avoidance areas as shown in Figure 4 attached and delineated by AMG coordinates listed in Schedule 2.
Subterranean Fauna – Troglofauna **EPA Objective:** *To protect subterranean fauna so that biological diversity and ecological integrity are maintained.*		
Outcome based provisions	**Condition environmental outcome**	1. The proponent shall implement the proposal to avoid disturbance of areas where troglofauna taxa represented by only one individual have been recorded (as shown in Figure 4 attached and delineated by AMG coordinates listed in Schedule 2). 2. The proponent shall establish a monitoring regime to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority to demonstrate the effectiveness of the disturbance avoidance areas as shown in Figure 4 attached and delineated by AMG coordinates listed in Schedule 2.
	Trigger criteria	1. > 0.1% volume of the retained habitat at Mesa K removed due to mining operations
	Threshold criteria	1. Disturbance to the demarcated Avoidance Areas at Mesa K (Figure 2-1)
Management based provisions	**EPA Environmental objective**	The Proponent shall protect the biological diversity and ecological integrity of the troglofauna assemblages of Mesa K by minimising impacts as far as practicable.
	Management targets	1. Troglofauna specimen capture rate is not below the baseline minimum for three consecutive sampling events at Mesa K 2. No statistically significant change in down hole temperature and relative at Mesa K relative to reference sites.

Corporate endorsement

I hereby certify that to the best of my knowledge, the provisions within this Mesa K Troglofauna Monitoring Plan are true and correct and address the legal requirements of MS776 in relation to the management of troglofauna.

Name: Phil Norris **Signed:** 

Designation: General Manager Robe Valley **Date:** 27/09/24

RioTinto

Table of Contents

1. Context, Scope and Rationale

1.1 Mesa K

The Mesa K Remnant Mining Project is located approximately 11 km south-west of Pannawonica in the Pilbara region of Western Australia (WA) (Figure 1-1).

Robe River Mining Co. Pty. Limited (the Proponent) manages and operates the Mesa K Remnant Mining Project (the Proposal) as approved by MS776 under Part IV of the *Environmental Protection Act 1986* (EP Act).

The Mesa K Remnant Mining Project includes the following key elements:

- mining of remnant iron ore in five (5) existing open cut pits
- mineral waste management
- haulage of ore by truck from Mesa K to Mesa J
- minor realignment and widening of the existing mine access road from Mesa K to Mesa J
- establishment of support facilities
- sourcing of water and fuel from existing Mesa J facilities

Mining, mineral waste management and supporting activities occur in the Development Envelope for the project (Figure 1-2).

The Mesa K 'Monitoring Regime – Troglofauna' as required under Condition 6-1 and 6-2 of MS776 was originally amalgamated into the Mesa J (MS208) Environmental Management Plan (EMP) and approved in December 2012 (RTIO-HSE-0162720).

The Mesa J Proposal was subsequently revised to include the Mesa H Proposal (as approved under MS1141 in July 2020) and requires the implementation of an EMP for the Revised Proposal (i.e., the Mesa J and H operations). The Mesa J and K Operations EMP, December 2012 will, therefore, be replaced by the Mesa J and H EMP (RTIO-HSE-0349253), resulting in the need to separate the Mesa K troglofauna monitoring requirements as required by MS776 into a separate 'Mesa K Monitoring Regime – Troglofauna' document.

The Mesa K monitoring regime for Troglofauna will be implemented to meet the requirements of MS776, Condition 6-1 and Condition 6-2 and addresses the separation of the Mesa K monitoring requirements from the Mesa J and K Operations EMP, December 2012 (Rio Tinto 2012; RTIO-HSE-0162720) once the Mesa J and H EMP is approved. The monitoring has been aligned (where feasible and relevant) with the approach approved in the Mesa A Hub troglofauna monitoring EMP (Rio Tinto 2019; RTIO-HSE-0335971) as required by Condition 6 of MS1112 (approved December 2019).

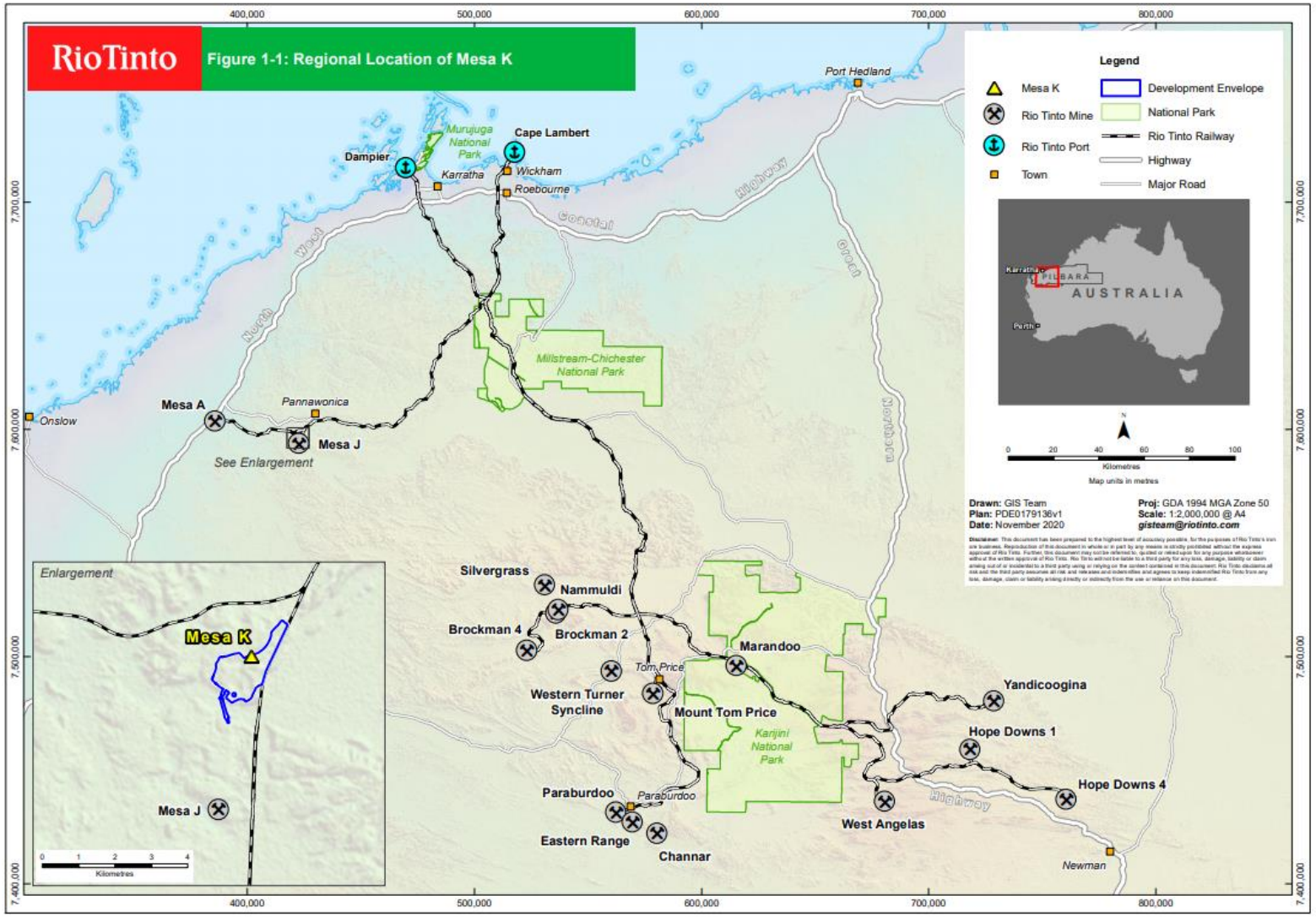


Figure 1-1 Regional Location of Mesa K

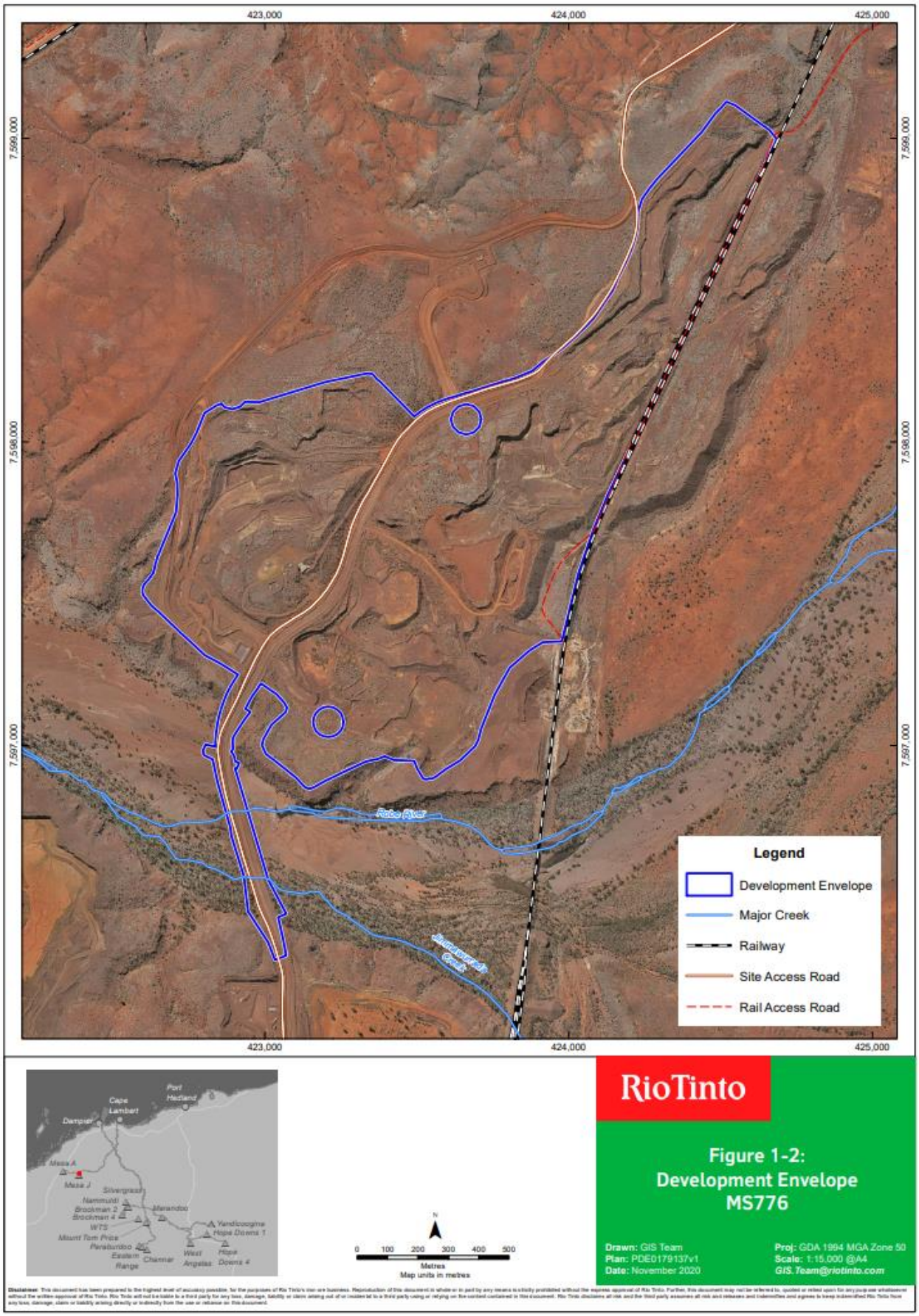


Figure 1-2 Development Envelope MS776

1.2 Key environmental factors

The key environmental factor addressed in this monitoring regime is Subterranean Fauna, specifically troglofauna.

The target ore bodies in the Mesa K Development Envelope comprise the Robe Pisolite which is considered to be highly prospective habitat for troglofauna. Most species of obligate troglofauna are considered to be Short Range Endemic (SRE), with many species believed to be endemic to individual mesas in the Robe Valley. Mine pit excavation to be conducted as part of the proposal will result in direct loss of troglofauna habitat and a loss of individuals, which in turn has the potential to result in changes to troglofauna habitat and assemblages.

1.3 Condition Requirements

This monitoring regime has been developed to demonstrate the effectiveness of the disturbance avoidance areas as required by Condition 6 of MS776, specifically Condition 6-2 (Table 1-1), noting that Mesa K has been historically mined, and the current proposal relates to *remnant mining*.

Table 1-1 Mesa K MS776 Conditions for the Proposal related to Troglofauna

Condition Number	Condition	Section in TMP
Protection of Troglofauna		
6-1	The proponent shall implement the proposal to avoid disturbance of areas where troglofauna taxa represented by only one individual have been recorded as shown in Figure 4 attached and delineated by AMG coordinates listed in Schedule 2.	Table 2-1
6-2	The proponent shall establish a monitoring regime to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority to demonstrate the effectiveness of the disturbance avoidance areas as shown in Figure 4[2] attached and delineated by AMG coordinates listed in Schedule 2	Table 2-1

1.4 Rationale and Approach

Mining occurred historically at Mesa K from 1988 to 1995 under a 'Notice of Intent' and operations pre-dated the EP Act. In the mid-2000's, approval for additional 'remnant mining' of areas of Channel Iron Deposit Iron Ore was sought. Due to the known presence of troglofauna, the Mesa K remnant mining Proposal was referred in April 2007 under s38 of the EP Act. The level of assessment was subsequently set as an Environmental Protection Statement (EPS). Mesa K Remnant mining was approved in 2008 under Ministerial Statement 776, followed by subsequent approval under section 45C (s45C) in 2012 which amended the proposal in the following ways in relation to troglofauna:

- 70% by volume of above water table (AWT) pre-remnant mining of troglofauna habitat (CID) committed to be retained
- AWT mining only
- Extension of the approved mine pit areas as per Figure 2 in Attachment 1, Schedule 1 of MS 776

[2] Figure 4 is replaced by Figure 2 of Attachment 1 of MS776

This TMP has been developed to address management of troglofauna during implementation of the proposal to meet the requirements of Condition 6 of MS776. Results of baseline surveys, monitoring and a number of assumptions and uncertainties inform the management approach for meeting the environmental outcomes stated in Condition 6 of MS776.

The identified performance indicators, management targets and response actions are aligned with the overall management approach and with monitoring and management as approved in the Mesa A Hub Troglofauna Management Plan (Rio Tinto 2019; RTIO-HSE-0335971).

Monitoring data are used to evaluate compliance with the trigger and threshold criteria to achieve the environmental outcomes, and management targets are used to assess whether the management actions are effective in meeting the environmental objectives.

1.4.1 Survey and study findings

Troglofauna were first recorded in the Robe Valley at Mesa A in 2003 as by-catch of stygofauna sampling. Since 2003 numerous troglofauna surveys and assessments have been undertaken across the Robe Valley. The combined coverage of these surveys provides a considerable knowledge base of the troglofauna present in the Robe Valley. Given similar troglofauna habitat units are present across all mesas within the Robe Valley, results from previous surveys and monitoring programs conducted at both Mesa A and Mesa K[3] have been used to guide the design of the monitoring described in Section 2 of this monitoring regime.

One of the key characteristics of geological units known to provide habitat for troglofauna relates to the physical features, particularly the presence of fractures and cavities sufficient in size to accommodate troglofauna. Throughout the Pilbara, a range of geological formations contain the necessary physical characteristics that have been shown to provide habitat for troglofauna. In the Mesa K Development Envelope, the Robe Pisolite is considered to be the geological unit that provides primary habitat for troglofauna as it contains the necessary cavities to accommodate troglofauna.

A review of the monitoring program at Robe Valley, including Mesa K, was undertaken by Astron Environmental Services (Astron) in 2017 to determine suitability of microclimate monitoring. Further reviews were undertaken in 2020 (Astron 2020a,b). Astron (2020b)is presented in Appendix I and incorporates the previous reviews of subterranean climate and troglofaunal habitat (Astron 2017) and analysis of long term down hole temperature and humidity data collected at Mesa K from 2011 - 2020. The review included justification for removal of three biophysical monitoring stations (MEK003, MEK004, MEK005) without compromising data quality in the monitoring program. Astron (2020b) also noted that there was no significant variation in CO_2 concentration between reference and impact sites showed, and that the risk of habitat modification to include permanent probes may affect CO_2 concentrations and therefore invalidate monitoring. Data analysis indicates that a monitoring program incorporating trapping and scraping in boreholes provides a robust dataset with high capture rates (Appendix II).

1.4.2 Key assumptions and limitations

The key assumptions relating to this monitoring regime are:

- The monitoring regime has been developed on the conservative assumption that each mesa formation represents isolated troglofauna habitat. Additional data from longer term monitoring may indicate a degree of troglofauna habitat connectivity between the mesas, potentially requiring revision of the monitoring regime.
- The effectiveness of blast management measures to prevent disturbance to the retained mesa escarpments. The Proponent has a strong record of managing and maintaining landform stability, as demonstrated at the existing Mesa A/Warramboo Iron Ore Project, with no record of mesa escarpment collapse or failure.

[3] The Mesa K operations as approved under MS 776 comprise approval for remnant mining of a historical mining operation previously mined in the 1980s - 1990s, prior to the first known troglofauna records.

The key limitations relating to the information used in this monitoring regime include:

- Pre-remnant mining habitat has been retained at Mesa K. This is the habitat that was available prior to the remnant mining (as approved in MS776), but post-dating the original mining in the 1980's – 1990's.
- Limited taxonomic framework and specialist expertise to identify and determine conservation significance of many groups of subterranean fauna.
- Inherent limitations in troglofauna sampling methodology that limit predictive ability of habitat modelling. Limitations include limited access to the subterranean environment (via drill holes only); modification of potential habitat through establishment of drill holes; trapping and scraping methodology may not be appropriate for some species depending on species preferences and mobility; sampling bias towards orebodies; difficulty in determining the specific geological strata that specimens originate from therefore limiting predictive ability of habitat modelling.
- Limited knowledge of troglofauna distribution patterns, ecological requirements and resilience.

1.4.3 Management approach

A risk-based approach has been taken through the Environmental Impact Assessment process which identified Troglofauna as a key environmental value that may be impacted by the proposal and warrants additional management. Regional data, baseline survey data and, where available, ongoing monitoring data have been used to assess the potential impacts of the proposal on environmental values.

This monitoring regime describes the monitoring that will be undertaken to measure performance against the environmental outcome nominated as part of the 2012 s45C application which relates to retention of 70% of pre-remnant mining troglofauna habitat. The monitoring to be undertaken as part of this monitoring regime has been designed to build upon and improve on existing monitoring programs conducted in the Robe Valley and build upon data from baseline surveys.

Key to the overall environmental management approach for the proposal is avoidance of direct disturbance to high value troglofauna habitat. Where avoidance is not practicable, the management approach is to minimise disturbance to troglofauna habitat.

1.4.4 Rationale for choice of provisions

Overall rationale

Environmental criteria have been developed based on consideration of:

- Threatening processes and risks associated with troglofauna;
- The current state of knowledge for troglofauna; and
- The availability of suitable monitoring methods.

The specific trigger and threshold criteria, management targets and actions have been chosen as they provide a basis for detecting and avoiding or otherwise managing potential impacts, such that the condition environmental outcomes stated in condition 6 of MS776 can be achieved.

Trigger criteria are set at a conservative level to ensure management actions are implemented well in advance of the environmental outcome being compromised. Exceedance of a trigger criterion will, therefore, not be treated as a non-compliance. Exceedance of a threshold criterion will be treated as a potential non-compliance against the environmental outcome if the exceedance is attributable to the proposal.

Monitoring is included in the EMP provisions to measure performance against the environmental outcomes and to determine whether trigger or threshold levels have been exceeded.

Rationale specific to management of troglofauna

Outcome-based and management based provisions have been adopted for troglofauna on the basis that objective measurement and reporting is possible for some parts of the environment but not for others.

Troglofauna surveys in general have low capture rates per survey effort meaning the abundance and diversity of troglofauna recorded during surveys are highly variable (Halse and Pearson 2014). These sampling artefacts mean that threshold criteria based on troglofauna abundance or diversity would be inappropriate at this stage. Protection of habitat for troglofauna is, therefore, considered the most appropriate strategy to protect troglofauna so that biological diversity and ecological integrity are maintained. The following environmental outcomes have been adopted:

- Ensure retention of 70% by volume of pre-remnant mining troglofauna habitat.
- Maintain disturbance avoidance areas

The Mesa K deposit comprises iron-rich Robe Pisolite. Within the Development Envelope, Robe Pisolite is considered to be the geological unit that provides primary habitat for troglofauna. As the Robe Pisolite is also the target ore body, a key part of the design of the proposal is to ensure retention of a significant volume of Robe Pisolite habitat. The approved pit extents are constrained by the requirement to retain at least 70% by volume of pre-remnant mining habitat. The environmental outcome has been selected to reflect this key part of the design of the proposal.

Trigger and threshold criteria have been developed to limit the direct removal, through operational error, of troglofauna habitat to be retained and ensure the retention of 'disturbance avoidance areas'. Blasting and excavation carried out as part of the mining process have a degree of operational error associated with them. The trigger and threshold criteria, while recognising the practical limits to operational precision, have been structured to ensure that significant volumes of troglofauna habitat are not lost from over the remaining life of the remnant mine. The trigger criterion has been set at a conservative level by:

1. Estimating the volume of habitat that would be retained if the mine plan were implemented without operational error;
2. Using the estimate from (1) to calculate the percentage habitat volume retained that would be in excess of the required 70% retention if the mine plan were implemented without operational error;

Minor exceedance of the annualised excess volume (0.1%) would need to be offset in the annual mine plan. This conservative trigger selection will allow trigger level actions to be implemented well in advance of the threshold criterion being reached by the end of the mine life. Volume excavated is readily measurable and is part of the causal relationship between mining and impacts on troglofauna.

The management objective adopted for troglofauna is:

- To protect the biological diversity and ecological integrity of the troglofauna assemblages of Mesa K by minimising impacts as far as practicable.

This management objective has been selected as it relates to the EPA objective for Subterranean Fauna and is specific to a key part of the proposal. Management targets have been selected to assess whether the management actions are effective in meeting the environmental objective. Management targets relate to:

- **Troglofauna specimen capture rate** to assess whether the proposal has an impact on troglofauna utilization of retained habitat
- **Down hole temperature and humidity** to assess whether the proposal has an impact on the subterranean climate.

Management actions and targets have been selected to address potential impacts of the proposal as well as to build upon existing data.

Changes from the current Mesa J and K EMP provisions

As part of the adaptive management process, troglofauna monitoring at Mesa K since 2009 has been reviewed to ensure that the monitoring parameters are relevant and provide meaningful information to support meting the EPA's objective for Subterranean fauna. As a result, some of the previous monitoring has been revised or removed and replaced with new criteria (with associated triggers and thresholds)

to align with the EPA's EMP template requirements, and to align with the recently approved monitoring and management approach as approved in the 2019 Mesa A Hub Troglofauna Management Plan (Rio Tinto 2019; RTIO-HSE-0335971).

Details of the monitoring changes and rationale are provided in Appendix 1.

2. TMP Provisions

This section of the TMP identifies the legal provisions that the Proponent will implement to ensure that the environmental outcomes of Condition 6 of MS776 are met during implementation of the proposal. Outcome based and management based provisions are provided in Section 2.1 and monitoring and reporting are further detailed in Sections 2.2 and 2.3.

2.1 Outcome-based and management-based provisions

The environmental outcomes, environmental criteria (trigger and threshold), response actions (trigger level and threshold level), management objectives, management actions and management targets are provided in Table 2-1.

Table 2-1. EMP provisions – Subterranean Fauna (troglofauna)

Subterranean Fauna – Troglofauna			
EPA objectives: To protect subterranean fauna so that biological diversity and ecological integrity are maintained **Key environmental values:** Subterranean Fauna - Troglofauna **Key impacts and risks:** Loss of habitat from mining as a result of implementation of the proposal			
Outcome-based provisions			
Outcomes: 1. The proponent shall implement the proposal to avoid disturbance of areas where troglofauna taxa represented by only one individual have been recorded as shown in Figure 4[4] attached and delineated by AMG coordinates listed in Schedule 2 2. The proponent shall establish a monitoring regime to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority to demonstrate the effectiveness of the disturbance avoidance areas as shown in Figure 4[4] attached and delineated by AMG coordinates listed in Schedule 2.			
Environmental criteria	**Response Actions**	**Monitoring actions**	**Reporting**
Trigger criterion: 1. Operational error during mining resulting in removal of greater than 0.1% by volume annually of the retained habitat at Mesa K	• Review 3-dimensional pit shells and adjust to ensure no predicted net loss of the retained habitat at Mesa K (i.e., amend mine plan to ensure retention of 70% of pre-remnant mining habitat as per s.45C approval 2013). • Assess the adequacy of work practices and propose changes if necessary to prevent future deviations from the planned 3-dimensional volume retained.	• Annual retained habitat reconciliation at Mesa K based on 3D pit shells	• The environmental outcome will be reported against the trigger criteria for each calendar year by 30 April in the ACAR for MS776. • If trigger criterion was exceeded during the reporting period, the ACAR will discuss potential reasons for exceedance of the trigger criterion and include a description of the effectiveness of trigger level actions to prevent removal of >70% retained pre-remnant mining habitat.

[4] Figure 4 is replaced by Figure 2 of Attachment 1 of MS776

Threshold criteria: 1. Removal of habitat within the demarcated Avoidance Areas at Mesa K (Figure 2-1) excluding existing disturbance (prior to MS776) 2. Removal of troglofaunal habitat such that the retained habitat represents less than 70% by volume of pre-remnant mining habitat at Mesa K	As per trigger level response actions with the addition of: • Cease activity within the avoidance area • Geotechnical assessment to ensure pit slopes are stable • If exceedance of threshold criterion is considered likely to be attributable to the proposal, remediate disturbance within the Avoidance Areas within a timeframe agreed with DWER • Monitor to ensure contingency actions are successful and review procedures, if appropriate	• Annual land clearing reconciliation • Monitor the effectiveness of contingency actions	• Notify the DWER within 7 days of the non-compliance being known and provide a report within 21 days of the non-compliance being known • The environmental outcome will be reported against the threshold criterion for each calendar year in the ACAR • If the threshold criterion was exceeded during the reporting period, the ACAR will include a description of the adequacy of threshold contingency action/s that have been implemented to manage the potential impact • Submit a report within 12 months after notification to the DWER of the non-compliance detailing the: ○ adequacy of contingency actions to re-instate the appropriate amount of lost habitat ○ schedule for ongoing monitoring and reporting
Management-based provisions			
Management objective: To protect the biological diversity and ecological integrity of the troglofauna assemblages of Mesa K, by minimizing impacts as far as practicable			
Management actions	**Management targets**	**Monitoring**	**Reporting**
• Maintain suitable subterranean biophysical habitat and microclimate to support troglofauna diversity and assemblages	• Troglofauna specimen capture rate is not below the baseline minimum[5] for three consecutive sampling events at Mesa K • No statistically significant change in down hole temperature and relative humidity at Mesa K relative to reference sites.	• Biennial troglofauna field sampling (Figure 2-1; Table 2-2). • Continuous down hole temperature and humidity monitoring (Figure 2-1; Table 2-2).	• The environmental outcome will be reported against the management target for each calendar year by 30 April in the ACAR for MS776 • If a management target was not met during the reporting period, the annual report will include discussion of the effectiveness of the management actions and whether revision of the management actions is required.

[5] Troglofauna specimen capture rates are provided in Appendix 2

		• Rainfall with daily total reporting (Table 2-2).	

2.2 Monitoring

This section of the monitoring regime identifies the monitoring that the Proponent will implement to demonstrate the effectiveness of the disturbance avoidance areas, as required by Condition 6-2 of MS776. Monitoring is summarised in Monitoring of rainfall and downhole temperature and humidity will continue to be undertaken at Mesa K to assess whether the proposal has an impact on the subterranean climate. The information collected from Mesa K, and the Mesa A Hub monitoring programs can be applied more broadly across the Robe Valley to assist in understanding the effect of mining on the downhole temperature and humidity in mesa formations. At Mesa A, a total of 24 troglofauna habitat monitoring stations spread across 13 locations within the Mining Exclusion Zone (MEZ) will continue to monitor temperature and humidity. Monitoring will also continue at Mesa B, with two of the three monitoring stations at Mesa A to be moved to the MEZ at Mesa B. An additional three monitoring stations have also been established at Mesa F as reference sites. Temporary downhole temperature and humidity monitoring stations will also continue to be used where practicable in the Mesa A pit floor. The design of the subterranean temperature and humidity monitoring program thus includes monitoring before mining (Mesa B), during mining (Mesa A and Mesa B) and in reference habitat (Mesa F).

Table 2-2 and rationale for amendments to the original Mesa K Monitoring regime (previously approved as part of the Mesa J/K Operational EMP) are included as Appendix 1.

2.2.1 Subterranean Habitat Retention and Avoidance Areas

Protection of high value habitat for troglofauna is considered the most appropriate strategy currently to protect troglofauna so that biological diversity and ecological integrity are maintained. High value habitat in the Development Envelope includes the Robe Pisolite comprising the Mesa landform. This approach reflects the key environmental outcome of relevance outlined in the Mesa K environmental assessment documentation, pertaining to the percentage of pre-remnant mining troglofauna habitat retained being ≥70%[6]. In addition, triggers and thresholds have been proposed to ensure that this outcome will be met.

2.2.2 Troglofauna field sampling

Sampling for troglofauna specimens will be conducted biennially and the troglofauna specimen capture rate (Appendix 2) will be analysed to assess whether the proposal has an impact on troglofauna utilization of the retained habitat at Mesa K. As a minimum, the survey will include trapping and scraping from approximately 30 available representative drill holes which provide a geographic spread commensurate with the size of the Mesa. Previously sampled sites will be used wherever possible to ensure results from each survey are readily comparable. All specimens will be identified to species level using morphological and molecular methods, which when used in conjunction ensure alignment with historic records. All specimens with troglomorphic characteristics will be included in the analysis and reporting as 'potentially troglobitic' until shown otherwise.

2.2.3 Subterranean Biophysical / Microclimate Habitat

Monitoring of rainfall and downhole temperature and humidity will continue to be undertaken at Mesa K to assess whether the proposal has an impact on the subterranean climate. The information collected from Mesa K, and the Mesa A Hub monitoring programs can be applied more broadly across the Robe Valley to assist in understanding the effect of mining on the downhole temperature and humidity in mesa formations. At Mesa A, a total of 24 troglofauna habitat monitoring stations spread across 13 locations within the Mining Exclusion Zone (MEZ) will continue to monitor temperature and humidity. Monitoring will also continue at Mesa B, with two of the three monitoring stations at Mesa A to be moved to the MEZ at Mesa B. An additional three monitoring stations have also been established at Mesa F as reference sites. Temporary downhole temperature and humidity monitoring stations will also continue to be used where practicable in the Mesa A pit floor. The design of the subterranean

[6] As calculated in the 2012 Mesa K s45C approval.

temperature and humidity monitoring program thus includes monitoring before mining (Mesa B), during mining (Mesa A and Mesa B) and in reference habitat (Mesa F).

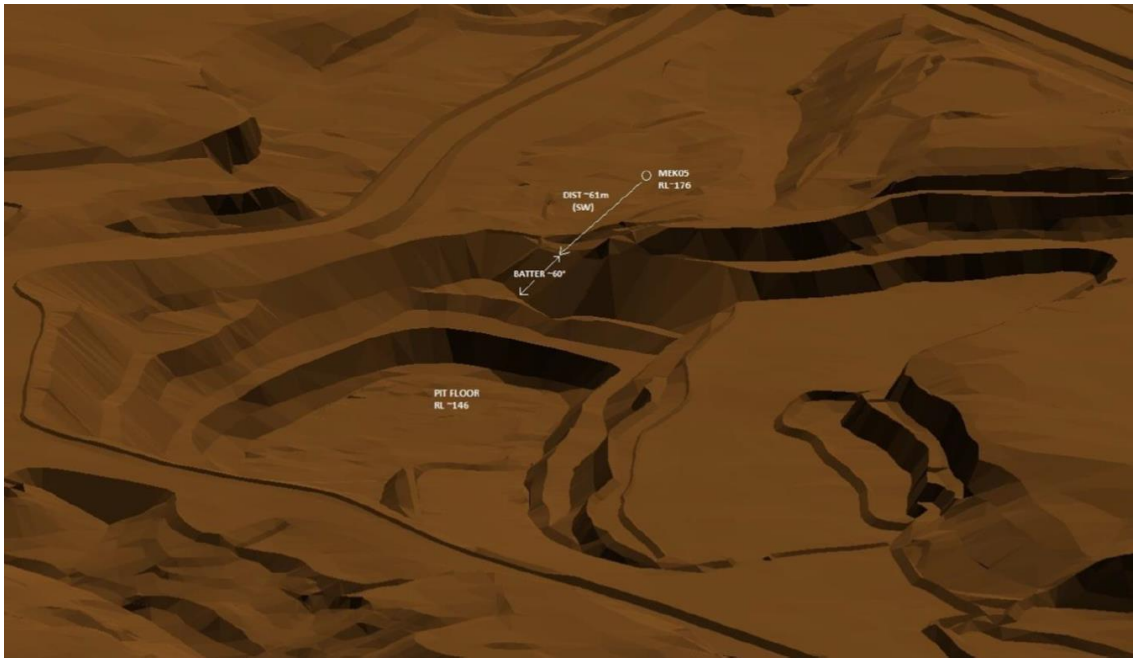
Table 2-2. Mesa K Troglofauna Monitoring

Aspect	Monitoring	Location	Frequency and timing	Data collection method	Monitoring / Data Analysis method	Responsible
Troglofauna Diversity and assemblages	Troglofauna field sampling	Approximately 30 representative drill holes at Mesa K (indicative hole locations shown in Figure 2-1[7]	Biennial during operational mine life	Trapping and scraping. Morphological and molecular species level identifications.	Comparison of scraping and trapping results to previous sampling results and environmental conditions. Review of specimen capture rates (Appendix 2)	Environment Operations
Subterranean Biophysical / Microclimate Habitat	Subterranean Biophysical / microclimate habitat monitoring	MEK01, MEK02, MEK06, MEK07, MEK08, MEK10	Continuous data collection with annual analysis during operational mine life	Downhole temperature and humidity monitoring using permanently installed specialised probes at previously disturbed, rehabilitated and undisturbed sites. Record the aspect of the pit face closest to the monitored drill holes.	Comparison between sites to determine difference in habitat conditions including RH and temperature. Statistical analysis of the biophysical monitoring data Comparison pit face aspect and habitat conditions.	Environment Operations
	Rainfall monitoring	Mesa J Weather Station	Continuous data collection of Rainfall with daily total	Weather station data download.	Comparison of rainfall, temperature and humidity data for analysis/calibration with downhole subterranean microclimate data. Comparison of rainfall, temperature and humidity data for analysis/calibration with troglofauna field sampling results.	Environment Operations

[7] Installation of monitoring sites to enable monitoring is subject to Traditional Owner and formal Heritage approval

Aspect	Monitoring	Location	Frequency and timing	Data collection method	Monitoring / Data Analysis method	Responsible
Subterranean Habitat Retention and Avoidance Areas	Maintaining Avoidance Areas	As per MS776 Figure 2 of Attachment 1 (Figure 2-1 of this EMP)	Annually during operational mine life	Disturbance data collection / reconciliation. 50m buffer demarcated around each singleton location (as depicted in Figure 2 of MS776). Pit blasting data and timing / dates Pit face aspect (Plate 1) recording of the pit face closest to the monitored drill holes	Minimising of new vegetation disturbance: • All clearing must be authorised by as per Approval Request permit. • Use established access tracks and roads as far as practicable. Where new tracks are required, they should be preferentially located within previously disturbed areas Mapping of pit progression to nominated pit outline and troglofauna Avoidance Areas. Disturbance data reconciliation against mapped avoidance areas. Blasting procedures undertaken near pit edges / Avoidance Areas. Comparison pit face aspect and habitat conditions	Environment Operations Mine Technical Services – Survey
	Subterranean Habitat Retained	Mesa K Development Envelope – Habitat remaining outside of approved mine pit areas	Annually	Volumetric calculation of 3D Pisolite (CID) habitat (as a percentage of total pre-remnant mining habitat) based on mine plans. Progressive rehabilitation of Mesa K pits: Backfilling of Central and Gravel Yard pits.	Verification of actual mine pits with remaining 3D Pisolite (CID) habitat within the Development Envelope (as a percentage of total pre-remnant mining habitat) to ensure that ≥70% pre-remnant mining habitat by volume is retained.	Mine Planning

Plate 1: Diagrammatic representation of how pit face vertical angle is calculated



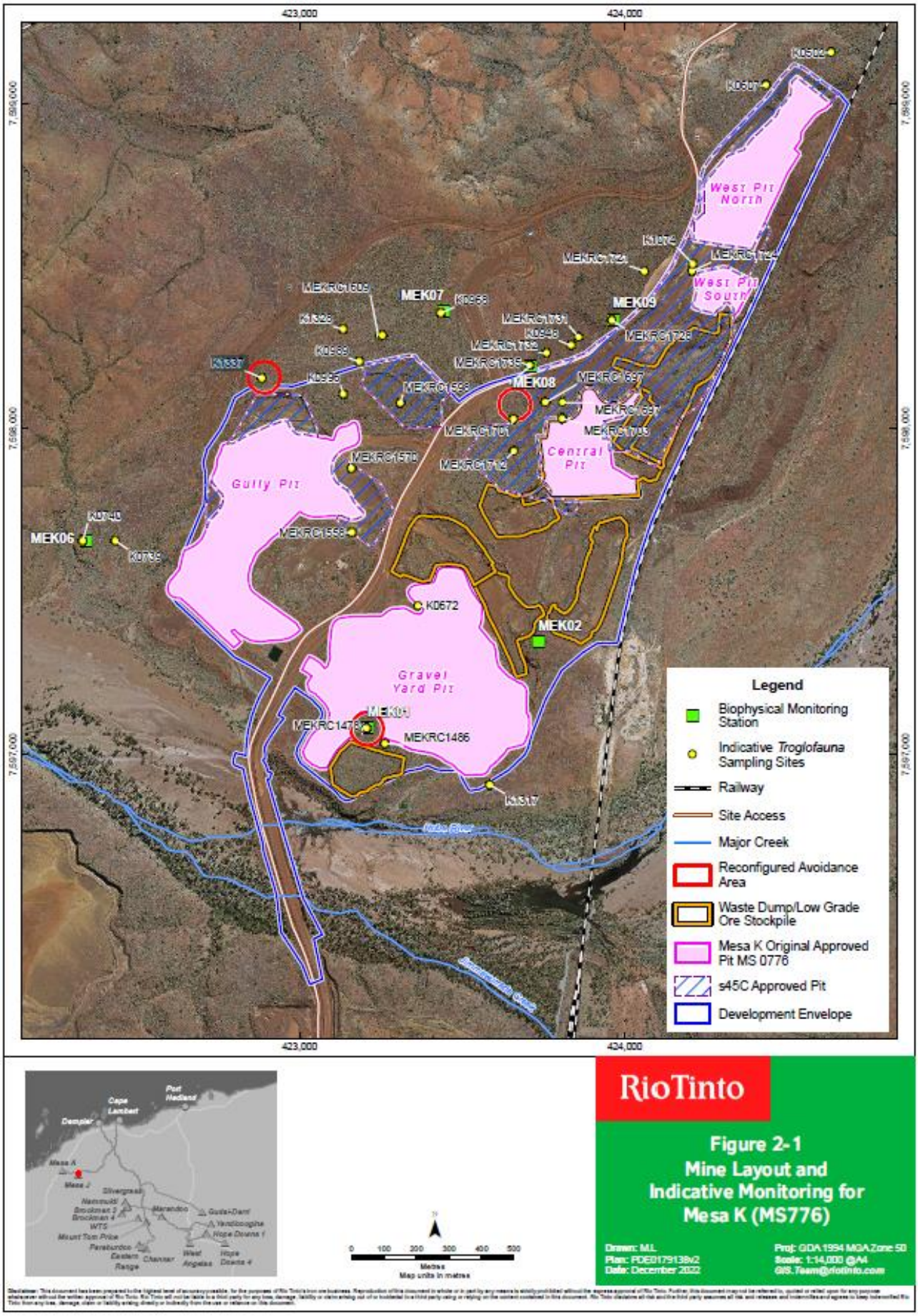


Figure 2-1 **Mine Layout and indicative monitoring for Mesa K (MS776)**

2.3 Reporting

The environmental monitoring results will be reported each calendar year in the Annual Compliance Assessment Report (ACAR) for Mesa K (formally referred to as the Annual Environmental Compliance Report (AECR)) as required by MS776.

In compliance with Condition 4-4 of MS776, the Proponent will make the environmental compliance reports required by Condition 4-1 publicly available on its website (including the Troglofauna Monitoring Plan itself).

The annual report will include:

- A summary of the monitoring undertaken to demonstrate sampling has been completed in accordance with the monitoring outlined in Section 2 and Monitoring of rainfall and downhole temperature and humidity will continue to be undertaken at Mesa K to assess whether the proposal has an impact on the subterranean climate. The information collected from Mesa K, and the Mesa A Hub monitoring programs can be applied more broadly across the Robe Valley to assist in understanding the effect of mining on the downhole temperature and humidity in mesa formations. At Mesa A, a total of 24 troglofauna habitat monitoring stations spread across 13 locations within the Mining Exclusion Zone (MEZ) will continue to monitor temperature and humidity. Monitoring will also continue at Mesa B, with two of the three monitoring stations at Mesa A to be moved to the MEZ at Mesa B. An additional three monitoring stations have also been established at Mesa F as reference sites. Temporary downhole temperature and humidity monitoring stations will also continue to be used where practicable in the Mesa A pit floor. The design of the subterranean temperature and humidity monitoring program thus includes monitoring before mining (Mesa B), during mining (Mesa A and Mesa B) and in reference habitat (Mesa F).
- Table 2-2.
- An explanation for any missed monitoring events and a discussion of the limitations of the monitoring achieved for that period.
- A summary of the analysis of monitoring data to facilitate adaptive management.

3. Adaptive management and review

The Proponent will implement adaptive management to learn from monitoring and evaluation, to more effectively meet the environmental condition objectives.

The following approach will apply:

- Monitoring data will be systematically evaluated and compared to baseline and reference site data on a regular basis following completion and assessment of ACAR with baseline data in a process of adaptive management to verify whether responses to the impact are the same or similar to predictions.
- Based on the analysis of this monitoring data, the Proponent will review and adjust the monitoring measures in consultation with the DWER.

4. Stakeholder Consultation

Stakeholder consultation in relation to the separation of the Mesa K (MS776) troglofauna monitoring requirements from the existing Mesa J and K EMP was undertaken with the EPA Services during late 2021 and early 2022.

Previous consultation for the existing approved Mesa J and K EMP, including the Terrestrial Ecosystems Branch, was undertaken during the original Mesa K approval and subsequent amalgamation into the Mesa J EMP which was approved in 2012.

The proposed updates to the Plan were briefly discussed with the Department of Biodiversity, Conservation and Attractions (DBCA) during November 2022.

5. References

Astron Environmental Services (2017). 2017 Troglofauna habitat analysis. Unpublished report to Rio Tinto, April 2017.

Astron Environmental Services (2020). Mesa K Troglofauna data analysis. Unpublished report to Rio Tinto, October 2020.

EPA 2008. Mesa K Remnant Mining Project. Ministerial Statement 776. December 2008 (incl. Attachment 1 to Ministerial Statement 776 – change to Proposal under s45C of the *Environmental Protection Act 1986,* February 2013)

Halse, S. A. and Pearson, G. B. 2014. Troglofauna in the vadose zone: comparison of scraping and trapping results and sampling adequacy, *Subterranean Biology* 13: 17-34.

Rio Tinto 2012. Mesa J and Mesa K Operations: *Operations Environmental Management Plan*. RTIO-HSE-0162720. December 2012.

Rio Tinto 2019. Mesa A Hub Revised Proposal: *Environmental Management Plan – Troglofauna*. RTIO-HSE-0335971. October 2019

6. Appendices

Appendix 1

Rationale and Justification for amendments to Mesa K Monitoring Regime - Troglofauna

Appendix 1

Rationale and Justification for amendments to *Mesa K Monitoring Regime – Troglofauna*

December 2022

Robe River Mining Pty Ltd
152 – 158 St Georges Terrace, Perth
GPO Box A42, Perth, WA 6837
RTIO-0972756

Disclaimer and Limitation

This report has been prepared by Rio Tinto's Iron Ore Group (Rio Tinto), on behalf of Robe River Mining Pty. Ltd., specifically for the Mesa K Remnant Mine. Neither the report nor its contents may be referred to without the express approval of Rio Tinto, unless the report has been released for referral and assessment of proposals.

Document Status					
Rev	**Author**	**Reviewer/s**	**Date**	**Approved for Issue**	
				To Whom	**Date**
A	M. Brand	Rio Tinto	February 2021		
B	M Brand	Rio Tinto	November 2021		
C	M Brand	Rio Tinto	October 2022		
0	M Brand	Rio Tinto	December 2022	DWER – EPA Services	

Contents page

1. Introduction

1.1 Background

This report sets out the rationale for proposed changes to the *Mesa K Monitoring Regime – Troglofauna* required to meet Condition 6-2 of Ministerial Statement 776 (MS 776) approved in 2008.

The proposed changes to the *Mesa K Monitoring Regime – Troglofauna* comprise:

- Removal of three (3) downhole biophysical monitoring sites located in approved pits (MS776 – Attachment 1)
- Removal of CO_2 monitoring
- Removal of downhole Optical Tele-Viewer (OTV) monitoring
- Removal of qualitative vegetation cover monitoring

The monitoring requirements for Mesa K were amalgamated with the Mesa J Environmental Monitoring Plan and approved as the *Mesa J and Mesa K Operations Environmental Management Plan* (OEMP) in 2012. The Mesa K Proposal was subsequently amended in 2013 via s45C, which increased the approved pit extents.

The key change for the Mesa K troglofauna monitoring program relates to the removal of three (3) troglofauna habitat monitoring stations which are located within the 2013 amended footprint of the mine pit shells (Schedule 1 of Attachment 1 of MS776). Since the 2012 *Mesa J and K* OEMP pre-dated the amended Mesa K pit footprint, the monitoring stations within the OEMP had not been subsequently updated to reflect the amended pits. This change is required to facilitate mining access to Mesa K's approved pits.

A number of additional changes to the monitoring program have also been proposed based on an assessment of 10 years of monitoring data and have been aligned to match the requirements of the more recently approved Mesa A Hub Troglofauna Management Plan (RTIO-HSE-0335971) in 2019.

In addition, as of 9 July 2020, the Mesa J Operation was revised to include the Mesa H Proposal and is subject to a new Ministerial Statement (MS1141). Condition 5-4 of MS 1141 requires the existing Mesa J and K OEMP (RTIO-HSE-0175388) to be implemented until the new Mesa J and H EMP is approved. The new Mesa J and H EMP was submitted on 8 January 2021 to meet the requirements of MS1141 Condition 5. Once the new Mesa J and H EMP is approved, it will supersede the Mesa J and K OEMP, and the Mesa K monitoring regime required under MS 776 that is currently included in the Mesa J and K OEMP will need to be separately documented. Separation of the monitoring and management required by each Ministerial Statement will assist with efficient management of the Statements and associated compliance reporting.

2. Mesa K Remnant Mining Approvals

2.1 Description of the original Proposal

The Mesa K mining area is located within the Robe Valley area of the Pilbara region in Western Australia, approximately 4 km north of the existing Robe Mesa J operation and 11 km south-west of the town of Pannawonica (Figure 1).

The Mesa K Remnant Mining Proposal was referred under s38 of the *Environmental Protection Act 1986* (EP Act) in April 2007 as an Environmental Protection Statement and was approved 2 December 2008 via Ministerial Statement (MS) 776. The proposal was to undertake mining of remnant iron ore at the Mesa K deposit which was historically mined from 1988-1995 but the site became non-operational between 1995 and 2008. The Mesa K Remnant Mining Project operates as a satellite deposit to the Mesa J operation, providing dry ore which is trucked to Mesa J via existing road infrastructure.

The Mesa K Remnant Mining Proposal includes above water table (AWT) mining by conventional drill and blast, load and haul occurring concurrently with Mesa J, utilising equipment fleet, personnel and other resources from the Mesa J Operations.

The Mesa K Remnant Mining Proposal as described (and approved in MS776) includes the following key features:

- Mining of remnant CID iron ore in five (5) existing AWT open cut pits: Gravel Yard pit, Central pit, West-South pit, West-North pit and Gully pit (refer to Figure 2-1).
- Clearing of an additional 10 ha of vegetation to support the remnant mining
- Mineral waste management: including waste dumps, topsoil and sub-soil stockpiles
- Minor realignment and widening of the existing mine access road across the Robe River from Mesa K to Mesa J
- Support facilities: including transportable offices, generators
- Progressive backfill.

A subsequent amendment in February 2013 was approved via s45C which resulted in the following changes:

- Extension of the approved mine pit areas within the Original Proposal area (now ‘Development Envelope’). Refer to Figure 2-2.
- Removal of the timeframe specifying the operational life of the mine
- Clearing of an additional 21 ha of vegetation to support the remnant mining (bringing the total to 31 ha for the Proposal)
- Update of the mining avoidance areas for troglofauna (due to singletons being found elsewhere)
- Contemporisation of Schedule 1 of MS776.

The Proposal commenced productive mining in 2009 and has, through intermittent mining, extracted approximately 12Mt of ore since this time.

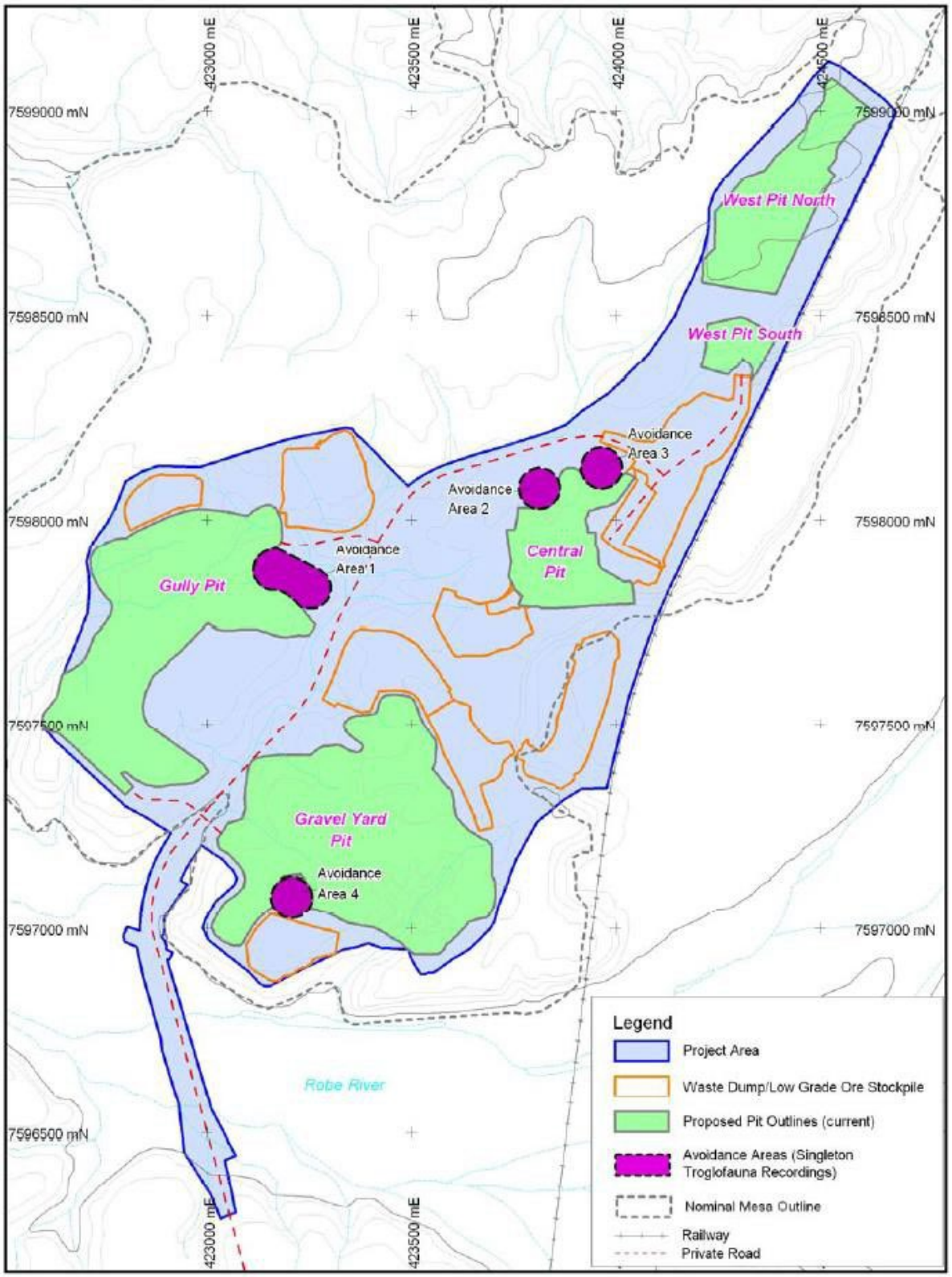


Figure 2-1: Original Figure 4 of MS776 (2008)

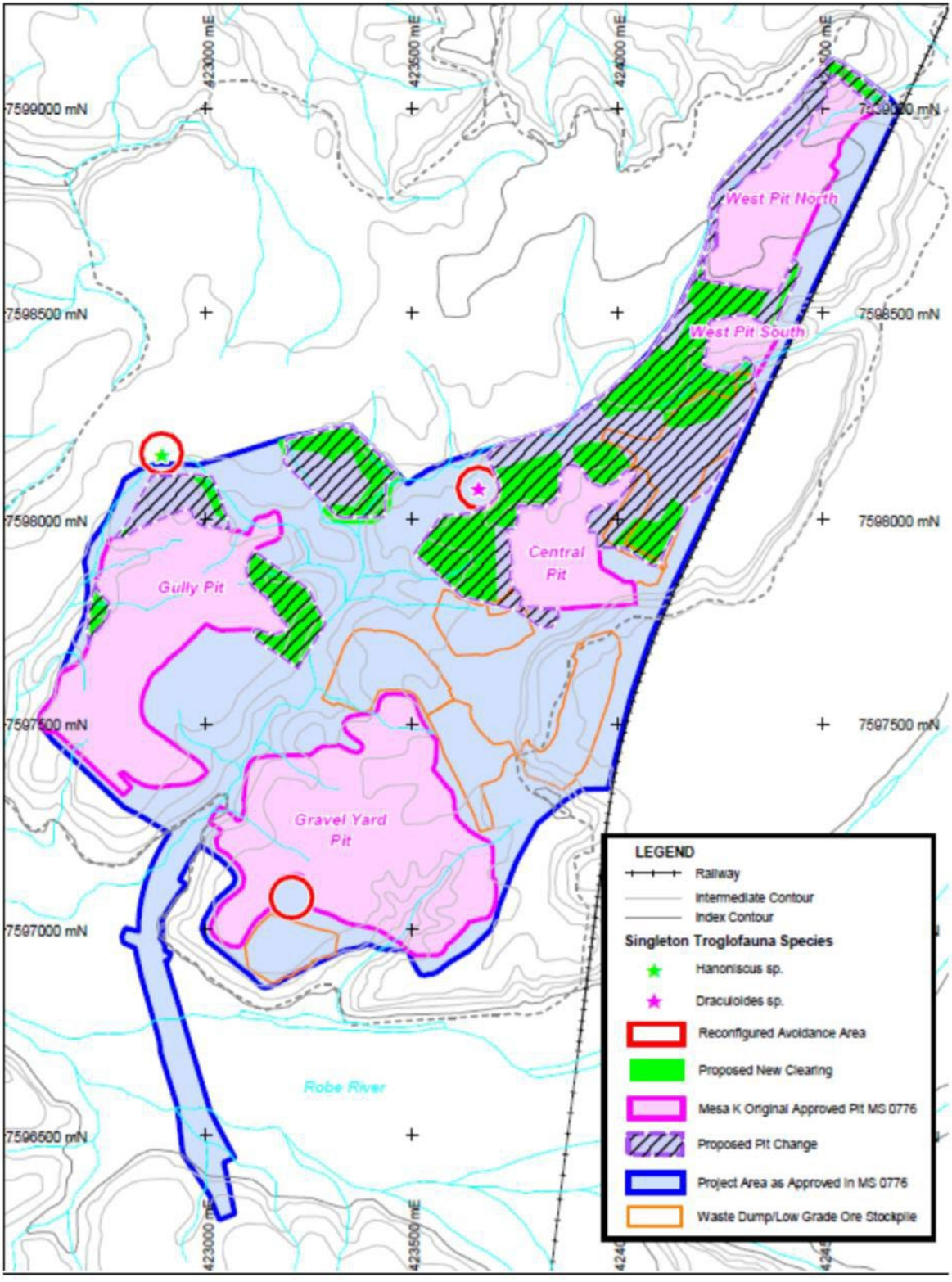


Figure 2-2: Revised Figure 2 of MS776 Attachment 1 (2013)

3. Current and proposed documents

3.1 Structure of the existing Mesa J & K OEMP

A *Subterranean Fauna Monitoring Plan* to satisfy condition 6-2 of Ministerial Statement 776 was submitted as part of an overall Mesa K Remnant Mining Project Environmental Management Plan. The Mesa K *Subterranean Monitoring Plan* was approved on 12 February 2009.

The Mesa K remnant mining monitoring requirements were subsequently incorporated into the 2012 version of the Mesa J (MS208) OEMP, resulting in a 'combined' Mesa J & K OEMP which encompasses both proposals (MS208 – Mesa J; and MS776 – Mesa K).

3.2 Proposed structure of documents for Mesa J and K

Table 1 shows the current and proposed documents to meet the requirements of MS1141 and MS776 and the current status of the documents.

Table 1. Proposed change to the documents to meet requirements of MS1141 and MS776

EMP	Site (MS)	Comments
Current Mesa J and K OEMP (2012)	• Mesa J (MS208) • Mesa K (MS776)	EMP requirements are currently combined to meet MS208 and MS776 conditions.
Proposed New plans submitted: • Mesa J Hub EMP • Mesa K Troglofauna Monitoring plan	• Mesa J Hub (Mesa J and Mesa H) (MS1141)	To meet requirements of MS1141 - Submitted 8th January 2021 - Awaiting final approval (based on addressing DWER comments)
	• Mesa K (MS776)	To meet requirements of MS776 - current submission

4. Current Mesa K Monitoring Regime - Troglofauna

The environmental factors considered relevant for the Mesa K Remnant Mining Proposal as described in the EPA's report 1283 included:

- Subterranean fauna (troglofauna)
- Closure planning and rehabilitation

These factors were considered in terms of both condition setting and environmental monitoring and management requirements for the Proposal. Of these two factors, Subterranean fauna (troglofauna) is relevant to the currently proposed changes to the EMP. Further information is provided below.

4.1 Requirements of MS776

In the EPA's Report 1283, the Mesa K Proposal was considered to meet the EPA's environmental objective for subterranean fauna based on conditional approval requiring:

- Avoidance of disturbance in areas where singleton troglofauna were recorded (Refer to Figure 3-1); and
- Troglofauna monitoring to be undertaken during mining and for a period after mine closure to provide more information about the effects of mining on troglofauna, and on the impact of troglobitic fauna populations after mining ceases.

Consequently, the following conditions of MS776 relate to the protection of troglofaunal communities:

Condition 6: Protection of troglofauna

6-1 *The proponent shall implement the proposal to avoid disturbance of areas where troglofauna taxa represented by only one individual have been recorded as shown in Figure 4 attached and delineated by AMG coordinates listed in Schedule 2.*

6-2 *The proponent shall establish a monitoring regime to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority to demonstrate the effectiveness of the disturbance avoidance areas as shown in Figure 4 attached and delineated by AMG coordinates listed in Schedule 2.*

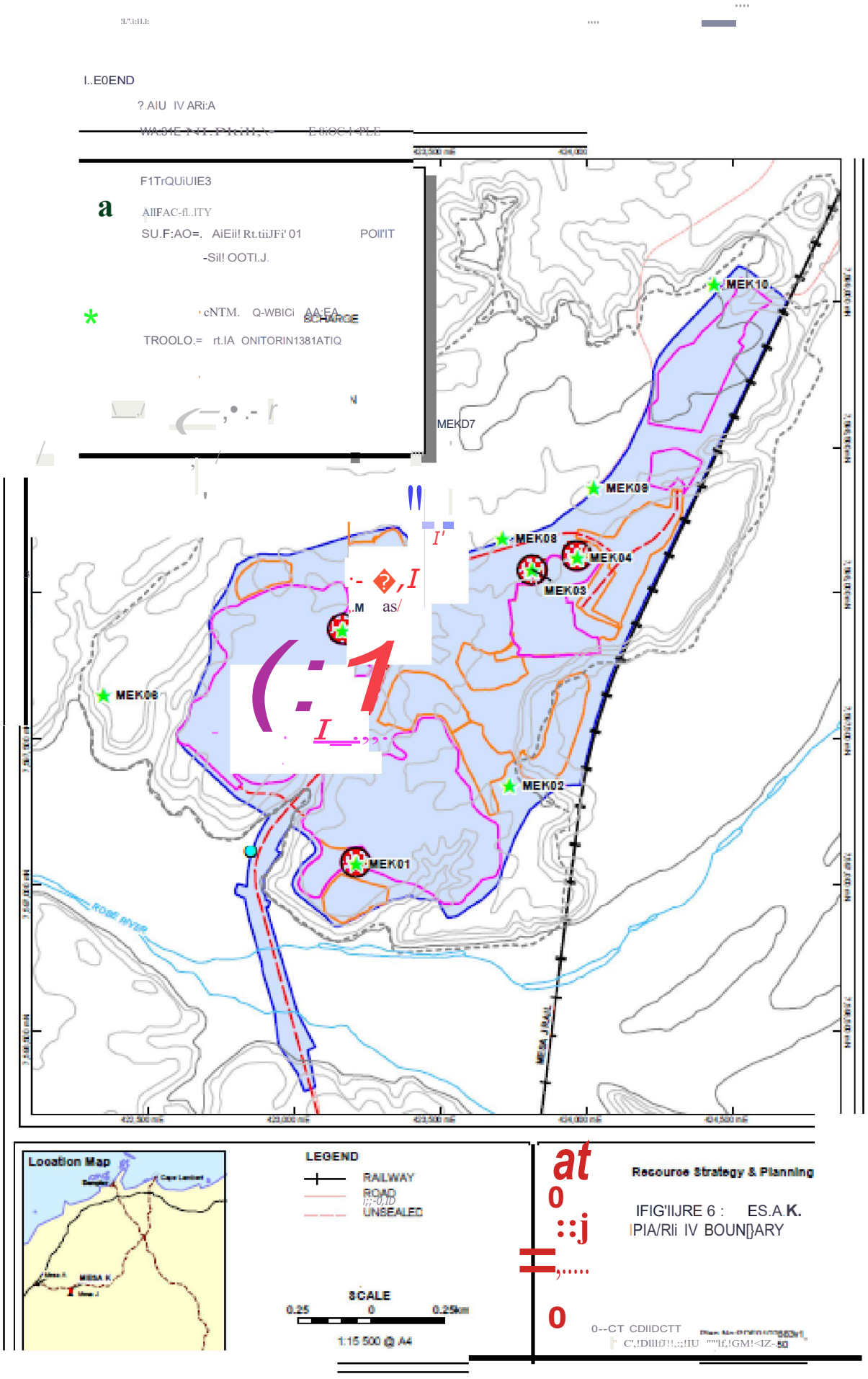


Figure 4-1: Current biophysical monitoring station locations as per Mesa J & K EMP (2012)

4.2 Troglofauna monitoring regime

The Proposal was designed to manage impacts to Troglofauna in the remnant Mesa K Channel Iron Deposit (CID) habitat by constraining the pit extents and excluding mining of known singleton species.

Monitoring as required by Condition 6-2 of MS 776 was designed to demonstrate that the outcomes for troglofauna were being met.

Troglofauna protection and monitoring at Mesa K focuses on monitoring of related environmental aspects that are considered to, or have the potential to, have a direct bearing on troglofauna and their habitat. These aspects include:

- direct habitat removal;
- changes to surface hydrology;
- changes to subterranean microclimate;
- surface water contamination;
- reduction in organic inputs; and
- vibration.

4.2.1 Biophysical monitoring

There are currently nine biophysical monitoring stations at Mesa K. These stations are located on previously disturbed, rehabilitated and undisturbed sites at Mesa K (

Figure **4-1**). Monitoring stations comprise probes which are permanently located downhole within uncased and uncapped boreholes and continuously measure these biophysical parameters and have been measuring subterranean habitat conditions (via drillholes) since 2009 including:

- Relative humidity
- Temperature
- Carbon dioxide (CO_2)

4.2.2 Troglofauna sampling

Troglofauna sampling has been undertaken annually across Mesa K including pre-remnant baseline from 2005 – 2008 and annual monitoring has been undertaken since 2010. The program currently includes colonisation trapping and scraping of approximately 45 sites, morphological identifications and molecular analysis. In addition, in-pit sampling is also undertaken in historically mined pit-floor areas of Mesa K.

4.2.3 Vegetation cover and nutrient monitoring

Reduction in organic inputs through clearing of vegetation was identified as a potential impact which may lead to a reduction in nutrient inputs to the subterranean environment during the Mesa K environmental impact assessment (Strategen 2008). Hence vegetation cover assessments have been undertaken as a surrogate measure of nutrient inputs to the subterranean environment to determine if changes to vegetation cover would have an impact on troglofauna communities.

Vegetation cover assessments have previously been conducted using imagery from 2006 and from 2009 through to January 2018, with earlier studies using visual estimation.

More recent vegetation monitoring comprises annual assessments to estimate the cover of vegetation within 50 x 50 m quadrats centred on 17 drill holes that are monitored for troglofauna. These quadrats are located in both rehabilitation areas and undisturbed areas.

4.2.4 Optical Tele-Viewer

The purpose of the Optical Tele-Viewer (OTV) monitoring was to determine if there have been observable changes in the structure and condition of the subterranean environment as a result of mining activities. Downhole image capture has been undertaken since 2009 across a total of six bores, with additional monitoring sites at Mesa A and B, totalling 20 boreholes.

OTV Image capture is undertaken using an Electromind high resolution optical televiewer. The instrument generates an unwrapped 360-degree image of the borehole wall and allows for direct comparison of the downhole bore images between annual monitoring events.

4.2.5 Other monitoring

In addition to drillhole habitat monitoring, troglofauna sampling, vegetation monitoring and OTV monitoring, the following aspects have also been monitored / recorded:

- Pit face aspect and distance to monitoring holes.
- Groundwater sampling - undertaken on a quarterly basis (Currently at two representative locations).

5. Proposed Changes to the Mesa K Monitoring Regime - Troglofauna

Consideration of the currently approved pit extents and analysis of data from the current troglofauna monitoring regime (refer Section 4 and Appendix 1) indicates changes to the current Mesa K monitoring regime (Figure 5-1) are warranted. The following changes are proposed:

- Removal of three (3) downhole biophysical monitoring sites located in approved pits to align with the approval granted in 2013 under section 45C (MS776 – Attachment 1)
- Removal of CO_2 monitoring
- Change frequency of troglofauna sampling from annual to biennial
- Removal of qualitative vegetation cover monitoring
- Removal of downhole Optical Tele-Viewer (OTV) monitoring

The nine (9) biophysical habitat monitoring sites are distributed across Mesa K, both inside and outside the Development Envelope and are individually listed both in the monitoring compliance table and Figure 6 of the Mesa J&K OEMP.

Remnant mining of the approved pit shells recommenced at Mesa K during 2020, however three of the nine biophysical monitoring sites are located directly within the five approved pit shells (as amended via s45C in 2013 in Attachment 1, Schedule 1 of MS776), and hence are required to be removed to enable mining of these pits (Refer to Figure 5-2 and **Figure 5-3**).

As discussed in Section 1.1, the proposed changes to the Mesa K monitoring sites had not been amended in the 2012 Mesa J & K OEMP in line with Figure 2 of Attachment 1 in MS776 as approved in 2013.

Review of the data from other monitoring parameters which have been monitored since 2011, indicates that changes to the monitoring program are warranted to ensure there is a focus on collection of data which contribute to either the understanding, or the management of the habitat for troglofauna. The proposed changes will align the Mesa K troglofauna monitoring program with the troglofauna monitoring program conducted at Mesa A Hub as approved under MS 1112.

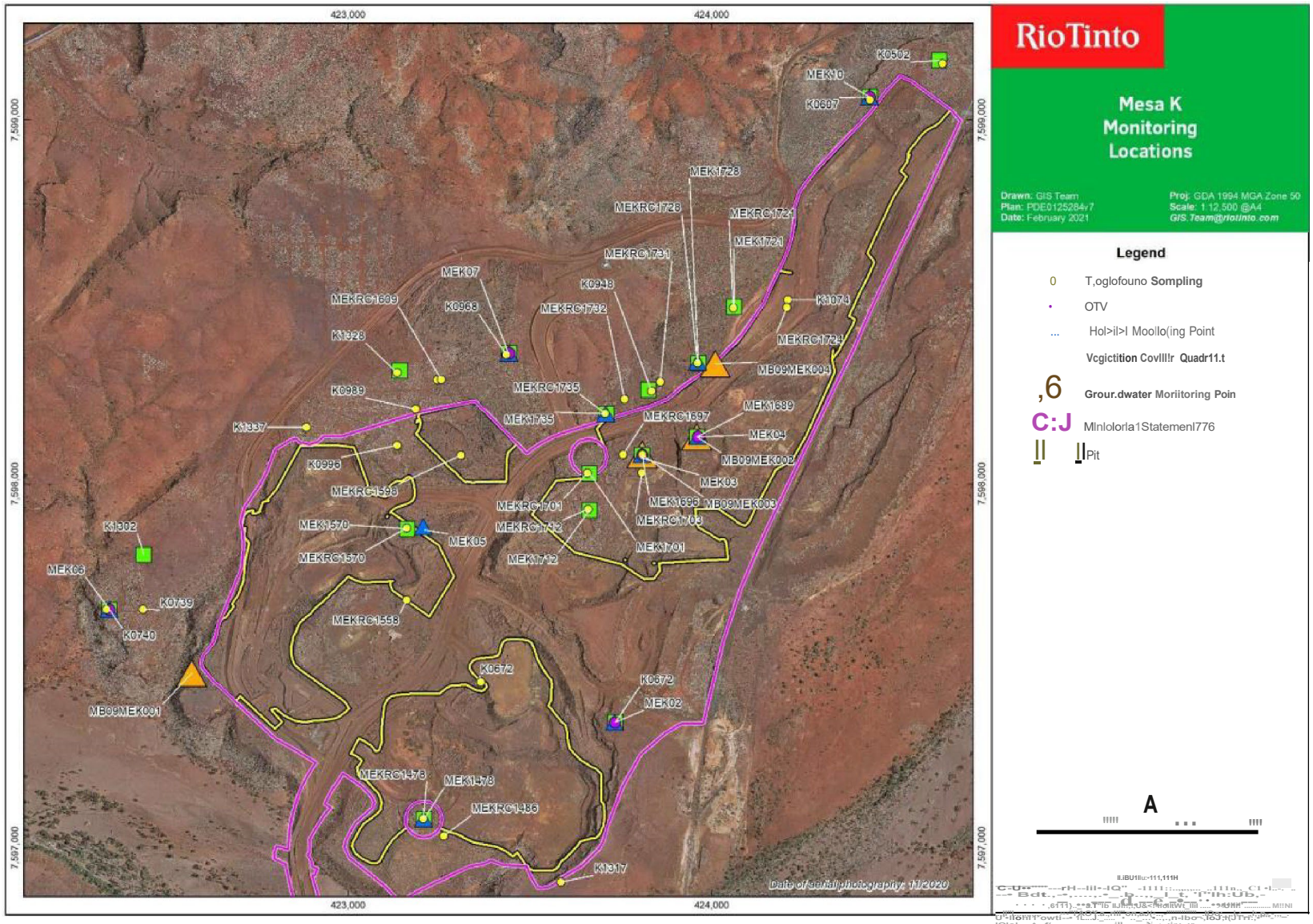


Figure 5-1: Location of all Mesa K Monitoring Locations

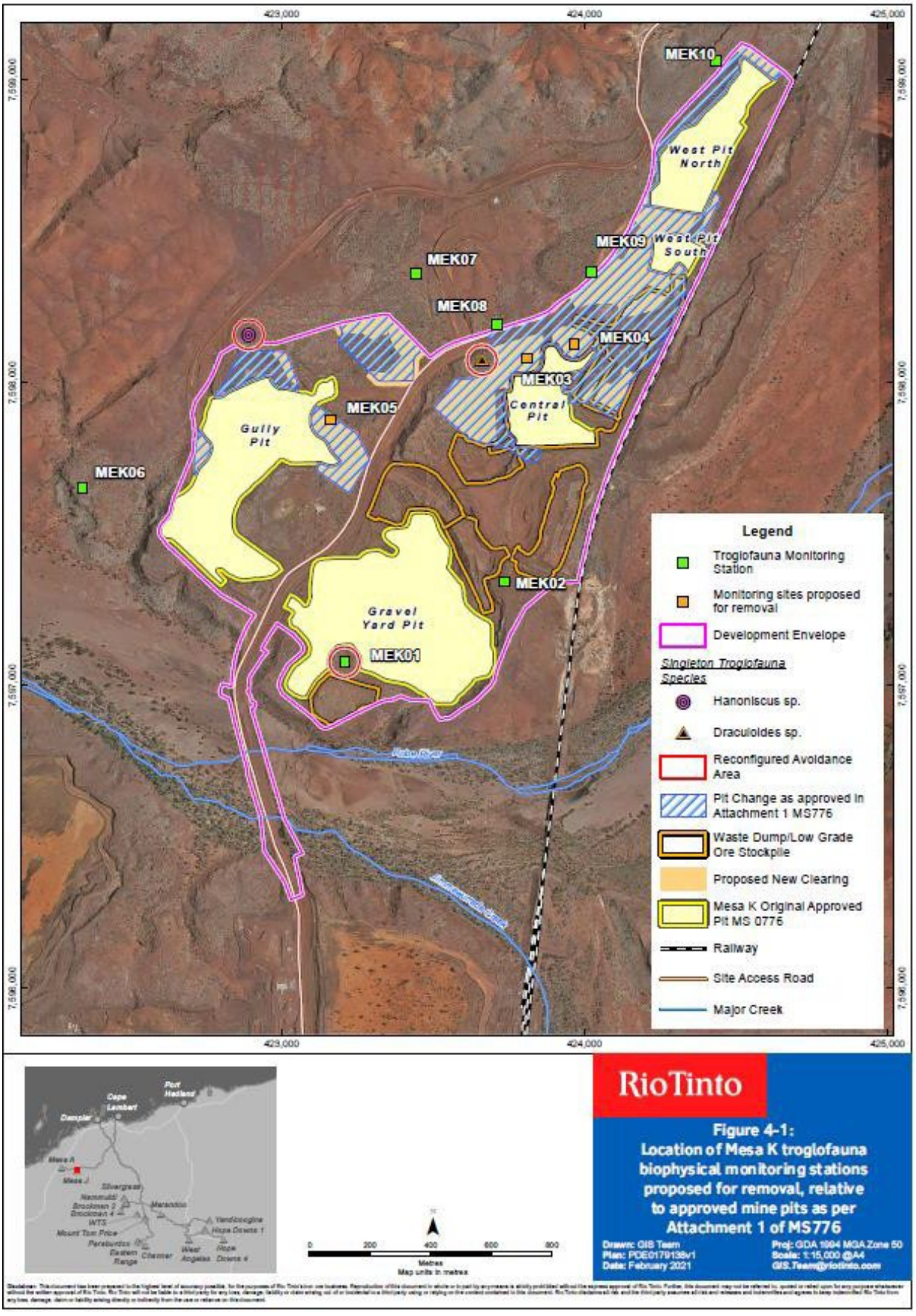


Figure 5-2 Location of Mesa K troglofauna biophysical stations proposed for removal, relative to approved mine pits as per Attachment 1 of MS776.

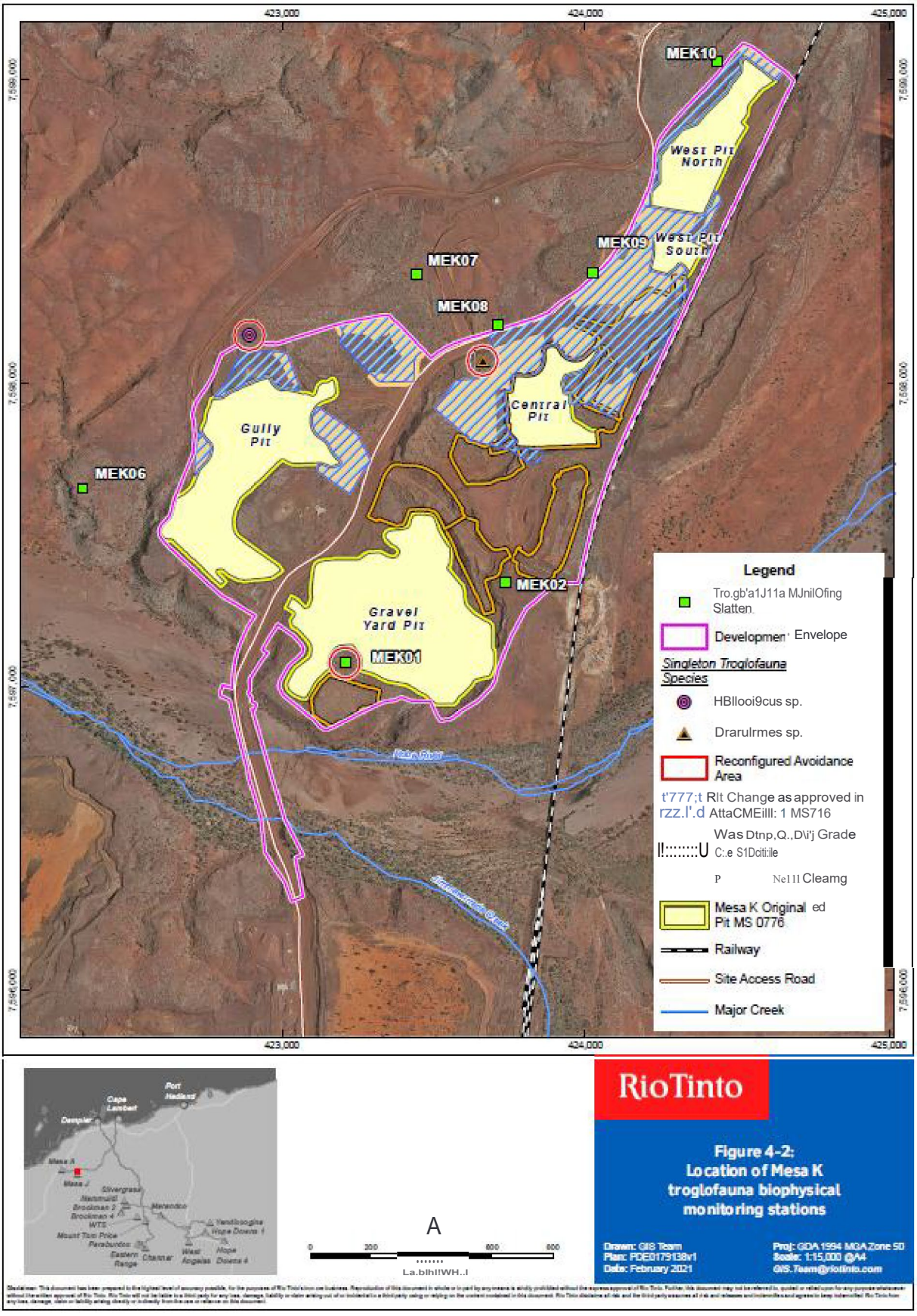


Figure 5-3: Location of Mesa K troglofauna biophysical monitoring stations

6. Rationale for proposed changes to monitoring

To understand the significance of the data from these three biophysical monitoring stations proposed for removal and to ensure that the removal of these stations would not be detrimental to achieving the outcome of understanding the potential impact of mining on the subterranean fauna habitat, a detailed analysis of the data was undertaken by Astron in 2020. Results of the analysis are discussed in Sections 6.1 and 6.2 and provided as Appendix 1. In addition, other monitoring parameters were reviewed in terms of their value in providing information to meet the EPA's objective for subterranean fauna, and the outcome of understanding the impacts of mining on the subterranean habitat and the troglofauna population. These results are discussed in Sections 6.3 and 6.4. Results of troglofauna sampling are discussed in Section 6.5.

6.1 Temperature and Relative Humidity

The proposed removal of three troglofauna habitat monitoring stations at Mesa K will leave six operable monitoring stations at Mesa K, representing approximately 70% of the original sites, including in areas within Mesa K which are immediately adjacent to mining areas. In addition, it is noted that the subterranean biophysical monitoring network extends beyond Mesa K, and includes a further 25 stations at Mesa A and three stations at Mesa B.

An analysis of the subterranean temperature and humidity data from the biophysical monitoring probes located at Mesa K (and also an analysis of the biophysical monitoring at other Robe Valley sites: Mesa A and Mesa B) was undertaken by Astron Environmental Services in 2017 (Astron 2017) and an updated analysis completed in 2020 (Astron 2020). These analyses focused on identifying differences between monitoring station types (potential impact and reference sites) and aimed to identify increased connectivity to surface conditions, that may indicate increased impacts to the subterranean bio physical features as a result of mining.

Data were firstly assessed in order to identify any significant issues associated with data quality. Down hole atmospheric conditions were compared between potential impact stations (at Mesa A and Mesa K) and reference stations (at Mesa B and Mesa F) using the following variables:

- mean temperature, relative humidity and carbon dioxide concentration
- variation (standard deviation) in temperature, relative humidity and carbon dioxide concentration
- Fit to sinusoidal curves for temperature and relative humidity

Each analysis was performed for all stations, and then after excluding the three stations proposed for removal at Mesa K, in order to assess the impact of removing these stations from the monitoring program.

The data analysis is the most comprehensive at Mesa A due to the set-up of the monitoring sites being orientated as transects from the pit edge to the Mesa escarpment face. The results of the analysis indicate that the biophysical parameters do not vary with proximity to the Mesa A mine pit (Astron 2017).

Subterranean mean temperature was found to differ between sites, with Mesa K being significantly cooler than other sites. This could be the result of Mesa K being more closely linked to surface climate due to previous disturbance from historical mining. However, results indicated that there was no increased evidence of a sinusoidal pattern in the temperature data and the patterns at Mesa K were not significantly different to the other sites (Astron 2017). Variation in temperature were found to be heavily influenced by probe depth, with much greater variation observed at shallower stations (5 m to 5.5 m). Although each analysis attempted to account for variation in probe depth, even after removing shallow stations of less than 6 m, a significant interaction was identified between probe depth and site type for R^2 fit of temperature to a sinusoidal curve. However, the absence of a corresponding increase in

variation (standard deviation) in temperature, suggests that this result may not be meaningful (Astron 2020).

No significant differences were observed between potential impact and reference stations for any of the other variables.

Based on the analyses, Astron 2020 concluded that the removal of the three Mesa K stations (MEK03, MEK04 and MEK05) would have little effect on the overall temperature-humidity results obtained.

Based on the results of the analysis conducted by Astron (2020) and given the broader Robe Valley monitoring program, including six monitoring locations at Mesa K will continue to operate, it is concluded that removal of the three monitoring sites at Mesa K will not significantly affect the value of future temperature-humidity monitoring results.

6.2 Carbon Dioxide monitoring

Measurement of down hole CO_2 concentrations revealed no significant variation between potential impact and reference stations. The CO_2 levels varied between stations from mean CO_2 levels of 0.001% to 4.7% (with atmospheric concentrations generally being approximately 0.04%).

The majority of studies that have assessed subterranean CO_2 levels have focussed on cave environments (Fernandez-Cortes et al. 2011 in Astron 2020) linking increased CO_2 concentrations to the introduction of microorganisms through human visitation in these environments. Although troglofauna have been found in environments with high CO_2 concentrations (up to 6% versus 0.04% in normal atmospheric condition (Howarth and Stone 1990 in Astron 2020)), there is also some evidence to suggest that elevated CO_2 levels are not necessarily a requirement of these species (Humphreys and Eberhard 1998, Humphreys 2000 in Astron 2020).

Whilst the measurement of changes to CO_2 levels may be a relevant biophysical parameter for maintaining troglofauna habitat, the sensitivity of the probes and method of measuring CO_2 levels via placement of probes in drillholes which are open to the atmosphere are likely to affect results (Astron 2020). In addition, it is unclear as to the effect on downhole CO_2 concentrations from root mass material found in some of the monitoring drillholes – a number of studies have demonstrated that some plants are capable of absorbing CO_2 through their root systems.

The assessment conducted by Astron (2020) of the CO_2 data at Mesa K concluded that continual monitoring of CO_2 at Mesa K to date has not provided a reliable dataset to understand changes to CO_2 concentrations. Based on this, the current monitoring of CO_2 is not considered to provide a reliable monitoring tool with which to meaningfully inform ongoing management for subterranean habitat and therefore is proposed to be removed from the monitoring program.

6.3 Troglofauna sampling

The findings from the troglofauna sampling program at Mesa K continue to demonstrate the persistence of a troglofauna community despite past and current mining related activity (Biota 2020b). In-pit sampling at Mesa K has also indicated a small number of records persisting beneath the current pit floor.

The known troglofauna assemblage for Mesa K currently totals 47 taxa across 14 orders including one conservation significant species of troglofauna: the schizomid *Draculoides kryptus* (listed as Vulnerable under the *Biodiversity Conservation Act 2016*) which is endemic to Mesa K (locations are represented both inside and outside of the Development Envelope). The most commonly collected taxonomic orders comprise the Schizomida, followed by Pseudoscorpiones.

Given the sampling density; low catch rate and limited remnant mining that has occurred at Mesa K since the original historical mining, trends in troglofauna populations and diversity are difficult to establish. New species are continuing to be found with each sampling phase. Hence ongoing monitoring is proposed to be maintained to identify any potential adverse trends.

The monitoring regime is proposed to be aligned with sampling across the broader Robe Valley, including alignment with the Mesa A Troglofauna Management Plan on a biennial sampling cycle. This change in sampling frequency is to ensure that troglofauna sampling is undertaken consistently across the Robe Valley and due to low density catch rates, that the sampling does not deplete the troglofauna population. To support the changed sampling rate, the sampling program now includes both trapping and scraping methodologies which will likely capture a greater range of species than the previous sampling methodology which comprised trapping only.

6.4 Vegetation cover and nutrient monitoring

Mesa K was historically mined in the 1980's – 1990's, hence the majority of the vegetation cover has historically been heavily disturbed for decades. Results of the vegetation cover analysis by Biota (2020a) indicate that there appears to be some trends in the vegetation cover determined in particular years (e.g. a lower cover was recorded for most sites in 2009 compared to 2006, in 2012 compared to 2011, and in 2014 compared to June 2013; while a higher cover was recorded for most sites in 2010/2011 compared to 2009, and in June 2013 compared to 2012) (Biota 2019). These patterns may, in part, be correlated with the rainfall preceding the acquisition of the vegetation cover imagery, with lower cover values calculated for most quadrats following the lower rainfall in 2012 and 2014. However, the higher rainfall periods did not necessarily result in an equivalent increase in cover, as would be expected if rainfall was a major contributing factor. For example, only 2.1 mm of rain was received in the nine months prior to the January 2018 imagery being acquired, and yet vegetation cover remained stable or increased at 14 of the 17 quadrats (Biota 2019). In contrast, close to 200 mm of rain was received in the nine months prior to acquisition of the June 2018 imagery, and yet vegetation cover remained stable or decreased at 12 of the 17 quadrats (Biota 2019).

Fire was also found to an influence on vegetation cover with inconsistent vegetation cover responses post-recovery. This inconsistency may suggest that local rainfall may have been variable over the Mesa K area (such spatial variability in rainfall is not uncommon for the Pilbara) or that other factors (topography, post-fire climate, burn severity etc.) are playing a larger role than rainfall in the recovery of the vegetation.

Due to inherently low catch rates of troglofauna and the numerous variables contributing to both changes in vegetation cover and ability to accurately correlate vegetation cover with variables in troglofauna catch rates, the current vegetation monitoring is not considered to be providing meaningful information or granularity to understand or quantify effects on nutrient cycling and its potential impact to troglofauna populations and therefore is proposed to be removed from the monitoring program.

6.4.1 Groundwater Monitoring

The proposed removal of the nutrient monitoring also includes removal of groundwater monitoring for nutrients (nitrogen and phosphorus) on a quarterly basis at two locations at Mesa K, given that the operation is only approved for above water table mining and no groundwater abstraction is approved under MS776. The groundwater quality monitoring has not to date provided information that can be readily correlated with troglofauna species abundance or diversity, nor inform adaptive management for troglofauna, and hence this monitoring aspect is proposed to be removed.

6.5 Annual OTV downhole assessment

Overall there have been no notable changes to the features, cavities and voids in the boreholes (MPC Kinetic 2019). The three main observable changes in the borehole wall comprise tree root growth; rock particle dislodgement; and movement of insects. Other changes observed included mud cake peeling or cracking off the wall, however this feature is considered to be likely attributed to natural drying and erosion in the borehole environment.

Given boreholes can naturally change or collapse based on the geology, hole features, clays and moisture levels, tree root changes and aspects relating to how the boreholes were drilled, it can be difficult to attribute changes to the downhole environment specifically related to mining activities. Whilst blasting activities may potentially cause changes or collapses in some void spaces, conversely, blasting can also result in fractures through the bedrock which may provide habitat or dispersal routes through the bedrock.

Based on the 13 years of OTV results and the lack of changes recorded in the structural features of the subterranean environment, and the existing management approach to blasting in the Robe Valley using trim blast shots against the troglofauna habitat to be retained (resulting in accurate blasting against the MEZ and a reduction in the blast propagation), the OTV monitoring is not considered to be a monitoring parameter which is adding value in either the understanding of the subterranean environment or informing proposed management approaches at Mesa K and therefore is proposed to be removed from the monitoring program.

7. Conclusion

In-situ troglofauna habitat at Mesa K is protected via limits to the approved *mining extent* (i.e. the approved mine pit extents) rather than a defined exclusion area (e.g. a MEZ as per Mesa A). Hence the removal of the three downhole troglofauna bio-physical monitoring stations (MEK03, MEK04 and MEK05) located in the approved mine pit extents at Mesa K are not considered detrimental to the monitoring or understanding of the troglofauna population or their habitat at Mesa K.

In addition, the statistical downhole data analysis undertaken by Astron 2020 concluded that the removal of three Mesa K stations (MEK03, MEK04 and MEK05) had little effect on the overall representation of the temperature-humidity data which informs the understanding of the microclimate of the subterranean habitat at Mesa K.

The proposed removal of other monitoring parameters (OTV, vegetation cover, CO_2, and groundwater) is based on > 10 years of data collection commencing in the late 2000's where detailed review and analysis (including multiple approaches to collection and analysis) either did not provide conclusive results or where natural variables may overprint the ability to make any meaningful interpretation and subsequent application of the data to the understanding of threatening processes or management for troglofauna.

In addition, Mesa K has previously been disturbed and mined. Hence the key strategy for ensuring the protection and maintenance of troglofauna populations and diversity in the *pre-mined* remnant Mesa K deposit has been focussed on the retention of in-situ troglofauna habitat. To achieve this outcome, as part of an adaptive management approach, habitat retention triggers and thresholds have been proposed, which align with the troglofauna management approach approved for the other Robe Valley Mesa's (noting that Mesa K is a pre-disturbed Mesa and subject to different conditions of approval under MS776, however has been aligned where relevant and feasible).

To supplement this approach, sampling of troglofauna will be undertaken on a biennial frequency and monitoring of downhole temperature and humidity will continue in the remaining six (6) monitoring sites at Mesa K. The biophysical monitoring at Mesa K supplements the broader Robe Valley downhole

biophysical monitoring program, which to date has not indicated any statistically notable temperature-humidity trends during the >10 years of mining and monitoring at Mesa A or Mesa K.

8. References

Astron 2017, *Troglofauna Habitat Data Analysis*, Unpublished report prepared by Astron Environmental Services for Rio Tinto, June 2017.

Astron 2020, *Mesa K Troglofauna Data Analysis*, Unpublished report prepared by Astron Environmental Services for Rio Tinto, October 2020.

Biota 2019, *Mesa K Troglofauna Sampling Sites – Vegetation Cover Assessment 2019*, Unpublished report prepared by Biota Environmental Sciences for Rio Tinto, September 2019.

Biota 2020a, *Mesa K Troglobitic Fauna Sampling Sites – Vegetation Cover Assessment 2020*, Unpublished report prepared by Biota Environmental Sciences for Rio Tinto, October 2020.

Biota 2020b, *Mesa K Troglobitic Fauna Compliance Monitoring 2019*, Unpublished report prepared by Biota Environmental Sciences for Rio Tinto, June 2020.

Strategen 2008, *Mesa K Remnant Mining Project - Environmental Protection Statement*. Prepared for Robe River Mining Company Pty Ltd by Strategen, March 2008

MPC Kinetic 2019, *Comparison of Downhole Optical Image Logs in Troglofauna Assessment Holes 2019, Rio Tinto Mesa A, Mesa B and Mesa K*. Unpublished report prepared by MPC Kinetic Logging Services for Rio Tinto, October 2019.

Appendix 2

Mesa K Troglofauna Data Analysis October 2020

Mesa K Troglofauna Data Analysis
October 2020

Prepared for
Rio Tinto

astron

Report Reference: 14328-20-BISR-1Rev0_210803

This page has been left blank intentionally.

Mesa K Troglofauna Data Analysis

Prepared for
Rio Tinto

Job Number: 14328-20

Reference: 14328-20-BISR-1Rev0_210803

Revision Status

Rev	Date	Description	Author(s)	Reviewer
A	04/11/2020	Draft Issued for Client Review	A. Funnekotter	A. Gove
B	10/12/2020	Draft Issued for Client Review	A. Gove	R. Archibald
C	18/03/2021	Draft Issued for Client Review	A. Gove	R. Archibald
0	03/08/2021	Final Issued for Information	A. Gove	R. Archibald

Approval

Rev	Date	Issued to	Authorised by	
			Name	**Signature**
A	04/11/2020	M. Brand	B. Lucas	
B	10/12/2020	M. Brand	B. Lucas	
C	18/03/2021	M. Brand	B. Lucas	
0	03/08/2021	M. Brand	B. Lucas	

Abbreviations

Abbreviation	Definition
°C	Degrees Celsius
Astron	Astron Environmental Services
CO_2	Carbon dioxide
km	kilometre
m	metre
MS 776	Ministerial Statement 776
RH	Relative humidity
Rio Tinto	Rio Tinto Iron Ore

Executive Summary

Rio Tinto Iron Ore operates the Mesa K deposit on behalf of the Proponent (Robe River Mining Co. Pty Ltd), situated 11 km south-west of Pannawonica in the Pilbara region of Western Australia. Operations at Mesa K were assessed by the Environmental Protection Authority and approved under Ministerial Statement 776. Under Condition 6 of the Ministerial Statement, the Proponent is required to monitor for effects of mining at Mesa K on troglofauna habitats.

Analysis of down hole temperature and relative humidity data collected between January 2011 and April 2017 was performed by Astron Environmental Services in June 2017 (Astron Environmental Services 2017), and additional analyses were completed in April 2020 (Astron Environmental Services 2020). These analyses focused on identifying differences between station types (potential impact and reference) and aimed to identify increased connectivity to surface conditions, that may indicate increased impacts from mining. This report provides an update to the analysis of down hole temperature and relative humidity data collected between January 2011 and October 2020, and also assesses changes in down hole carbon dioxide concentration which is currently monitored alongside temperature and relative humidity as part of the Mesa K Environmental Management Plan.

Data was firstly assessed in order to identify any significant issues associated with data quality. Down hole atmospheric conditions were compared between potential impact stations (at Mesa A and Mesa K) and reference stations (at Mesa B and Mesa F) using the following variables:

- mean temperature, relative humidity and carbon dioxide concentration
- variation (standard deviation) in temperature, relative humidity and carbon dioxide concentration
- goodness of fit to sinusoidal curves for temperature and relative humidity.

Each analysis was performed for all stations, and also, after excluding three stations at Mesa K, in order to assess the impact of removing those stations from the monitoring program.

Variation in temperature was heavily influenced by probe depth, with much greater variation observed at shallower stations (5 m to 5.5 m). Accounting for variation in probe depth, either by including depth as a factor in the analysis or removing the shallowest stations (less than 6 m) from the data set, indicated that in most cases there was no significant difference between potential impact and reference stations. Although a significant interaction was identified between probe depth and site type for R^2 fit of temperature to a sinusoidal curve, the absence of a corresponding increase in variation suggest that this interaction is not meaningful.

Removal of three Mesa K stations (MEK03, MEK04 and MEK05) had little effect on the overall results obtained.

Table of Contents

List of Figures

List of Tables

List of Appendices

This page has been left blank intentionally.

1 Introduction

1.1 Background

Rio Tinto Iron Ore (Rio Tinto) operates the Mesa K deposit on behalf of the Proponent (Robe River Mining Co. Pty Ltd), which is situated 11 km south-west of Pannawonica in the Pilbara region of Western Australia. Operations at Mesa K were assessed by the Environmental Protection Authority and approved under Ministerial Statement 776 (MS 776). Under Condition 6 of MS 776, the Proponent is required to monitor for effects of mining at Mesa K on troglofauna habitats.

Analysis of down hole temperature and relative humidity data collected between January 2011 and April 2017 was performed by Astron Environmental Services (Astron) in June 2017 (Astron Environmental Services 2017). In April 2020 Astron completed an additional analysis of 2019 down hole temperature and relative humidity data following the methods used in 2017 (Astron Environmental Services 2020).

1.1.1 Subterranean Climates and Troglofauna Habitat

A comprehensive review of literature on subterranean climates and troglofauna habitat was previously prepared by Astron Environmental Services (2017). Briefly, most isolated recesses of caves in which obligate troglofauna live, are characterised by complete darkness, constant temperature and high humidity (Poulson and White 1969, Howarth 1980, 1983). Humidity is often at saturation point (Howarth 1980, 1983, 1993).

Depending upon the level of connectivity to surface conditions, microclimate may display a sinusoidal pattern of variation, based on an annual cycle (Cigna 2002, Jury and Horton 2004). This cycle usually lags based on the rate of propagation from the surface (Cigna 2002), and climate change at the surface may take several years to be reflected in the cave habitat (Mammola et al. 2017).

Water loss is generally higher in troglofauna than in their surface dwelling relatives, and their tolerance to different, or variable, temperature may be limited (Poulson and White 1969, Rizzo et al. 2015). Howarth (1983) suggests that the "most critical environmental factor governing [troglofauna] distribution appears to be the stable saturated atmosphere", and that troglofauna live in a virtual aquatic environment where water loss ceases to be an ecological challenge. It can therefore be expected that decreases in humidity below saturation, and changes to temperature could significantly affect troglofauna survival and/or distribution.

1.1.2 Impact of Carbon Dioxide Levels on Troglofauna

Little research has been done into the effects of changing carbon dioxide (CO_2) levels on subterranean environments. As Humphreys and Eberhard (1998) suggest, this may partially be due to the fact that the impact of degrading activities on subterranean habitats is very subtle and difficult to quantify, given that degradation often occurs before fauna are even detected.

The majority of studies that have assessed subterranean CO_2 levels have focussed on the impact of frequent visitation to cave environments. Such studies have commonly linked increased CO_2 concentrations to the introduction of microorganisms through human visitation (Fernandez-Cortes et al. 2011). However, Pilbara troglofauna habitats are more likely to include cavities and fissures, and ground disturbance rather than visitation as the key disturbance. While no previous studies have assessed changes in CO_2 in these kinds of environments, it seems possible that CO_2

concentrations in habitats that have been impacted by ground disturbance, may exhibit a shift in CO_2 levels towards atmospheric concentrations (approximately 0.04%).

Although there are a wide variety of troglofauna species, many are commonly found in environments with high CO_2 concentrations (up to 6% versus 0.04% in normal atmospheric condition (Howarth and Stone 1990)). This is potentially due to their capacity to function more efficiently in high CO_2 environments (Howarth 1988, Howarth and Stone 1990). However, there is also some evidence to suggest that elevated CO_2 levels are not necessarily a requirement of these species (Humphreys and Eberhard 1998, Humphreys 2000).

While the impact of changing CO_2 levels on troglofauna is not well understood, in general subterranean species have often been shown to have a very low tolerance for changes in abiotic conditions (Novak et al. 2014, Raschmanová et al. 2018, Mammola et al. 2019). There is therefore potential for small changes in CO_2 levels to significantly impact troglofauna survival, and hence monitoring of CO_2 may be capable of indicating where enclosed volumes have been exposed to atmospheric conditions through disturbance. However, if monitoring requires opening of the enclosed void to atmospheric conditions, then such conditions are likely to be altered immediately and ongoing monitoring will not necessarily provide reliable data on changes to CO_2 concentrations.

1.2 Scope of Works

In October 2020, Astron was commissioned to further expand on the analyses completed in June 2017 and April 2020. The scope of works included:

- Identify and remove erroneous data from the data set (for example, error caused by probe malfunction).
- Present the complete timeline of temperature and relative humidity data collected at the Mesa K monitoring sites, following the analysis methods developed in June 2017.
- Present the complete timeline of down hole CO_2 data collected at the Mesa K monitoring sites.
- Review the available literature relating to CO_2 levels in subterranean environments. Discuss the relevance of CO_2 data collection to determining mining impacts and the validity of continued collection of this data.
- Assess whether the down hole measurements correspond with changes in surface temperature, humidity or rainfall, and if so, analyse the data collected in relation to meteorological data collected at Mesa K.
- Utilise the data collected across Mesa A, Mesa B, Mesa F and Mesa K to assess whether mining has altered down hole temperature and relative humidity.
- Assess whether the removal of three in-pit monitoring sites at Mesa K (MEK03, MEK04 and MEK05) will be detrimental to understanding the subterranean habitat conditions at Mesa K, given the remaining monitoring network that is currently in place.

2 Methods

2.1 Data Overview

The total monitoring data set consisted of temperature and relative humidity data from 45 stations: 24 at Mesa A, three at Mesa B, three at Mesa F and nine at Mesa K. Six 'mobile' stations at Mesa A were also included in the analysis. The location of each station is outlined in Appendix A. Temperature and relative humidity were recorded at hourly intervals between January 2011 and October 2020. Capacitive sensors were used to monitor relative humidity.

Carbon dioxide data was collected from 13 stations: one at Mesa A, three at Mesa B and nine at Mesa K. Carbon dioxide concentrations were measured using a Vaisala GMM221 CO_2 transmitter module, with measurements recorded at hourly intervals between October 2011 and October 2020.

2.2 Data Quality Control

Data from each station were initially assessed visually.

In line with previous methods, pre-2014 temperature and humidity data were removed from the data set prior to analysis. Justification of this exclusion is further discussed in Astron Environmental Services (2017).

Step changes, generally considered to be a consequence of probe maintenance (Rio Tinto Iron Ore 2014), are apparent throughout the data set. Data were not adjusted to account for these step changes. This is further discussed in Section 2.4.

Following removal of the pre-2014 data, all temperature values occurred within the expected range (between 28°C and 40°C), and no further adjustments were therefore required. Humidity probes at all sites recorded some values higher than 100%. Humidity probes generally do not function accurately near the point of saturation (100% relative humidity (RH)), with accuracy lost when RH reaches around 95% (Cigna 2002, Rio Tinto Iron Ore 2014, R. Vlad per. comm. June 2017). Humidities over 105% would indicate probable probe failure (for example, damage from corrosion), while values of 100% to 105% should be considered to be 100% (Rio Tinto Iron Ore 2014, R. Vlad per. comm. June 2017). All relative humidity values between 100% and 105% were therefore adjusted to 100%, and values greater than 105% were excluded from further analysis.

Carbon dioxide concentrations ranged between -0.01% and 76.09%. Measurement ranges for the Vaisala GMM221 module are between 0% and 10%, and accuracy at 25°C is given as ± 1.5% of the range + 2% of the reading. Given the measurement range and accuracy of the module, any values below 0% were adjusted to 0%, and any values above 10% were excluded from further analysis.

2.3 Data Analysis

Location was the primary factor used to approximate the level of potential impact from mining activities. Stations at Mesa A (including the mobile stations) and Mesa K were considered to be under potential impact, while stations at Mesa B and Mesa F acted as the reference group.

Analysis generally followed the methods previously developed by Astron Environmental Services (2017). The variables analysed included:

- mean levels of humidity, temperature and CO_2, with the expectation that disturbance would lead to a decrease of humidity and a change in temperature and CO_2

- mean levels of variation (standard deviation) in humidity, temperature and CO_2, with the expectation that disturbance from mining would expose habitats to surface climate, therefore increasing the level of variation
- goodness of fit to sinusoidal curves, which describe a pattern of regular oscillation on an annual cycle (see Section 2.3.1 for further detail).

In order to assess the impact of removing stations MEK03, MEK04 and MEK05 from the program, at Rio Tinto's request, each analysis was performed firstly with all Mesa K stations included, and secondly with the data from MEK03, MEK04 and MEK05 excluded.

Linear models were used to compare potential impact and reference groups for each variable. Residuals were assessed for normality using a Shapiro-Wilk test of normality (Shapiro and Wilk 1965). Where data were not normal, a permutational linear model was performed using the package lmPerm (Wheeler and Torchiano 2016). All analyses were performed using the R software (R Core Team 2019).

2.3.1 Sinusoidal Curves in Climate Data

With increased exposure to surface climate, subterranean microclimate takes on an increasingly sinusoidal pattern, based on a 12 month cycle (Cigna 2002). This exposure will increase with decreasing depth, or other processes such as contrasts in substrate materials, which expose habitats to external surface climate. Once the influence of depth has been controlled for, disturbance is expected to increase the amplitude of climate data, with the data fit to a sinusoidal curve increasing with proximity to significant disturbance. Data fit to a sinusoidal curve was quantified using the R^2 values based on an individual model for each probe. R^2 values indicate the proportion of variation in the response variable that is explained by the predictor variable, with a zero-value indicating no variation is explained, and a value of one indicating that all variation is explained. This approach aims to differentiate between model fits to a sinusoidal curve despite unexplained step changes in the data because the sinusoidal curves are expected to remain in the data despite the step changes. Given that atmospheric CO_2 concentrations area relatively stable, a sinusoidal pattern of variation is not expected for subterranean CO_2 levels with increased exposure to atmospheric conditions. Down hole CO_2 concentrations were therefore not assessed against sinusoidal curves.

2.4 Limitations

Data with step changes and other unexplained variation is a source of intrinsic error. The principal consequence of this error is higher variation, leading to lower statistical power and a lower ability to detect statistically significant differences, such as the effect of an environmental impact. Any increase in data quality is usually aimed at increasing the likelihood of detecting an impact, if one had occurred. Clearly, less noisy data sets have less error around statistical estimates and are hence more powerful (that is, more likely to detect an impact). While these data could be improved by making adjustments where known probe changes occurred, no such adjustments have been made due to the lack of 'actual' values (for example, no record of true values at the time of probe change) to enable calibration. Further discussion of this limitation is available in Astron Environmental Services (2017).

3 Results

The analysed data, presented as plots by individual probes, is provided in Appendix B (raw data), and Appendix C (following the quality control steps outlined in Section 2.2). Mean values across all potential impact stations and all reference stations are presented in Table 1.

Table 1: Mean values for each station type (potential impact and reference).

Variable		Potential impact	Reference
Temperature (°C)	Mean	32.3	32.5
	Standard deviation	0.2	0.1
	R^2 fit to sinusoidal curve	0.09	0.04
Relative humidity (%)	Mean	99.4	99.4
	Standard deviation	1.0	0.6
	R^2 fit to sinusoidal curve	0.05	0.08
Carbon dioxide (%)	Mean	2.4	1.8
	Standard deviation	1.0	1.5

3.1 Temperature

Temperature was generally lowest at MEK05 (mean = 29.2°C) and highest at MEA01C (mean = 33.4°C). Mean temperature across the potential impact stations was 32.3°C and across the reference stations was 32.5° (Table 1). There was no significant difference in mean temperature between potential impact and reference stations (Table 2).

Temperature variation was lowest at MEA10B (standard deviation = 0.03°C) and highest at MEA11 (standard deviation = 0.75°C). Mean temperature standard deviation was 0.2°C for the potential impact stations and 0.1°C for the reference stations (Table 1). There was a significant effect of probe depth on temperature variation and a significant interaction between probe depth and site type (Table 2).

The sinusoidal model was least appropriate for temperature data at MEA01A (R^2 = 0.0001) and provided the best fit for temperature data at MEA11 (R^2 = 0.85). Mean R^2 at the potential impact stations were 0.09 and at the reference stations were 0.04 (Table 1). There was a significant effect of probe depth on temperature R^2 (Table 2), and a significant interaction between probe depth and site type (Table 2).

The significant interactions between probe depth and site type suggested shallow potential impact stations showed greater variation in temperature than reference stations and are more influenced by surface conditions. Although this analysis aimed to control for the effect of probe depth, the difference in probe depth between potential impact stations (ranging between 5 m and 25 m) and reference stations (one station at 8 m and all others over 32 m), means that probe depth is likely to still be driving the contrast between potential impact and reference stations. Removal of those stations with probe depths of less than 6 m (i.e. those sensors most likely to be impacted by surface conditions), suggests that there is no difference between standard deviation in temperature at potential impact and reference stations (Figure 1; $F_{3,35}$ = 2.17, P = 0.73). A significant interaction remained between probe depth and site type for sinusoidal goodness of fit after the shallowest stations were removed (Figure 2; $F_{3,35}$ = 3.6, P = 0.003). However, this result is unlikely to be meaningful given the absence of a corresponding increase in temperature variation, which would have been expected if climatic variation was having an influence on these sites.

Table 2: Summary results for all stations examining the statistical relationship between site type (reference and potential impact), and environmental variables. Model fit (R^2) represents the proportion of variation explained by the model. Numbers in bold indicate significant values (P < 0.05).

Variable		F	df	Model fit	P (probe depth)	P (site type)
Temperature	Mean	0.43	3,40	0.03	0.75	0.46
	Standard deviation^	4.94	3,40	0.27	**0.002**	0.98
	R^2 fit to sinusoidal curve*	7.09	3,40	0.35	**0.005**	0.65
Relative humidity	Mean	1.43	3,40	0.10	0.13	0.14
	Standard deviation	1.02	3,40	0.07	0.23	0.66
	R^2 fit to sinusoidal curve	2.82	3,40	0.17	**0.04**	0.06
Carbon dioxide	Mean	0.36	3,8	0.12	0.44	0.99
	Standard deviation	0.87	3,8	0.25	0.91	0.20

^Includes a significant depth x site type interaction term (P = 0.04).

*Includes a significant depth x site type interaction term (P = 0.001).

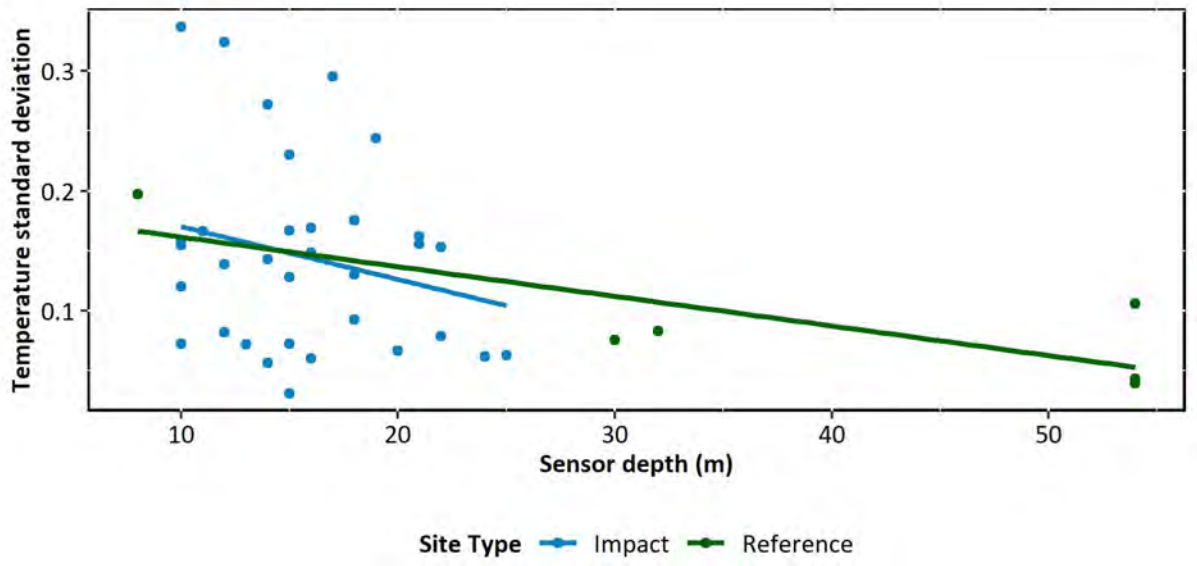


Figure 1: Mean of the standard deviation in temperature at different sensor depths for each site type. Solid lines indicate the regression between standard deviation and sensor depth for each site type.

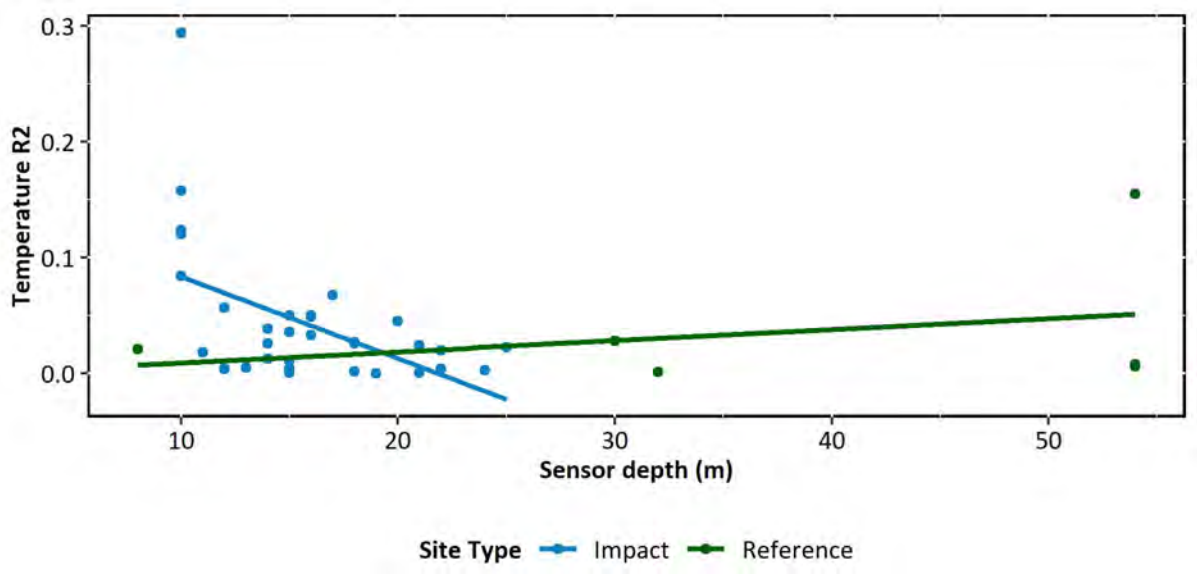


Figure 2: Mean of the R^2 sinusoidal goodness of fit for temperature at different sensor depths for each site type. Solid lines indicate the regression between standard deviation and sensor depth for each site type.

3.2 Humidity

Humidity was lowest at potential impact station MOB03 (mean = 97.0%) and highest at reference stations MEF01 and MEF02 and potential impact stations MEA12, MOB01B, MEK02, MEK03, MOB03B, MEA02B and MOB01 (mean = 100%). Mean humidity was 99.4% across both potential impact and reference stations (Table 1). There was no significant difference between potential impact and reference stations (Table 2).

Variation in humidity was lowest at potential impact station MEA12 and reference station MEF01 (standard deviation = 0.02%), and highest at potential impact station MOB02B (standard deviation = 4.7%). Mean humidity standard deviation across the potential impact stations was 1.0% and across the reference stations was 0.6% (Table 1). There was no significant difference between potential impact and reference stations (Table 2).

The sinusoidal model was least appropriate for humidity data at MEK02 and MEK03 ($R^2 < 0.0001$) and most appropriate to humidity data at MEA11 ($R^2 = 0.50$). The mean R^2 at potential impact stations was 0.05 and at reference stations was 0.08 (Table 1). There was a significant effect of probe depth on relative humidity, but no significant difference between potential impact and reference stations (Table 2).

3.3 Carbon Dioxide

Carbon dioxide levels were lowest at reference station MEK05 (mean = 0.001%) and highest at reference station MEK07 (mean = 4.7%). Mean CO_2 levels were 2.4% across the potential impact stations and 1.8% across the reference stations (Table 1). There was no significant difference between potential impact and reference stations (Table 2).

Variation in CO_2 levels were lowest at MEK05 (standard deviation = 0.003%) and highest at reference station MEA05 (standard deviation = 2.0%). Mean CO_2 standard deviation was 0.6% across the potential impact stations and 0.3% across the reference stations (Table 1). There was no significant difference between the potential impact and reference stations (Table 2).

3.4 Mesa K Station Removal

The statistical analysis presented above in Table 2 were repeated following the exclusion of data from MEK03, MEK04 and MEK05, at the request of Rio Tinto. Removal of these stations had minimal effect on the results of any of the temperature analyses (Table 3). However, removal of these sites revealed a significant effect of probe depth on mean relative humidity and variation in relative humidity (Table 3). The probes at MEK03, MEK04 and MEK05 were positioned at 18 m, 21 m and 14 m, respectively. Given that none of the reference probes occur at depths of this range, the removal of these sites has most likely highlighted the effect of probe depth. Regardless, no effect of site type on relative humidity was detected.

Although no changes to the statistical results were noted for mean or standard deviation in CO_2, it should be noted that MEK05 displays quite different concentration levels to any of the other Mesa K stations. As indicated in Section 3.3, mean CO_2 concentration at MEK05 was the lowest of any of the stations (0.0007%), with the next lowest CO_2 concentrations recorded at MEK06 (0.6%). Given that the atmospheric concentration CO_2 is approximately 0.04%, it is likely that measurements at MEK05 is the result of probe error. Standard deviation of CO_2 at MEK05 was 0.003% with the next lowest again recorded at MEK06 (0.4%).

Table 3: Summary results following removal of MEK03, MEK04 and MEK05 examining the statistical relationship between site type (reference and potential impact), and environmental variables. Model fit (R^2) represents the proportion of variation explained by the model. Numbers in bold indicate significant values (P < 0.05).

Variable		F	df	Model fit	P (probe depth)	P (site type)
Temperature	Mean	1.29	3,37	0.09	0.13	0.96
	Standard deviation^	4.98	3,37	0.29	**0.003**	0.94
	R^2 fit to sinusoidal curve*	6.53	3,37	0.35	**0.008**	1.00
Relative humidity	Mean	1.79	3,37	0.13	**0.03**	0.07
	Standard deviation	1.61	3,37	0.12	**0.04**	0.30
	R^2 fit to sinusoidal curve	2.70	3,37	0.18	**0.01**	0.05
Carbon dioxide	Mean	0.70	3,5	0.30	0.42	0.89
	Standard deviation	2.80	3,5	0.63	0.34	0.05

^Includes a significant depth x site type interaction term (P = 0.04). Following removal of the shallowest stations, as discussed in Section 3.1, there was no significant interaction (P = 0.38).

*Includes a significant depth x site type interaction term (P = 0.006). Following removal of the shallowest stations, as discussed in Section 3.1, the significant interaction remained (P = 0.007).

4 Conclusions

As expected, variation in temperature was heavily influenced by probe depth, with much greater variation observed at shallower stations (5 m to 5.5 m). Although each analysis attempted to account for variation in probe depth, the lack of reference stations at this depth means that in several cases the effect could not be fully accounted for. In these cases, the shallowest stations were removed from the analysis. Even after removing stations of less than 6 m, a significant interaction was identified between probe depth and site type for R^2 fit of temperature to a sinusoidal curve. However, the absence of a corresponding increase in variation (standard deviation) in temperature, suggests that this result may not be meaningful. No significant differences were observed between potential impact and reference stations for any of the other variables.

Measurement of down hole CO_2 concentrations revealed no significant variation between potential impact and reference stations. A review of the available literature suggests that measuring CO_2 levels may be more critical in assessing changes to cave habitats rather than the fissures and cracks frequented by Pilbara troglofauna. Opening up these habitats to monitoring and inclusion of probes may also immediately alter CO_2 concentrations and lead to uninformative long term monitoring. We suggest that CO_2 monitoring is of little additional value to that already achieved with the humidity and temperature monitoring and could be removed from the program to better align with related troglofaunal monitoring programs.

Removal of three Mesa K stations (MEK03, MEK04 and MEK05) had little effect on the overall results obtained.

5 References

Astron Environmental Services. 2017. Troglofauna Habitat Data Analysis, June 2017. Unpublished report to Rio Tinto Iron Ore.

Astron Environmental Services. 2020. Troglofauna Habitat Data Analysis, April 2020. Unpublished report prepared for Rio Tinto Iron Ore.

Cigna, A. A. 2002. Modern Trend in Cave Monitoring. Acta Carsologica 31:35–54.

Fernandez-Cortes, A., S. Cuezva, S. Sanchez-Moral, J. C. Cañaveras, E. Porca, V. Jurado, P. M. Martin-Sanchez, and C. Saiz-Jimenez. 2011. Detection of human-induced environmental disturbances in a show cave. Environmental Science and Pollution Research 18:1037–1045.

Howarth, F. G. 1980. The Zoogeography of Specialized Cave Animals: A Bioclimatic Model. Evolution 34:394–406.

Howarth, F. G. 1983. Ecology of Cave Arthopods. Annual Review of Entomology 28:365–89.

Howarth, F. G. 1988. Environmental ecology of north Queensland caves: or why there are so many troglobites in Australia. Pages 76–84 Proceedings 17th biennial conference, Australian Speleological Federation Tropicon Conference, Lake Tinaroo, Far North Queensland. Australian Speleological Federation.

Howarth, F. G. 1993. High-Stress Subterranean Habitats and Evolutionary Change in Cave-Inhabiting Arthropods. The American Naturalist 142:S65–S77.

Howarth, F. G., and F. D. Stone. 1990. Elevated carbon dioxide levels in Bayliss Cave, Australia: implications for the evolution of obligate cave species. Pacific Science 44:207–218.

Humphreys, W. F. 2000. The hypogean fauna of the Cape Range peninsula and Barro Island, northwestern Australia. Pages 581–601 *in* H. Wilkins, D. C. Culver, and W. F. Humphreys, editors. Ecosystems of the World, vol. 30: Subterranean Ecosystems. Elsevier.

Humphreys, W. F., and S. M. Eberhard. 1998. Assessment of the ecological values and management options for cave use on Christmas Island. Unpublished report prepared for Parks Australia North.

Jury, W. A., and R. Horton. 2004. Soil Physics. Wiley, New York.

Mammola, S., P. Cardoso, D. C. Culver, L. Deharveng, R. L. Ferreira, C. Fišer, D. M. P. Galassi, C. Griebler, S. Halse, W. F. Humphreys, M. Isaia, F. Malard, A. Martinez, O. T. Moldovan, M. L. Niemiller, M. Pavlek, A. S. P. S. Reboleira, M. Souza-Silva, E. C. Teeling, J. J. Wynne, and M. Zagmajster. 2019. Scientist's warning on the conservation of subterranean ecosystems. BioScience 69:641–650.

Mammola, S., S. L. Goodacre, and M. Isaia. 2017. Climate change may drive cave spiders to extinction. Ecography.

Novak, T., N. Šajna, E. Antolinc, S. Lipovšek, D. Devetak, and F. Janžekovič. 2014. Cold tolerance in terrestrial invertebrates inhabiting subterranean habitats. International Journal of Speleology 43:265–272.

Poulson, T. L., and W. B. White. 1969. The Cave Environment. Science 165:971–981.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Raschmanová, N., V. Šustr, L. Kováč, A. Parimuchová, and A. Devette. 2018. Testing the climatic variability hypothesis in edaphic and subterranean Collembola (Hexapoda). Journal of Thermal Biology 78:391–400.

Rio Tinto Iron Ore. 2014. Environmental Protection Act 1986 Part IV Environment Compliance Report. Ministerial Statement 756: Mesa A/Warramboo Iron Ore Project. Rio Tinto Iron Ore, Perth.

Rizzo, V., D. Sánchez-Fernández, J. Fresneda, A. Cieslak, and I. Ribera. 2015. Lack of evolutionary adjustment to ambient temperature in highly specialized cave beetles. BMC Evolutionary Biology 15.

Shapiro, S. S., and M. B. Wilk. 1965. An analysis of variance test for normality (complete samples). Biometrika 52:591–611.

Wheeler, B., and M. Torchiano. 2016. Package “lmPerm.”

This page has been left blank intentionally.

Appendix A: Station Locations

This page has been left blank intentionally.

Table A1: Summary of station locations, type (potential impact or reference) and sensor depth.

Station	Location	Site type	Sensor depth (m)
MEA01A	Mesa A	Potential impact	19
MEA01B	Mesa A	Potential impact	24
MEA01C	Mesa A	Potential impact	25
MEA02A	Mesa A	Potential impact	12
MEA02B	Mesa A	Potential impact	22
MEA02C	Mesa A	Potential impact	16
MEA03A	Mesa A	Potential impact	15
MEA03B	Mesa A	Potential impact	15
MEA03C	Mesa A	Potential impact	15
MEA04A	Mesa A	Potential impact	18
MEA04B	Mesa A	Potential impact	13
MEA04C	Mesa A	Potential impact	12
MEA05	Mesa A	Potential impact	NA
MEA06	Mesa A	Potential impact	14
MEA07	Mesa A	Potential impact	17
MEA08	Mesa A	Potential impact	14
MEA09A	Mesa A	Potential impact	10
MEA09B	Mesa A	Potential impact	10
MEA10A	Mesa A	Potential impact	20
MEA10B	Mesa A	Potential impact	15
MEA10C	Mesa A	Potential impact	22
MEA11	Mesa A	Potential impact	5
MEA12	Mesa A	Potential impact	21
MEA13	Mesa A	Potential impact	18
MEB01	Mesa B	Reference	30
MEB02	Mesa B	Reference	32
MEB03	Mesa B	Reference	8
MEF01	Mesa F	Reference	54
MEF02	Mesa F	Reference	54
MEF03	Mesa F	Reference	54
MEK01	Mesa K	Potential impact	11
MEK02	Mesa K	Potential impact	15
MEK03	Mesa K	Potential impact	18
MEK04	Mesa K	Potential impact	21
MEK05	Mesa K	Potential impact	14
MEK06	Mesa K	Potential impact	16
MEK07	Mesa K	Potential impact	12
MEK08	Mesa K	Potential impact	5.5
MEK10	Mesa K	Potential impact	16

Station	Location	Site type	Sensor depth (m)
MOB01	Mesa A	Potential impact	10
MOB01B	Mesa A	Potential impact	5
MOB02	Mesa A	Potential impact	10
MOB02B	Mesa A	Potential impact	5
MOB03	Mesa A	Potential impact	10
MOB03B	Mesa A	Potential impact	5

Appendix B: Raw Monitoring Data

This page has been left blank intentionally.

Temperature

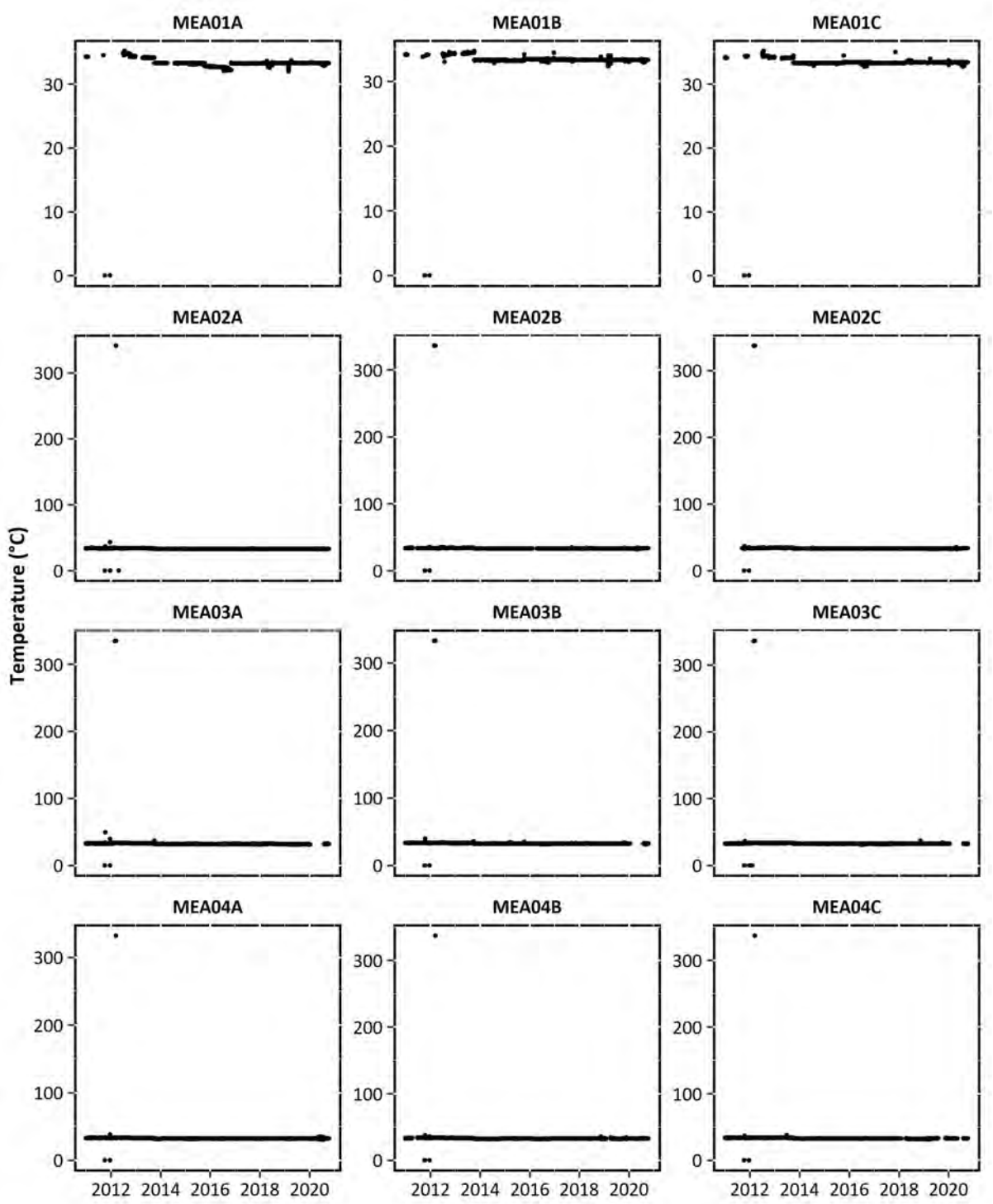


Figure B1: Plotted temperature data from each subterranean probe (MEA01A to MEA04C).

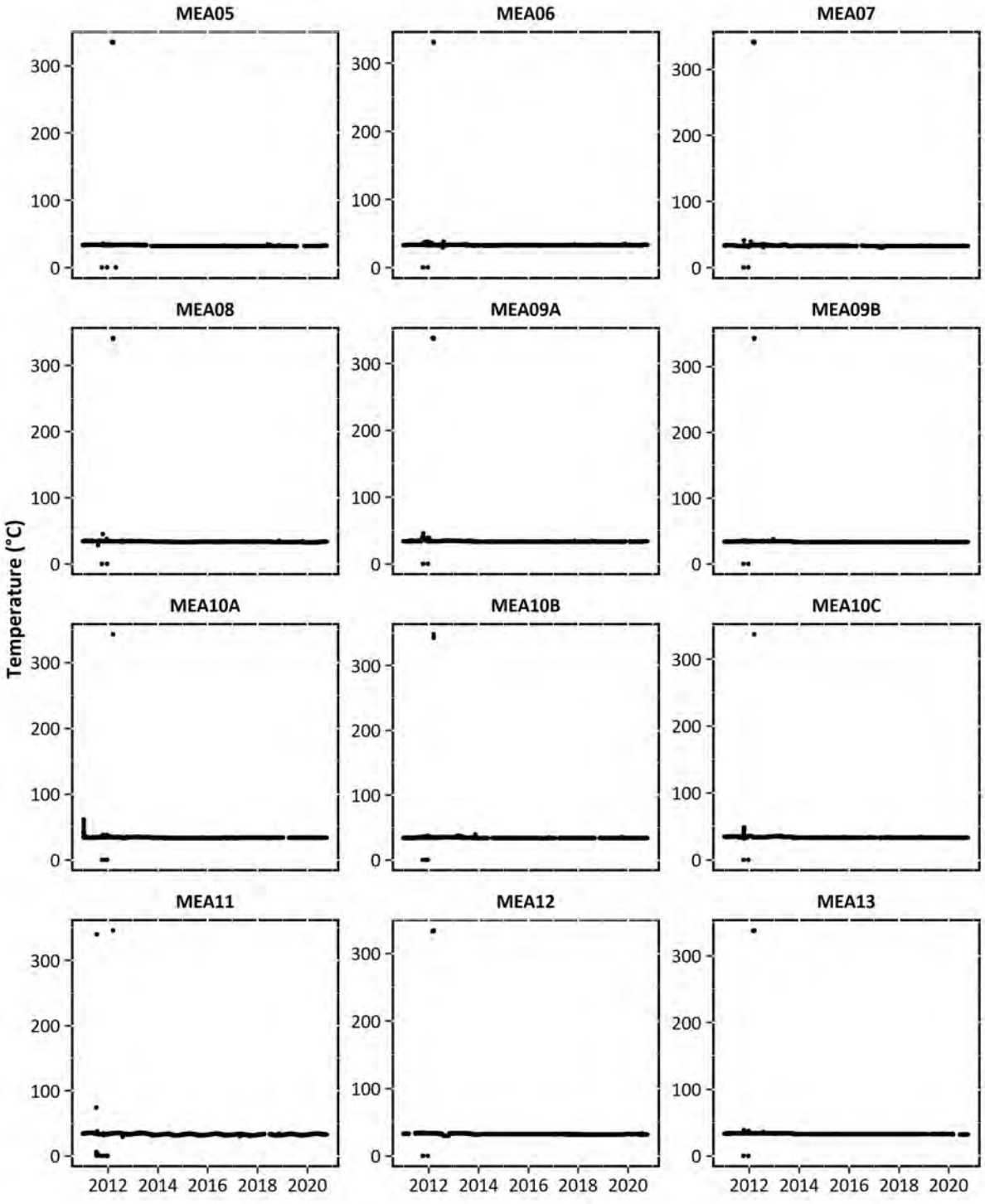


Figure B2: Plotted temperature data from each subterranean probe (MEA05 to MEA13).

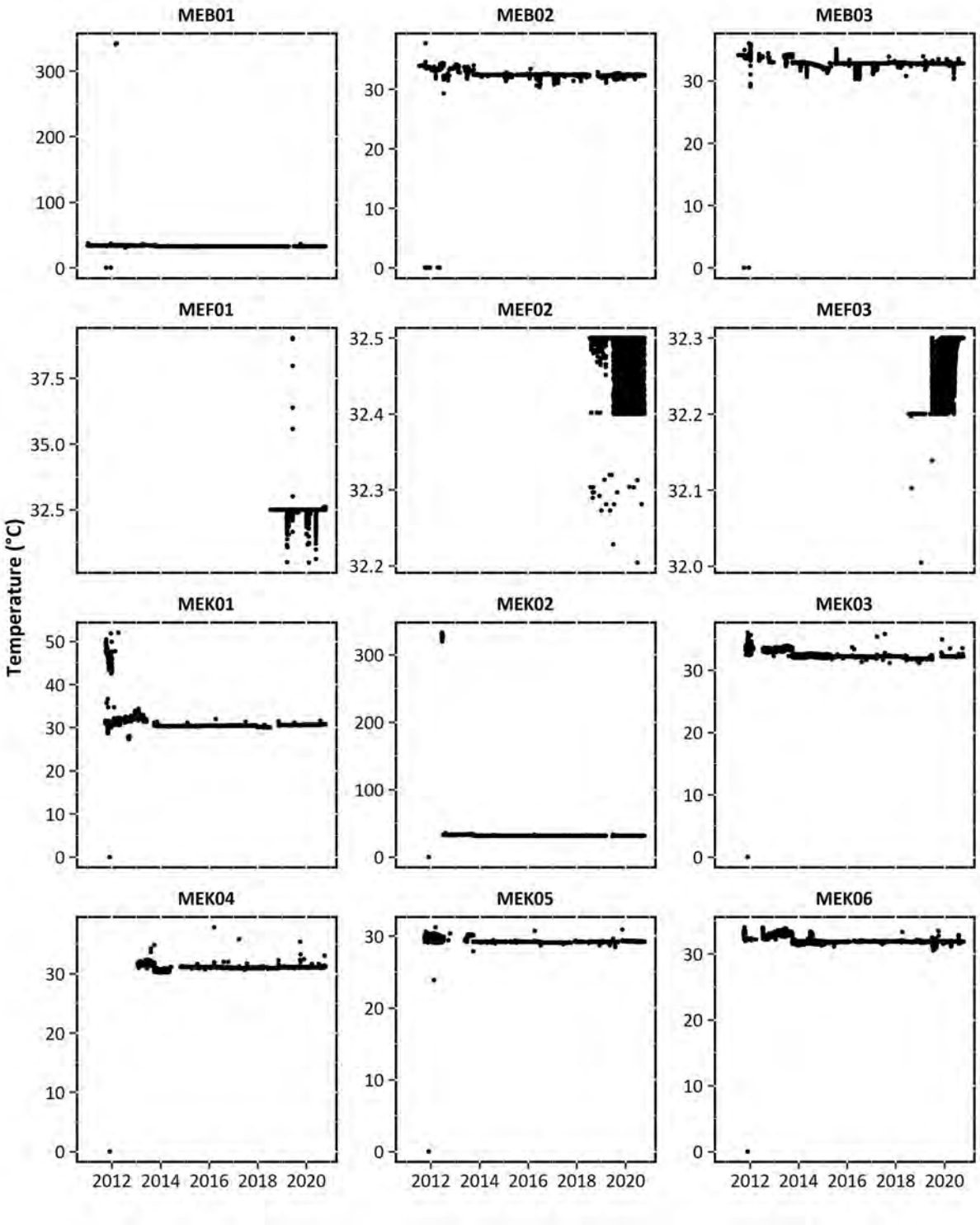


Figure B3: Plotted temperature data from each subterranean probe (MEB01 to MEK06).

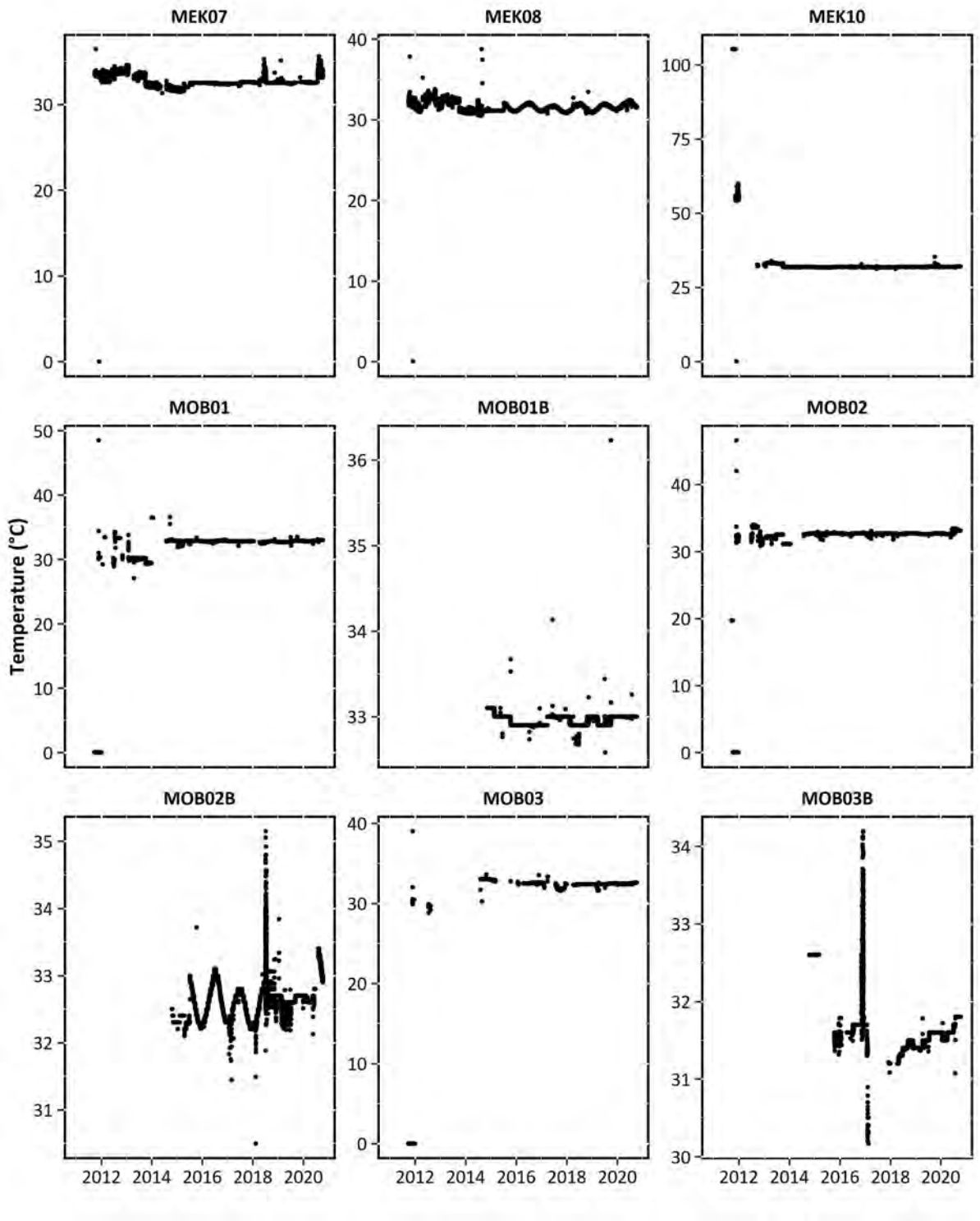


Figure B4: Plotted temperature data from each subterranean probe (MEK07 to MOB03B).

Humidity

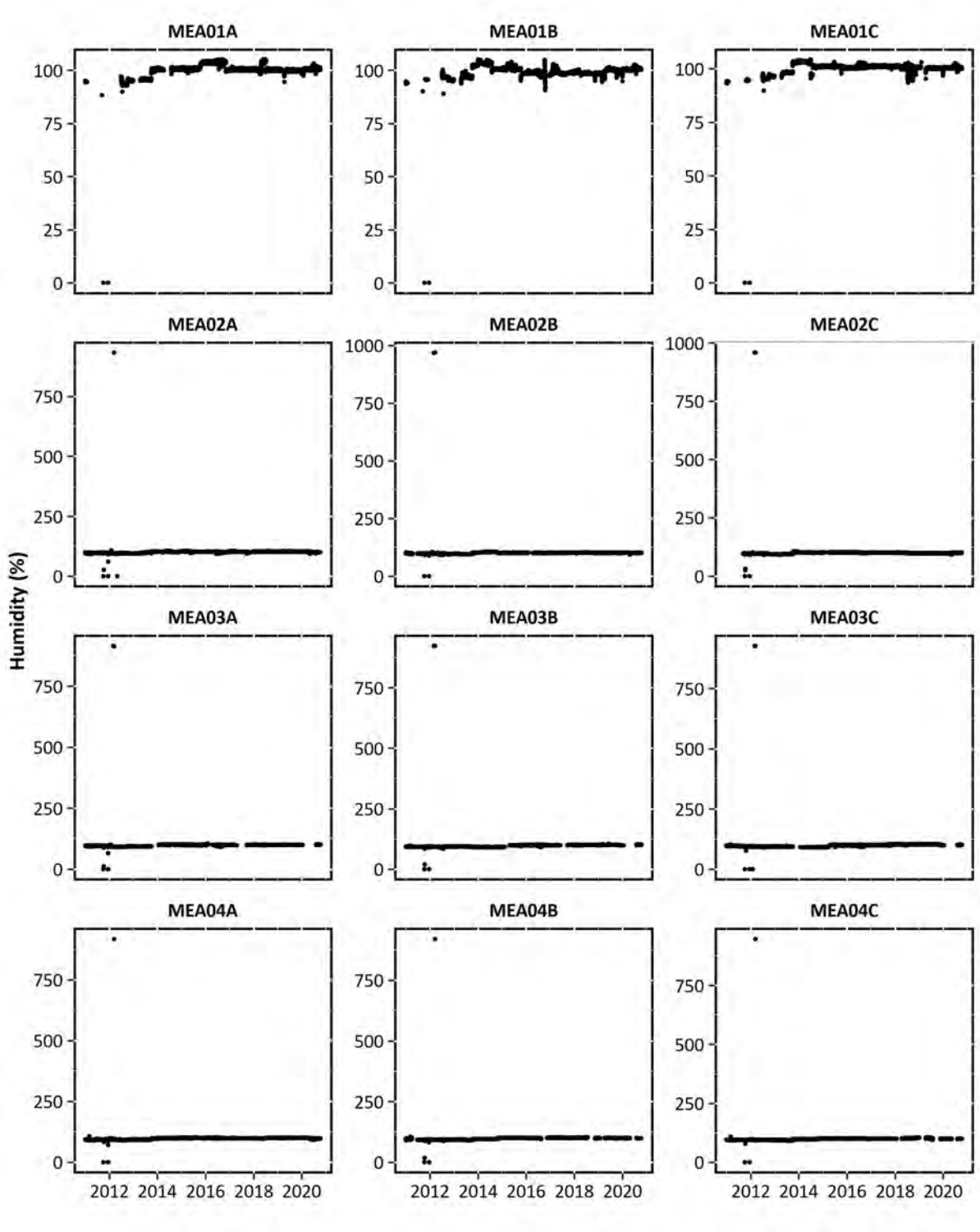


Figure B5: Plotted humidity data from each subterranean probe (MEA01A to MEA04C).

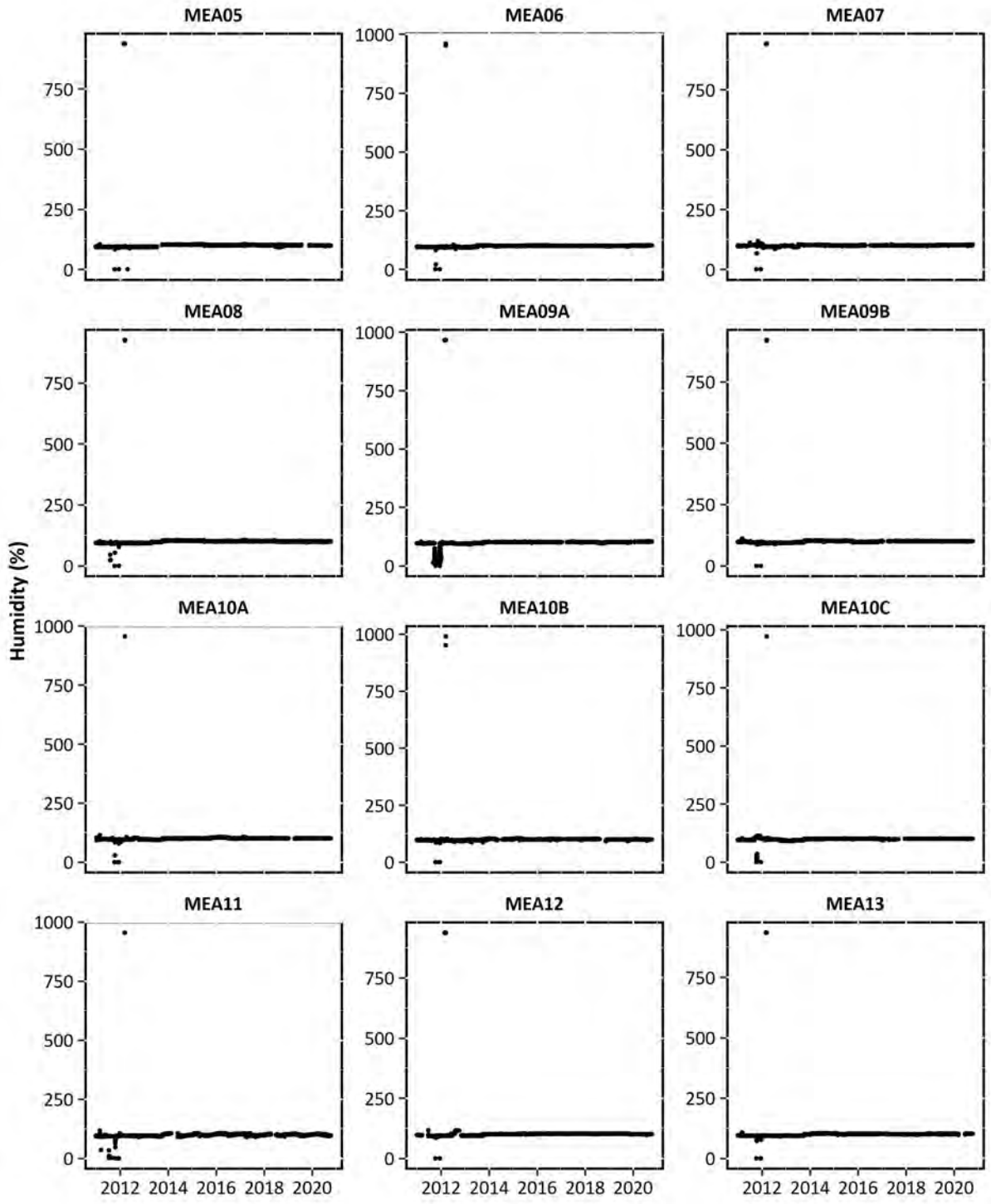


Figure B6: Plotted humidity data from each subterranean probe (MEA05 to MEA13).

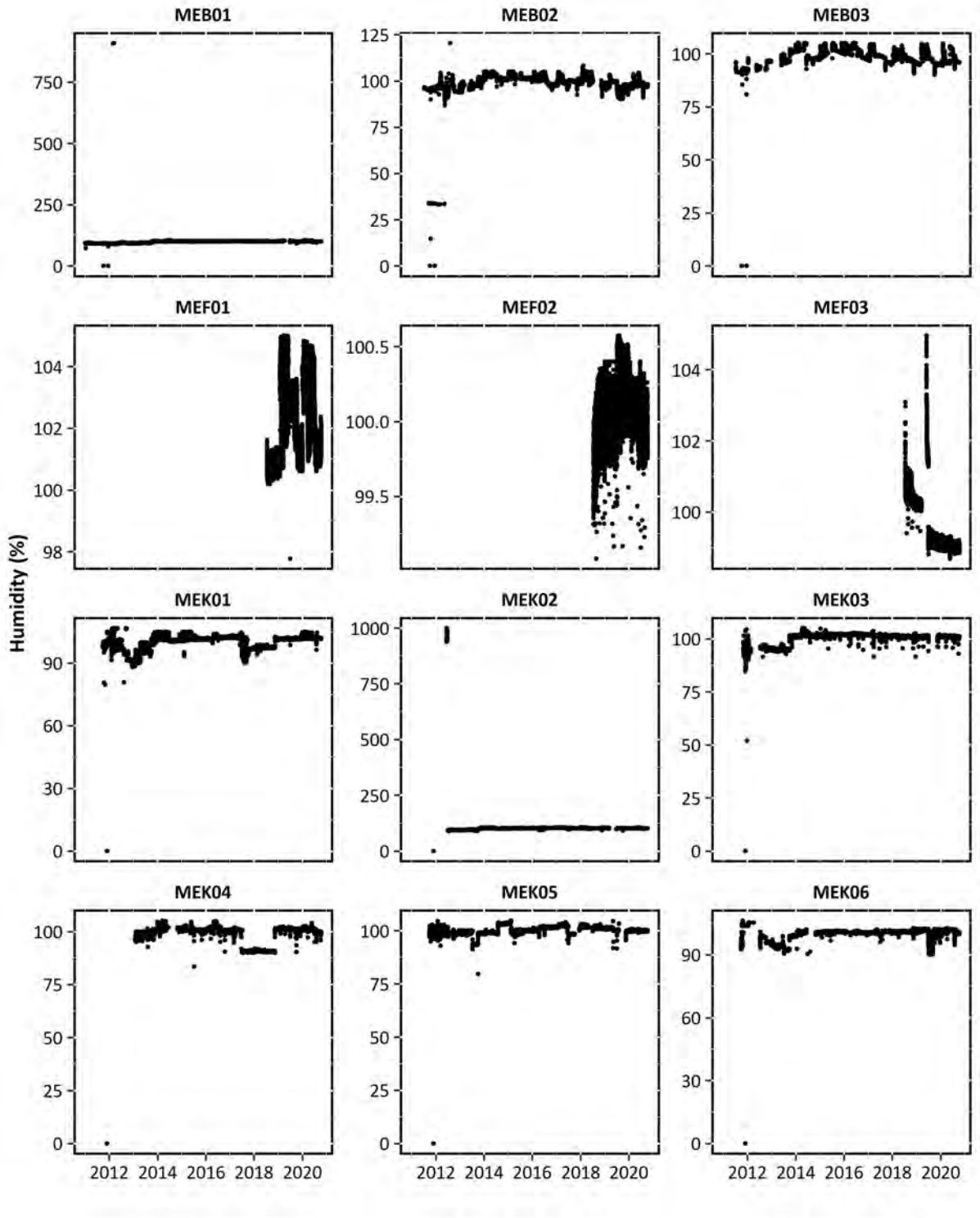


Figure B7: Plotted humidity data from each subterranean probe (MEB01 to MEK06).

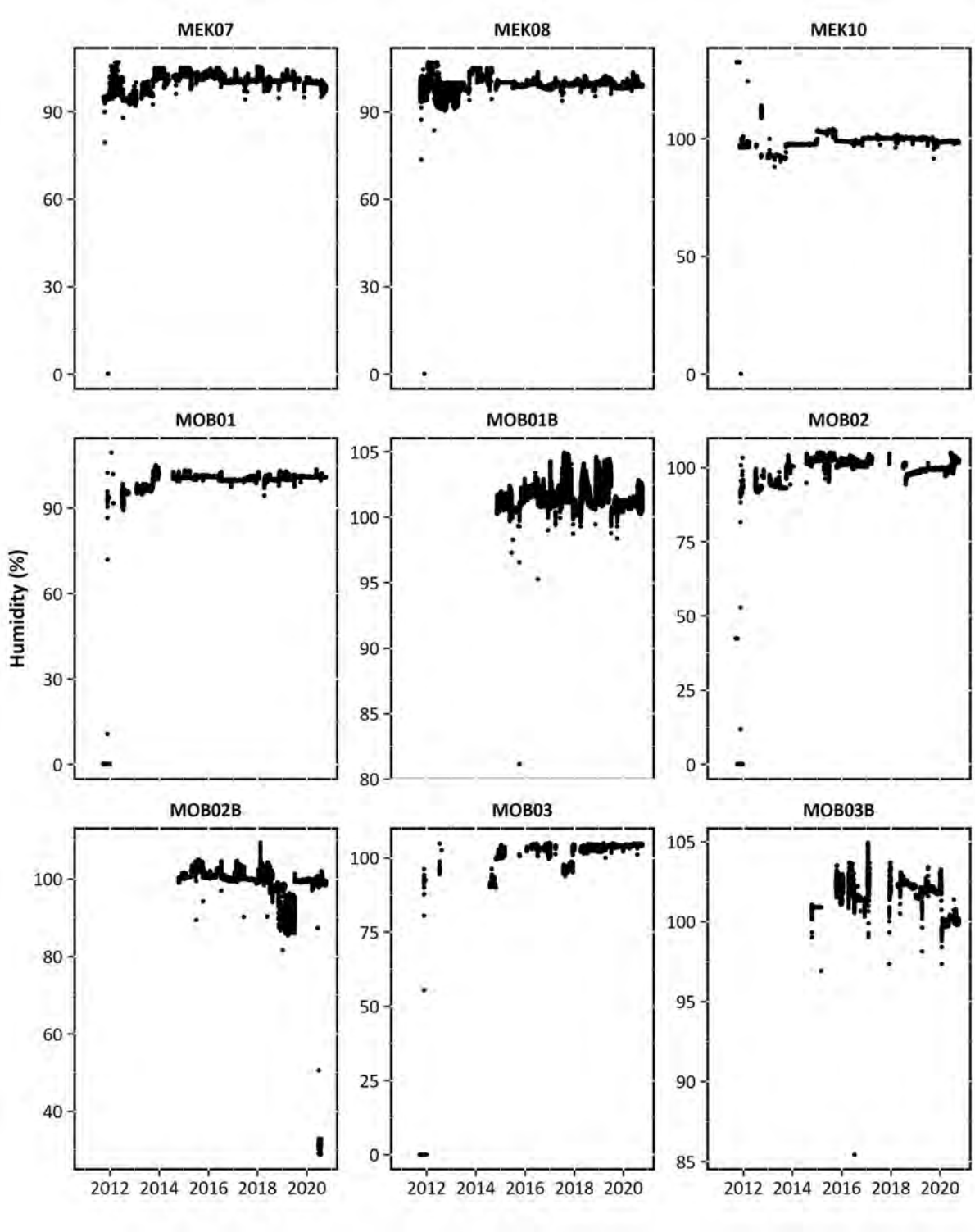


Figure B8: Plotted humidity data from each subterranean probe (MEK07 to MOB03B).

Carbon Dioxide

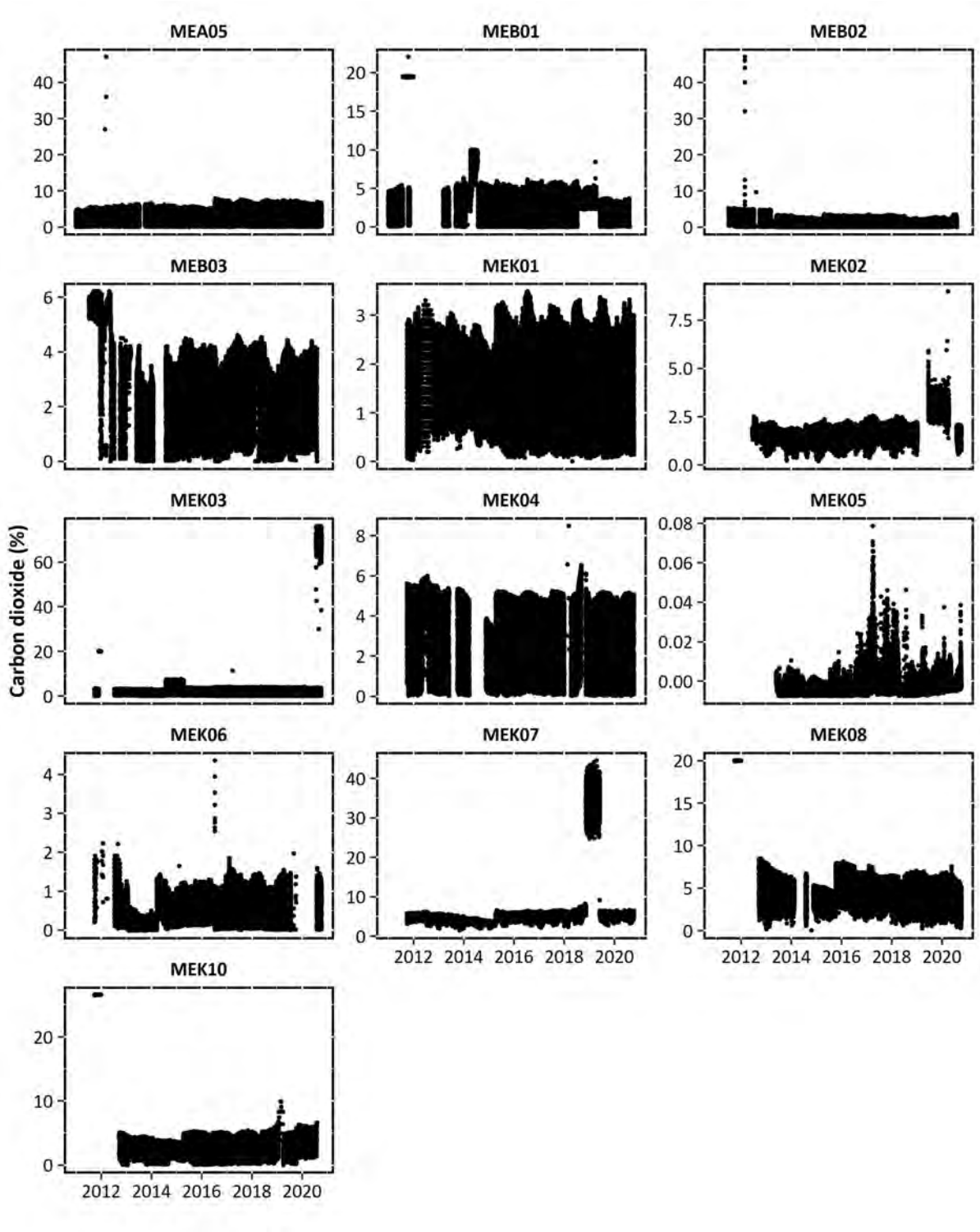


Figure B9: Plotted carbon dioxide data from each subterranean probe.

This page has been left blank intentionally.

Appendix C: Adjusted Monitoring Data

This page has been left blank intentionally.

Temperature

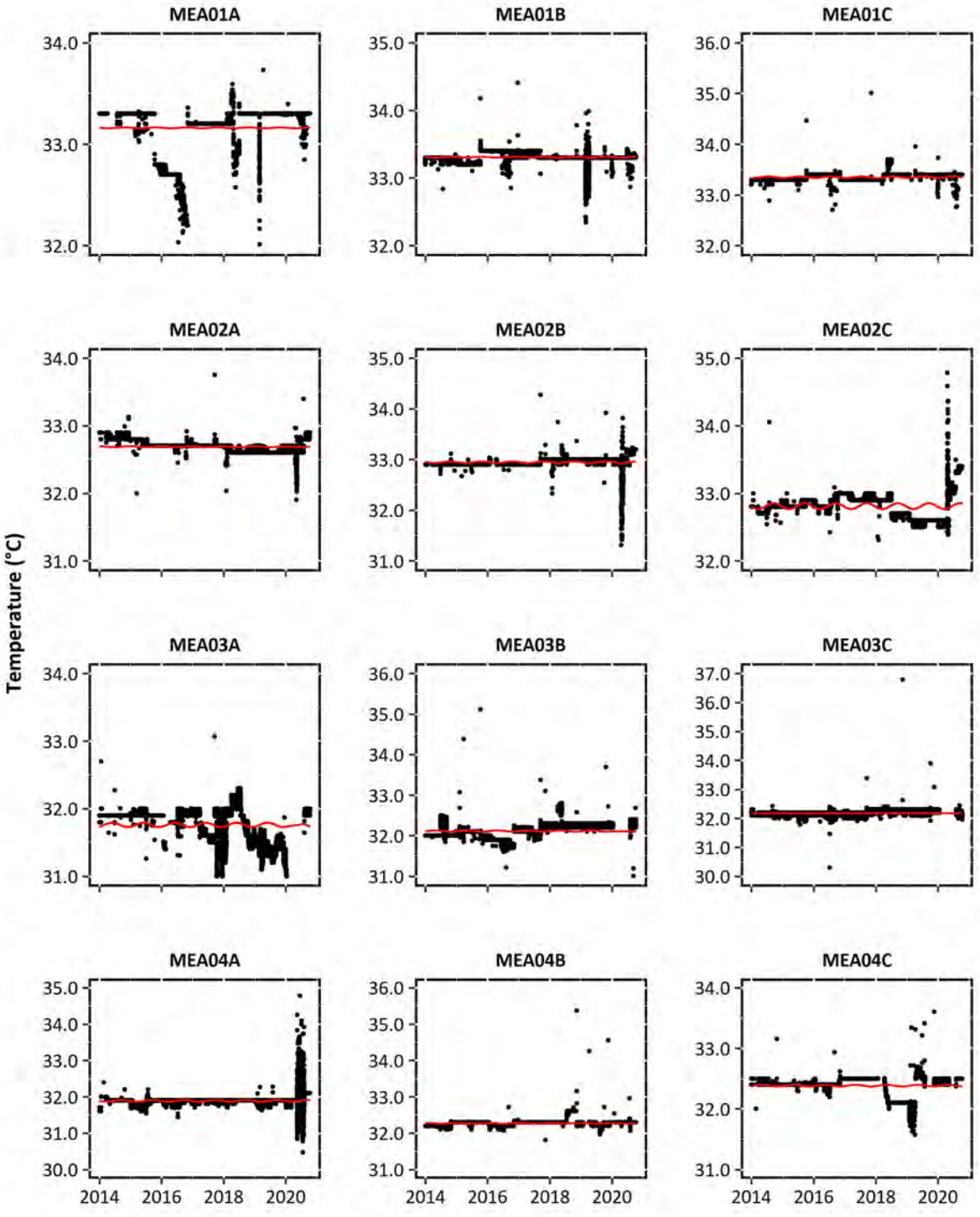


Figure C1: Plotted temperature data from each subterranean probe (MEA01A to MEA04C). Red line indicates the best fitted sinusoidal curved based on an annual cycle.

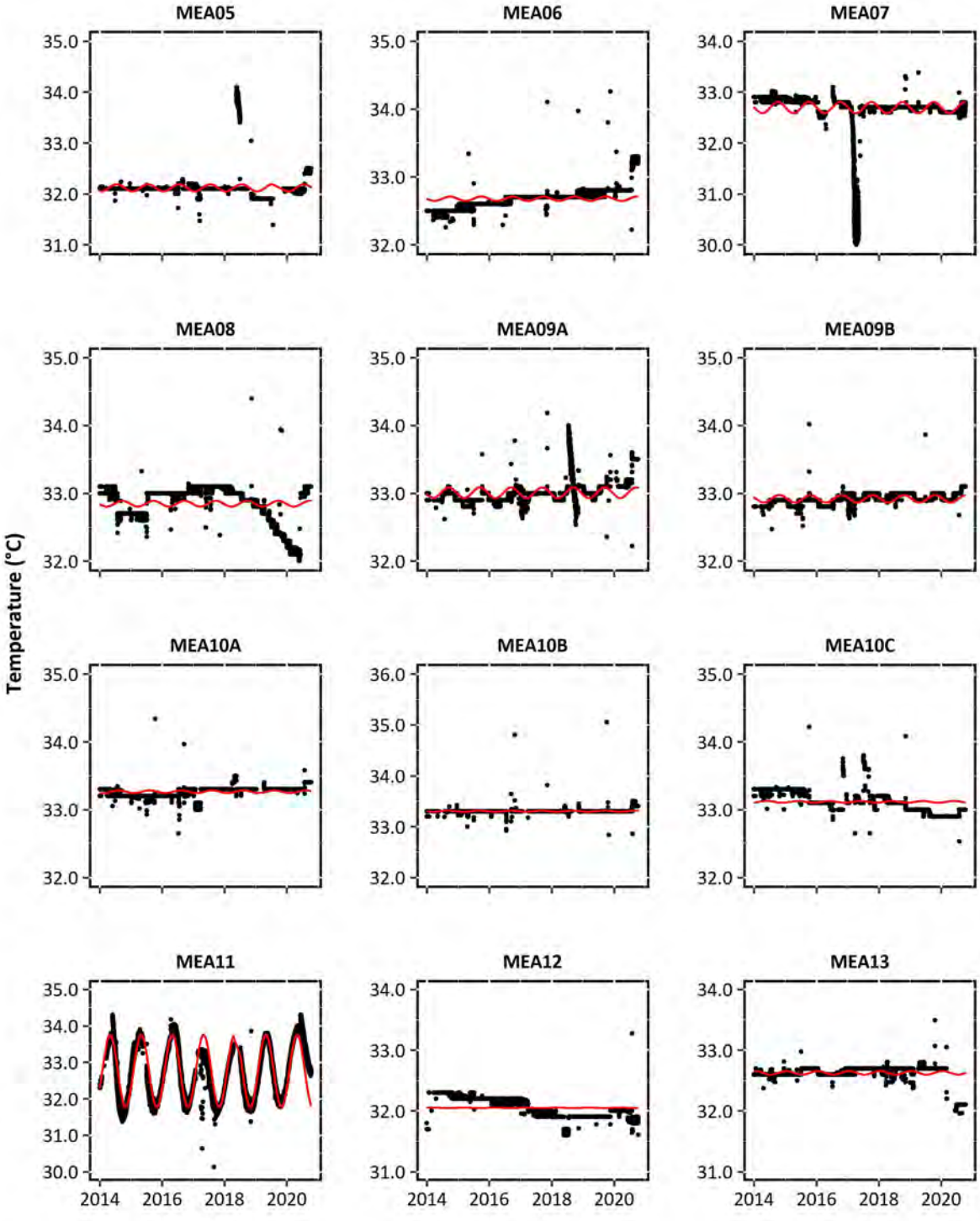


Figure C2: Plotted temperature data from each subterranean probe (MEA05 to MEA13). Red line indicates the best fitted sinusoidal curved based on an annual cycle.

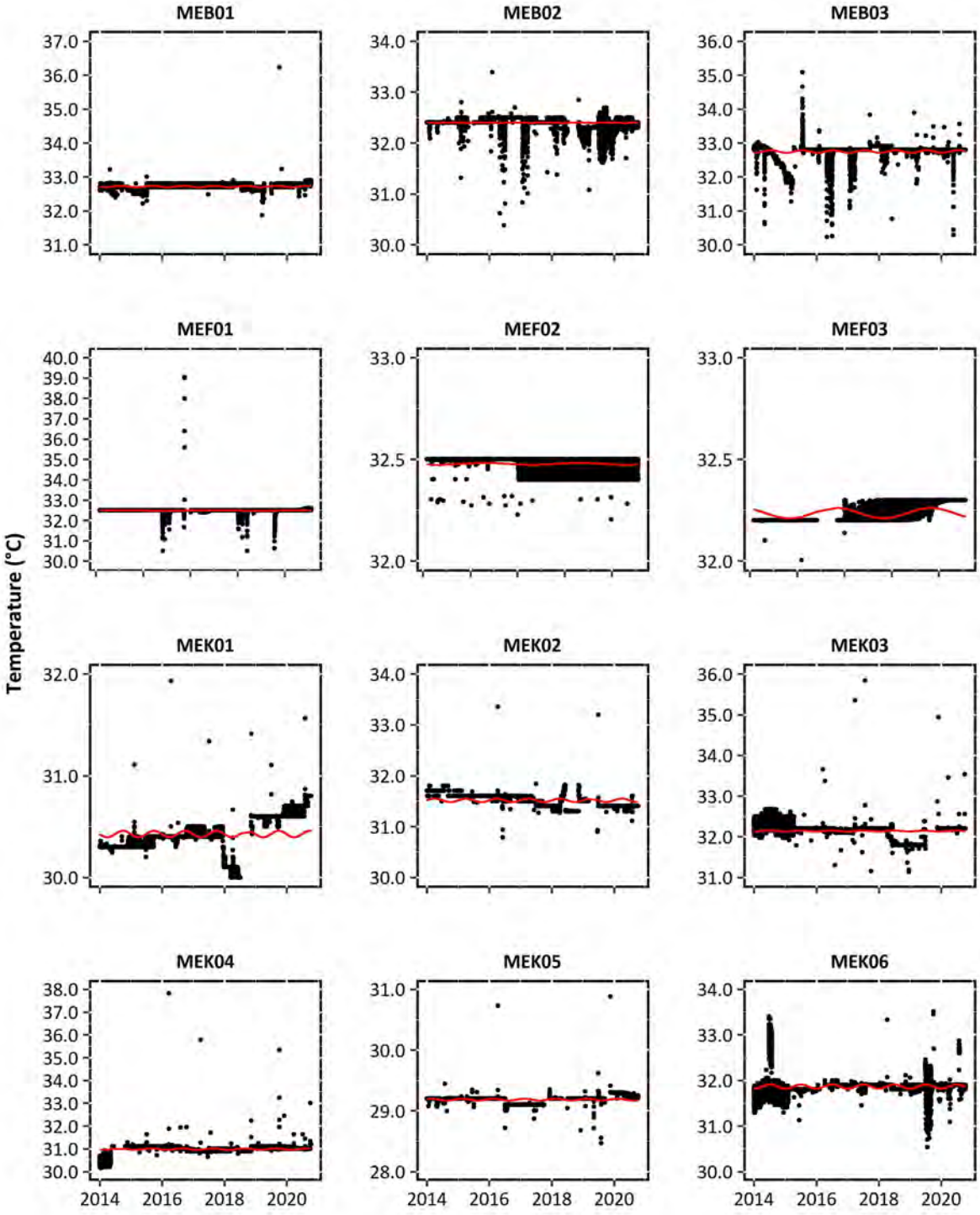


Figure C3: Plotted temperature data from each subterranean probe (MEB01 to MEK06). Red line indicates the best fitted sinusoidal curved based on an annual cycle.

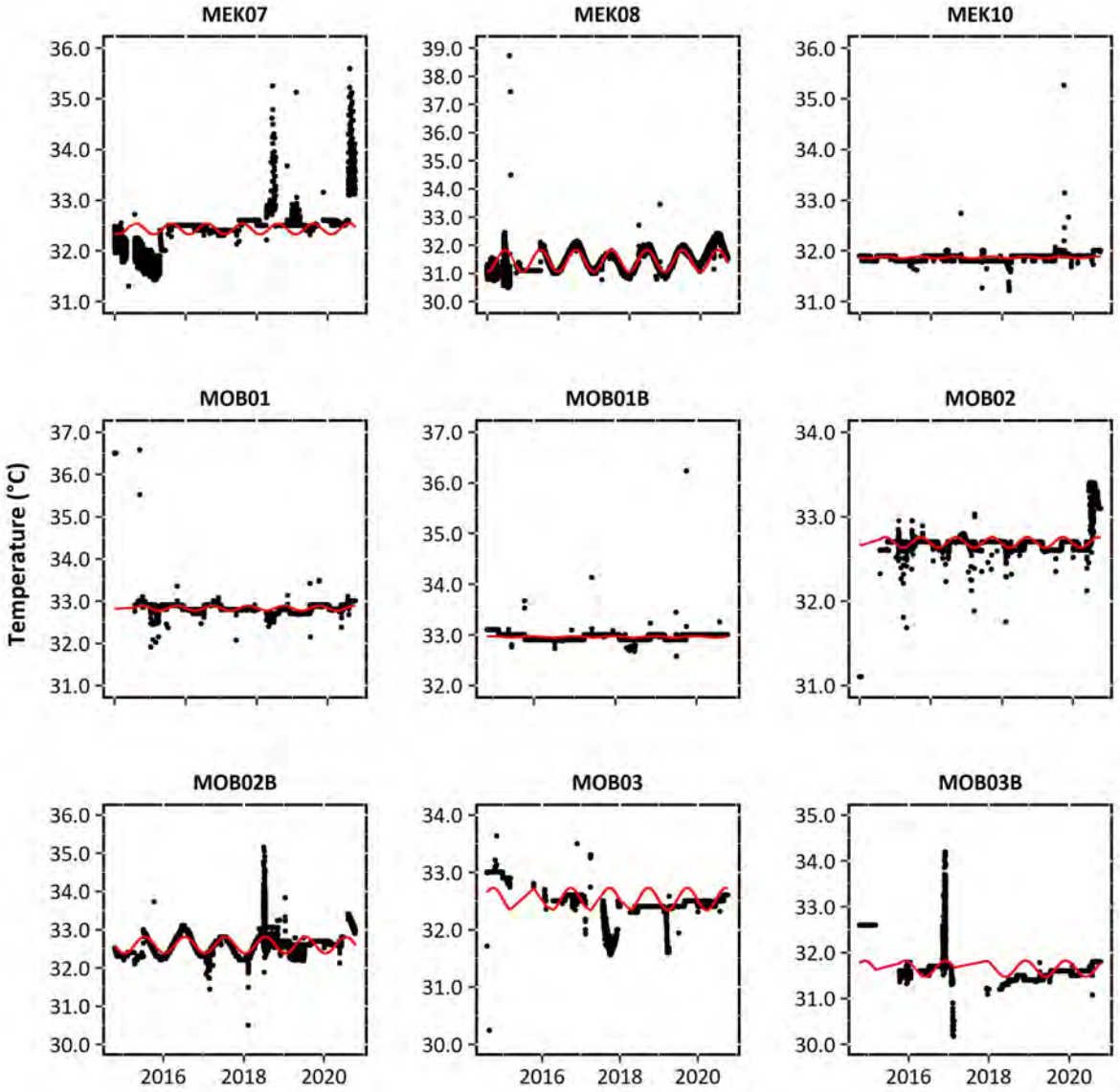


Figure C4: Plotted temperature data from each subterranean probe (MEK07 to MOB03B). Red line indicates the best fitted sinusoidal curved based on an annual cycle.

Humidity

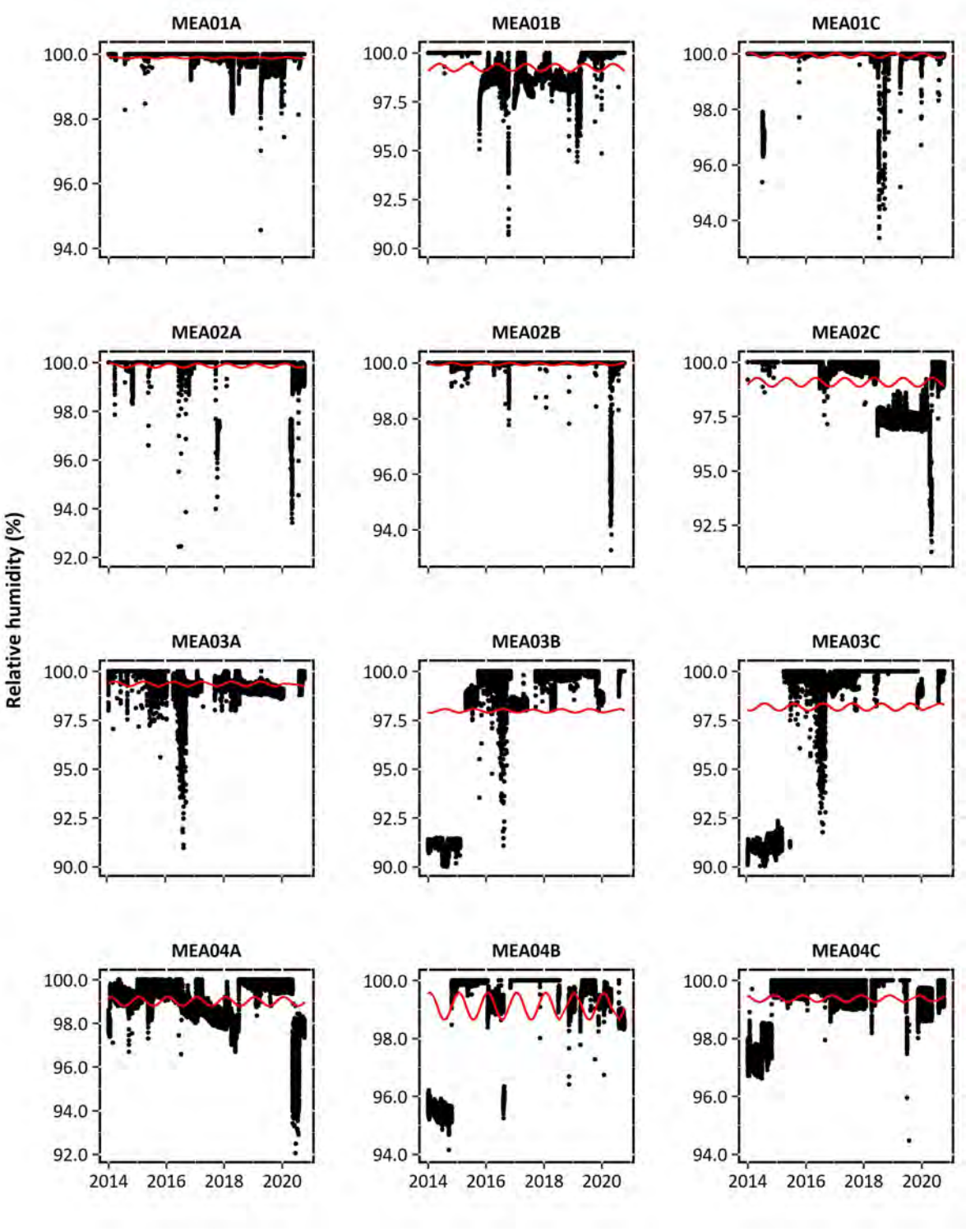


Figure C5: Plotted humidity data from each subterranean probe (MEA01A to MEA04C). Red line indicates the best fitted sinusoidal curved based on an annual cycle.

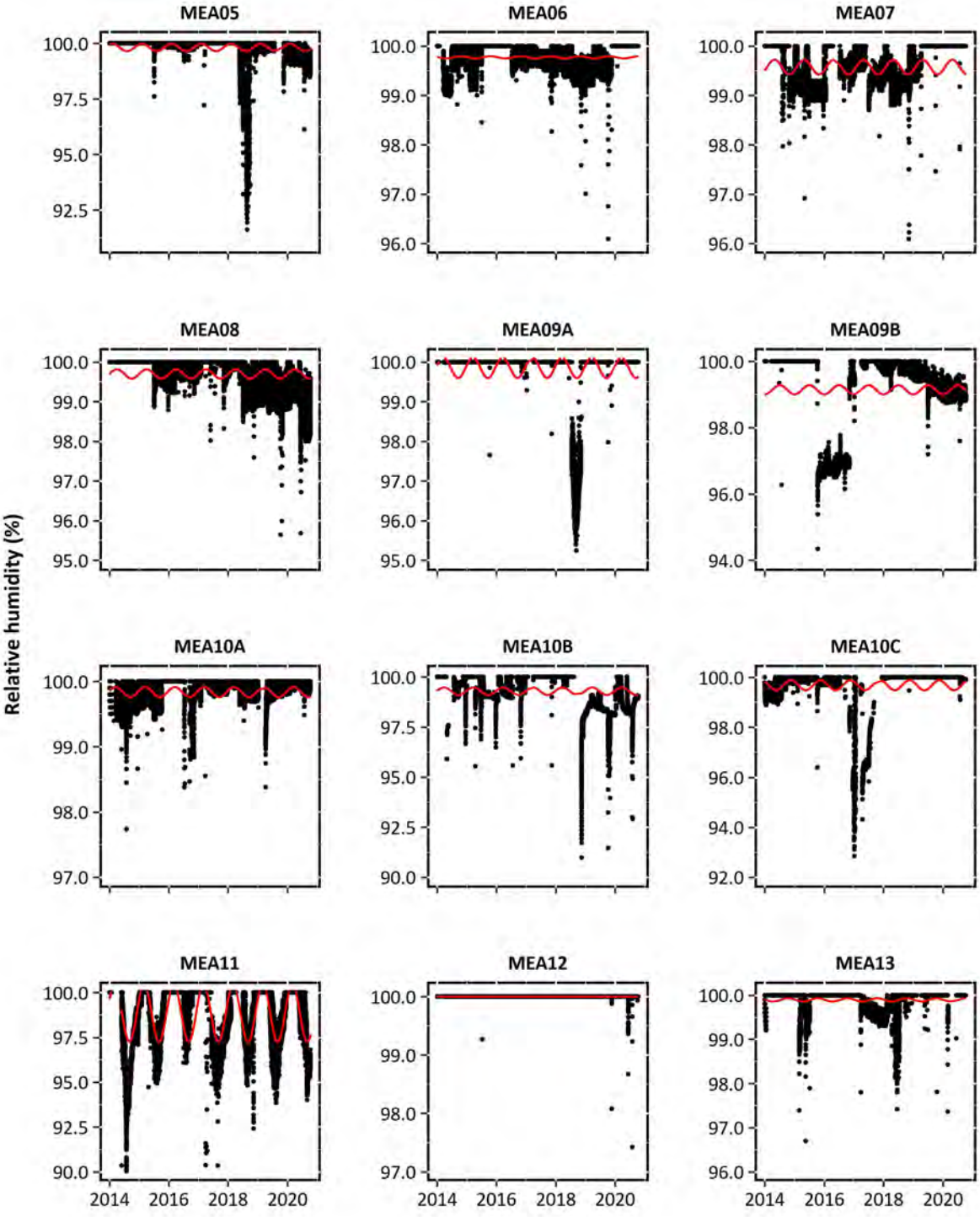


Figure C6: Plotted humidity data from each subterranean probe (MEA05 to MEA13). Red line indicates the best fitted sinusoidal curved based on an annual cycle.

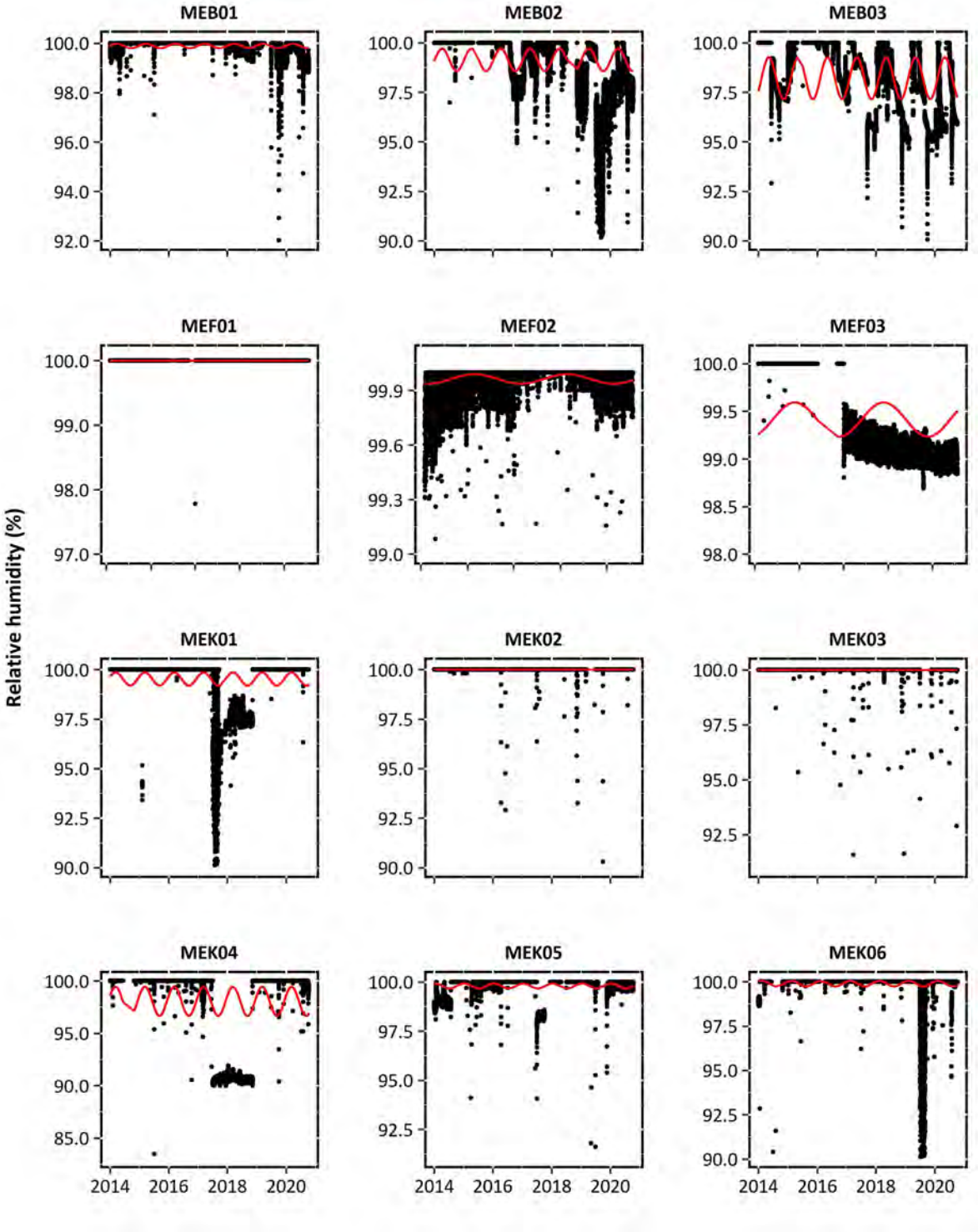


Figure C7: Plotted humidity data from each subterranean probe (MEB01 to MEK06). Red line indicates the best fitted sinusoidal curved based on an annual cycle.

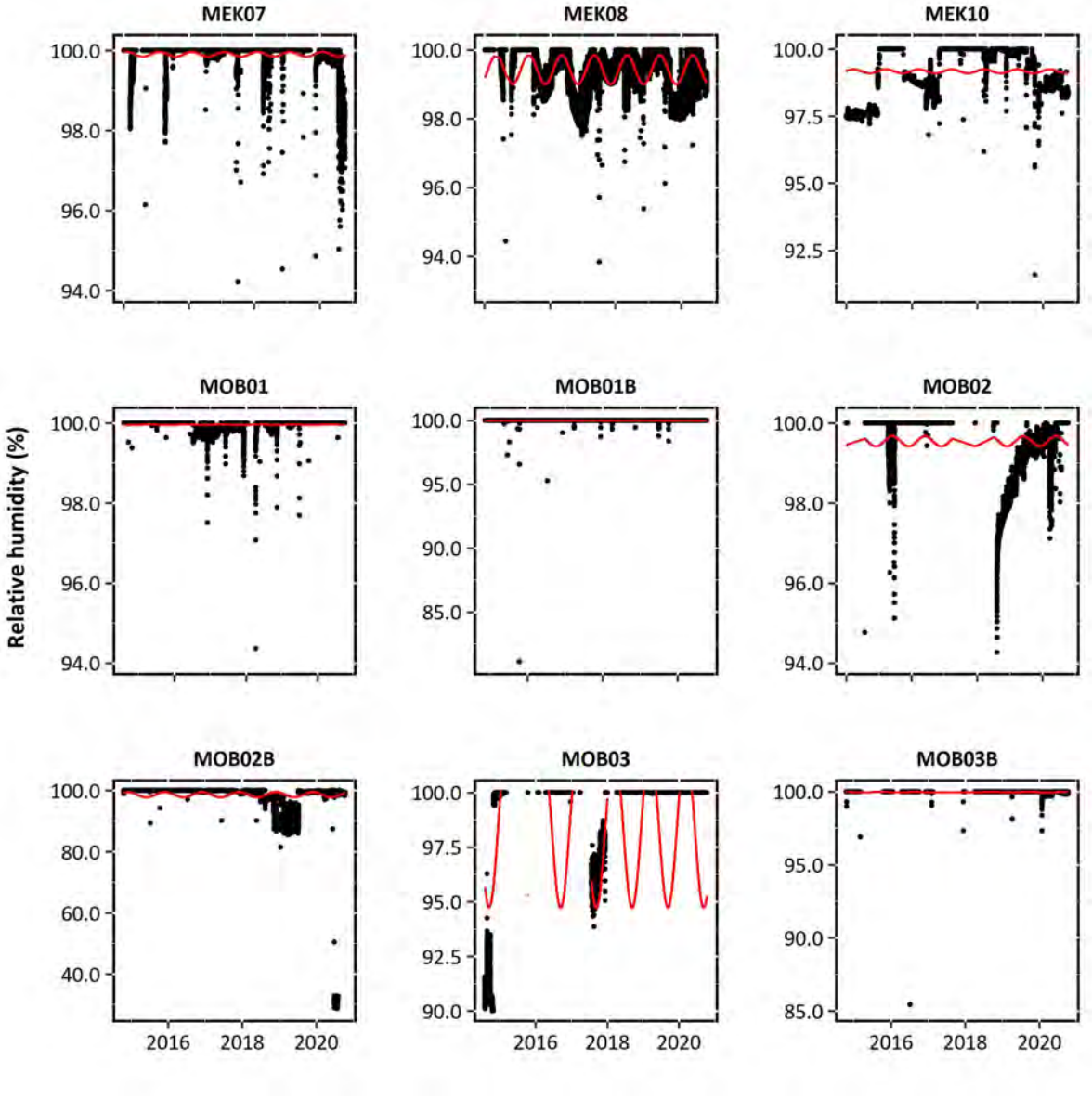


Figure C8: Plotted humidity data from each subterranean probe (MEK07 to MOB03B). Red line indicates the best fitted sinusoidal curved based on an annual cycle.

Carbon Dioxide

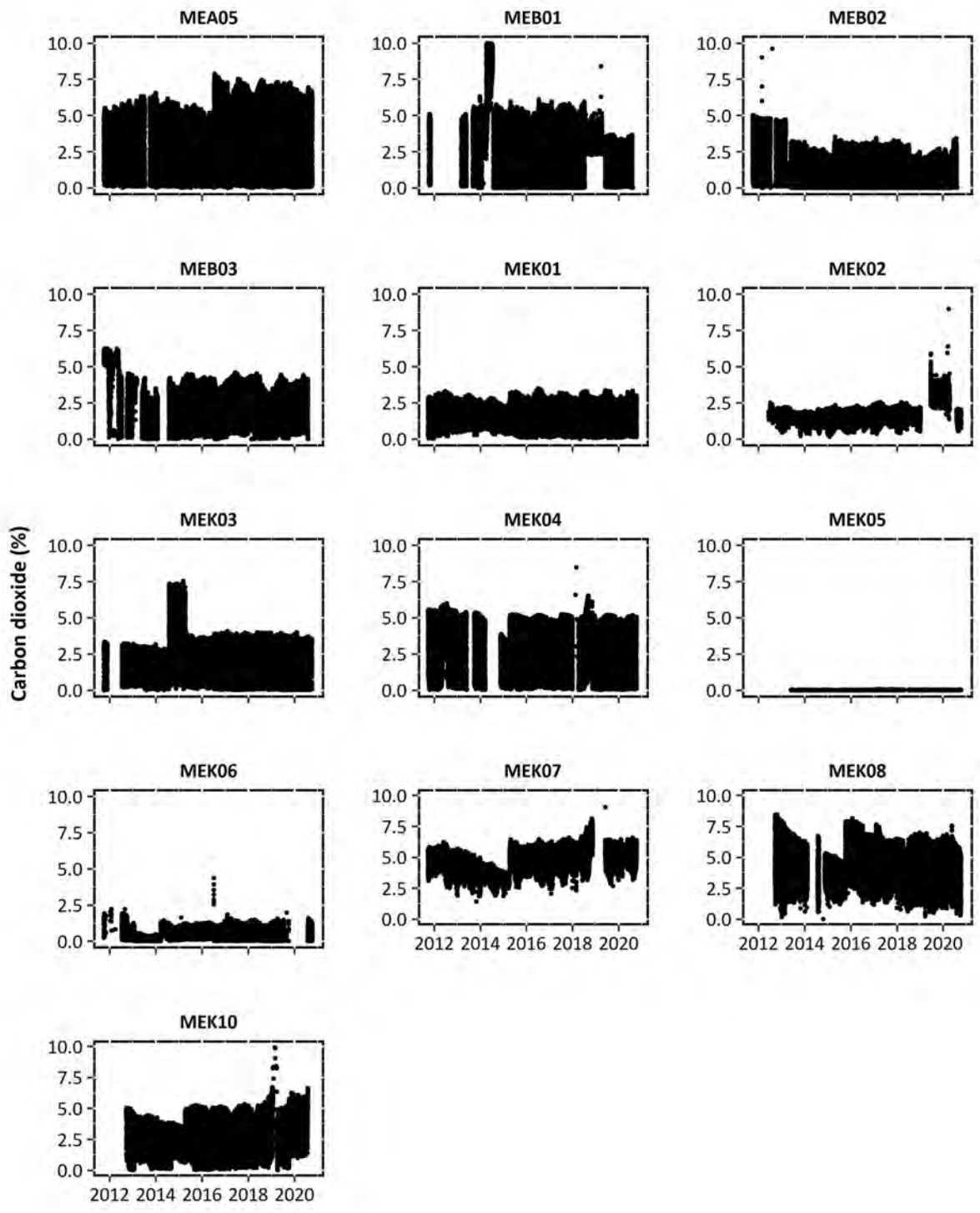


Figure C9: Plotted carbon dioxide data from each subterranean probe.

This page has been left blank intentionally.

Appendix 3

Baseline troglofauna capture rates for Mesa K

Table A2-1 shows the troglofauna capture rate per 100 trapped holes at Mesa K. Seventeen sampling events over a 17-year period are shown. All troglobitic specimens (including indeterminate specimens) have been included for completeness in the calculations.

Mesa K	Baseline (Pre Remnant Mining)				During Remnant Mining														
Sample collection date	**Apr-05**	**Jun-06**	**Oct-06**	**Jan-07**	**Oct-10**	**Oct-11**	**May-12**	**Sep-13**	**Jun-14**	**Jun-15**	**Jul-16**	**Dec-16 / Jan-17**	**Jul-17**	**May-18**	**Jul-19**	**Jul / Aug-20**	**Jun-21**	**Jul-22**	**May-23**
Number of trapped holes	12	34	45	44	30	33	33	32	29	24	31	10	37	35	45	43	35	54	53
Number of scraped holes	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	31	37	31	5	35	30	21	38	35	42	52
Number of specimens collected via trapping and scraping	13	68	54	16	19	47	77	46	66	77	62	3	44	184	47	121	147	204	908
Number of specimens collected via trapping	13	68	54	16	19	47	77	46	57	67	40	3	7	154	43	95	131	16	291
Number of specimens collected via scraping	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	9	10	22	0	37	30	4	26	16	188	617
Number of specimens per 100 trapped holes	108	200	120	36*	63	142	233	144	197	279	129	30	19	440	96	221	374	30	549
Number of specimens per 100 scraped holes	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	29	27	71	0	106	100	19	68	46	448	1187
Number of specimens per 100 trapped and scraped holes	108	200	120	36	63	142	233	144	228	321	200	30	119	526	104	281	420	378	1713

* minimum baseline troglofauna specimen capture rate