Government of **Western Australia**
Department of **Water and Environmental Regulation**

# Murujuga Rock Art Monitoring Program: Independent peer reviews of *Monitoring Studies Report 2023* and supporting documents

Department of Water and Environmental Regulation

May 2025

Department of Water and Environmental Regulation
Prime House, 8 Davidson Terrace
Joondalup Western Australia 6027
Locked Bag 10 Joondalup DC WA 6919

Phone: 08 6364 7000
Fax: 08 6364 7001
National Relay Service 13 36 77

dwer.wa.gov.au



May 2025

24250289



**Acknowledgements**

The Department of Water and Environmental Regulation recognises the Traditional Owners and Custodians of Murujuga; the past, present and future generations of Ngarda-Ngarli, and their ongoing connection to this sacred country. All aspects of the program will be conducted with respect for, and be guided by, the cultural law, knowledge and practices of the Circle of Elders, Traditional Owners and Custodians of Murujuga.

The Murujuga Aboriginal Corporation and the Department of Water and Environmental Regulation jointly oversee the implementation of the Murujuga Rock Art Strategy.



This publication is available at our website www.wa.gov.au/dwer. Please contact the department to arrange access to alternative formats including video, audio, large print and Braille.

# Contents

# Background

The Murujuga Rock Art Monitoring Program (the program) will monitor, evaluate and report on changes and trends in the integrity or condition of the rock art and determine whether the rock art is being subject to accelerated change; specifically, whether anthropogenic emissions are accelerating the natural weathering, alteration or degradation of the rock art. The program will underpin the environmental quality management framework (EQMF) for managing environmental quality to protect the rock art on Murujuga. This will enable timely and appropriate management responses by the State Government and stakeholders to emerging issues and risks.

The program is a joint initiative of the Murujuga Aboriginal Corporation (MAC) and the Department of Water and Environmental Regulation (the department). It is being delivered by Calibre Professional Services One Pty Ltd[1] (Calibre) and Curtin University (Curtin), with the assistance of consultants from ArtCare, University of Wollongong, University of Melbourne, and L & K Engineering.

Reports and documents produced as part of the program are subject to independent peer review by experts of national and international reputation in relevant fields. Independent peer reviewers are engaged by DWER, in consultation with MAC. The department and MAC are jointly responsible for overseeing MRAMP, with MAC providing cultural and heritage expertise.

This document collates the peer reviews completed in 2022 and 2023 for the following documents:

- *Murujuga Rock Art Monitoring Program: Monitoring Studies Report 2023* (referred to within this document as the 2023 Technical Report)
- Murujuga Rock Art Monitoring Program: Passive Sampling Tube Evaluation and Testing Report (2022) (Section 2)
- Murujuga Rock Art Monitoring Program: IVL Passive Sampler Characterisation Study (2023) (Section 2)
- Methodology Statements for component studies, as referenced in Table 2.1 of the Monitoring Studies Report 2023 (Section 3).

All comments are those of the independent peer reviewer and may not reflect the views of the department or MAC. The department has only edited the content of reviews where required to correct minor errors or clarify issues arising and therefore references to page numbers and section numbers may have changed in the published documents. The methodology statements (Section 3) have not been published; however, they will form the standard operating procedures for the ongoing monitoring program.

[1] Calibre was acquired by WSP in June 2023

# 1 *Murujuga Rock Art Monitoring Program: Monitoring Studies Report 2023*

## 1.1 Dr António Batarda Fernandes (2023)

| | |
|---|---|
| **Document title** | **Murujuga Rock Art Monitoring Program: Draft Technical Report (March 2022 – March 2023) (Including ADDENDUM: Murujuga Rock Art Monitoring Program DRAFT Technical Report: Corrections to Rev D provided 16/05/2023)** |
| **Document revision** | **COPP21065-REP-G-101** – Version D (3 May 2023) |
| **Reviewer** | **António Batarda Fernandes** |
| **Date of review** | 18 September 2023 |

| Item no. | Section | Peer reviewer comment<br>18 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>11 November 2023 |
|---|---|---|---|---|---|
| 0 | General / overarching comments | An overarching initial comment is that the overall study project is en route to gather valuable data to attempt answering research questions, namely, the quintessential one: does pollution from industrial activities negatively impact the conservation of the Murujuga rock art? It may be that at the end of the current project assembled data indeed allows drawing relevant insights that may help answering research questions, even if some subsets will authorise more solid assumptions than others. However, both the data and inferred conclusions are permanently subject to revision, due to data that, hopefully, will keep on being collected at Murujuga, as well as treated and interpreted, after the current project is over. The longer data is collected, the sturdier will be inferences towards resolving research questions. | Agreed. | - | - |
| 1 | General / overarching comments | It was found that throughout the 2023 Technical Report, and specially throughout some methodology statements, it is not clear the instances in which collected rock samples, for different purposes (microbiome or patina and weathering rind studies, for instance), were taken, or not, from rock art panels. Also, if so, if rock art motifs were affected. Such instances should be summarised in the 2023 Technical Report, and the cases in which samples were taken from rock art panels, if at all, justified. | As stated in the *Murujuga Rock Art Monitoring Program: Monitoring studies data collection and analysis plan* (MSDCAP) Section 3.3, “All samples have been selected under guidance from Murujuga Elders, Rangers and archaeologists”. In addition, approval for all works was obtained from the Western Australian Department of Planning, Lands and Heritage under regulation 10 of the Aboriginal Heritage Regulations 1974. This approval required us to demonstrate that sample collection would not impact any rock art panels and furthermore any cultural heritage sites or values. No microbiome or other laboratory samples were collected from rock art panels. Ongoing, non-invasive (see MSDCAP Section 3.2) studies on rock art panels, are limited to photography/spectrometry, pH (potential of hydrogen), Eh (oxidation-reduction potential), Cl | So, the separate heritage report will not be made public? I understand that this falls outside the scope of the present review but can a version of this report be made public, eventually with rock art images and precise locations edited out. Would that be amenable/useful?<br>I understand what is stated in the MSDCAP and that the present report should be read together with that document. My concern, also understanding that the present report is to be made publicly available, is that it should be completely clear in all instances and outputs of the overall project that a rock art non-invasive methodology was strictly adhered to.<br>See also comment 6 below. | No, MAC has requested the heritage report remain confidential to protect MAC’s cultural intellectual property.<br><br>**Additional comment from MAC and DWER**<br>The heritage report referred to in the peer review includes culturally sensitive images and descriptions of rock art that senior knowledge holders have not consented to release in a public forum. |

| Item no. | Section | Peer reviewer comment<br>18 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>11 November 2023 |
|---|---|---|---|---|---|
| | | | (chlorine), and pXRF (portable X-ray fluorescence) measurements. In general, samples referred to in MSDCAP Section 3.3 for microbiome and other laboratory analyses were collected from locations at least 25 metres (m) distance from any rock art panels or other cultural heritage site. This information and precise locations are detailed in a separate heritage report which MAC has not consented to release. | | |
| 2 | General / overarching comments | Akin to the previous comment, it is not clear the cases in which rock art panels and motifs were touched, and to what extent, during measurements in the different dimensions under study. Even if it is admissible to touch rock art panels for research purposes, namely regarding its conservation (but do see Kolber 2019), it should be clearly documented the instances in which there has been the need to touch rock at panels and motifs, and why. | See above. | See above. | - |
| 3 | General / overarching comments | Besides a more detailed comment regarding the JAZ instrument (portable spectrometer for rock surface colour measurement) below, there is a general comment regarding the relatively high number of cases of instrument malfunction in different dimensions of the study. The question here is if more reliability can be conferred to instrument functioning… | This has been addressed in two ways. In the short term an on-site spectrum integrity validation protocol has been introduced to ensure that viable spectra are collected for all targets at each site. Where the spectra don't pass the measurements are repeated.<br>Going forward a second Ocean Insight spectrometer will be introduced, comparable to and calibrated to the JAZ. The next campaign will have both run together to ascertain whether the unreliability is instrument specific or due to environmental or operational excesses. | I agree that the introduction of a second Ocean Insight spectrometer will help to confer more reliability to rock surface colour measurement. However, issues regarding overall instrument (mal)functioning remains. | Comprehensive characterisation of the existing instrument is underway. |
| 4 | General / overarching comments | Figure number referencing is, on occasions, missing from the text. Moreover, the links from text to figure are not correct in some cases. An example of such is provided below (comment 7). | Calibre will fix the figure numbers and the table of contents. | Apparently, each section of the 2023 Technical Report now begins with a non-numbered or labelled figure. Is this intended? | Neither Calibre nor Curtin could see "non-numbered or labelled figure" at the start of each report section. We asked DWER to clarify with the reviewer. Below is his response:<br>"Since I based my close out reviews from reading the word file (as changes are highlighted and it is easier to check them), what I stated in those close out reviews is valid for the word file only. Going through the PDF file, I note that what I mentioned regarding the word file does not apply to the PDF.<br>I commend you for identifying further issues as noted in your email and recommend careful further checking of all the documents' PDF versions to avoid such issues. Even if they do not prevent a correct understanding of the |

| Item no. | Section | Peer reviewer comment<br>18 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>11 November 2023 |
|---|---|---|---|---|---|
| | | | | | text, they can be a source of unwanted misperception by readers." |
| 5 | General / overarching comments | The documents have not been extensively checked regarding grammar and spelling. However, a few typos have been identified suggesting further checking. | DWER and other reviewers have identified numerous grammar and spelling mistakes. These have been fixed. The full document has been checked by Curtin and will be checked by Calibre. | Careful checking should be continued to be enforced. | Agree. |
| 6 | Executive summary | Paragraphs 3, 4 and 5 are examples of what is noted in comments #1 and 2 is not clearly addressed. It is understood that an Executive summary must be concise and to the point. However, a brief note of how what was previously established (namely in the MSDCAP) regarding non-invasive sample collection in rock art panels should be added. | The Executive summary has been expanded to address these issues and those raised in 1, 2 item numbers above. | I believe the Executive summary* has not been expanded to address these issues and those raised in item numbers 1 and 2, as it reads, to this regard, akin to the previous version.<br>And it would be enough to add to the end of the sentence "(…) Murujuga Aboriginal Corporation (MAC) Elders for inclusion in the Program." something along these lines: ", meaning that there wasn't any impact on rock art panels and cultural heritage sites or values."<br>*included in the docx. version of 20/10/2023. | A paragraph (new paragraph 3) has been added to the Executive summary to comprehensively address this. |
| 7 | Executive summary | Both figures in the Executive summary (Figures ES-1 and 2) are not linked to the correct position in which they appear in the 2023 Technical Report. | Calibre will fix this and the table of contents. | See comment #4. | Executive summary figure numbering links to the Executive figure text correctly.<br>See comment #4. |
| 8 | Summary of key findings to date | It is noted as a key (preliminary) finding that *"*the observed relationships for the first two air pollutants are the reverse of what would be expected for a simple acid-deposition hypothesis*"*. In the carrying out of the current project, great care should be employed regarding data, and its interpretation, that can further confirm (or not) this statement, as it is a matter that other authors have examined, reaching, it is believed, somewhat different conclusions. That is the case of the work, cited in the present report, accomplished by Smith et al. (2022). | It is a key commitment of the project contract that all statistical analysis will be performed with the utmost care and adhering to the highest international standards. The statistical analysis reported in the 2023 Technical Report is confined to exploratory data analysis, which has the goal of validating data sources and identifying general features and apparent patterns in the data. It does not support any formal findings at this stage because the exploratory analysis does not take other factors into account. The quoted text is simply an observation that the pattern observed in the data in this case (in an exploratory sense, without accounting for other variables) appears to be the reverse of what might have been expected. | Noted the alteration of this passage in the revised report (docx. Version of 20/10/2023).<br>Regarding the question raised perhaps it is a matter of including this passage, partially taken from your response in the text of the section, stating something of the sort: "These are simply remarks regarding the patterns observed in the data in an exploratory sense." | We have added the following sentence:<br><br>"This unexpected negative association does not take account of other variables which may have been involved; it is purely an empirical association observed in the exploratory phase of data analysis; however, it merits close attention." |
| 9 | Summary of key findings to date | It is noted that *"*A specific focus will also be given to campaigns during dry times and the mechanisms which may occur in the atmosphere or on the rock surface during those times". Can a brief justification of the preference for a specific focus to be given in the future to campaigns during dry times be added? | Discrepancies between the observations in campaign 1 and the other campaigns were noted in several sections of the 2023 Technical Report. Possible explanations for these discrepancies were discussed in Section 7.2.2, page 125. Since campaign 1 occurred at the end of a very long dry period, while the other campaigns occurred after recent rain, one possible explanation is related to weather. In order to evaluate or eliminate this | Ok, but perhaps those notes included in other sections can be concisely added to this introductory section. | This section has been expanded to include this information. |

| Item no. | Section | Peer reviewer comment<br>18 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>11 November 2023 |
|---|---|---|---|---|---|
| | | | possible explanation it is necessary to conduct at least one additional campaign during or after a dry period. This was stated in Section 7.8.2 and Section 9. | | |
| | | | | | |
| 10 | Section 1.2 – Objectives of the MRAMP monitoring studies | It is noted that "may be involved in accelerating or preventing the degradation of the petroglyphs". It has been noted previously by this reviewer in the MSDCAP review that while this a highly commendable pioneering effort to determine if and how industrial emissions are involved in rock art degradation, notwithstanding agreeing that the other listed objectives are amenable and reachable, it is doubtful that "minerals, inorganic and organic chemicals, and microbes… involved in accelerating or preventing the degradation of the petroglyphs" can be identified in an isolated fashion (that is, that only contribute to acceleration or prevention) as these different dimensions constitute extremely intricate and interdependent systems and subsystems. | In general, we agree with this statement however the terms of the project contract include any measurable effect or response in the system which can be conclusively attributed to anthropogenic emissions or exposures. Studies may necessarily examine the system as a whole or isolated/simplified sub-components as necessary. | Ok, it will be quite relevant if the development of the project delivers data that may help to identify how isolated items precisely contribute to the acceleration or prevention of the degradation of the petroglyphs. | Agreed. |
| 11 | Section 1.4.3 - Glossary | Although a glossary should be succinct, it is believed that the provided definition for "lichen" should be developed, encompassing data regarding these organisms gathered in the 2010's (see Spribille et al. 2016). | The glossary has been updated. | Ok, but I believe there is a "to" missing in "thought occur". | Done. |
| 12 | Section 1.4.3 - Glossary | The entry "Patina" does not follow alphabetical order, so further revising reading this issue is suggested. | All glossary terms are now in alphabetical order. | Ok. | - |
| 13 | Section 1.4.4 - Site and sample numbering nomenclature | This could also (see comment #6) be an adequate place for a more detailed explanation regarding what was noted in comments #1 and 2 above. | A more detailed explanation as per above has been added to Section 1.4.4. | Ok, although I believe in the paragraph added at the end of page 15, "it's" should read "its". | Done. |
| | | | | | |
| 14 | Section 3.1.1 - Location of field monitoring sites | Although it is praiseworthy to note that "All sites and artifacts included in the Program were approved by the Murujuga Aboriginal Corporation's Circle of Elders.", it is believed that this information should be complemented with the explanation noted in the previous comment. | See above. | Ok, accepted. | - |
| 16 | Section 3.3.3 - Fieldwork outcomes | "The pXRF results collected in campaigns 1 to 4 may be sufficient for the study". Why? Does this sentence contradict what is said two paragraphs bellow: "the main concern is that these measurements are affected by seasonally varying weather, and measurements are missing for the driest season monitored to date season. | The pXRF results collected in campaigns 1 to 4 may be sufficient for the study, depending on whether a degradation-related signal can be recognised through the noise of natural variability and instrument precision. Further statistical | Ok. | - |

| Item no. | Section | Peer reviewer comment<br>18 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>11 November 2023 |
|---|---|---|---|---|---|
| | | Accordingly, the statistical team recommends that the upcoming second year of fieldwork should include field visits on four different occasions at the same time as those undertaken in the first year"? | analysis will be used to establish the signal: noise ratio. | | |
| 17 | Section 3.4.2 - Methodology | "There was no discrimination between the sampling of the varnish layer and the weathering rind layer. The surface of the rock was wet with sterile molecular grade water and a sterilised Dremel® tool was used to create a paste of the surface of the rock, which includes the varnish and up to a maximum of 1 mm of the weathering rind." What is meant by no discrimination? | Meaning the varnish layer and the weathering rind were sampled together. | Ok, consider substitute "discrimination" for "the patina* and the weathering rind were sampled together."<br>*As per your response to comment #19 | Amended. |
| | | | | | |
| 18 | Section 4.2.6 - Scanning electron microscopy and energy dispersive x-ray spectroscopy analysis | "… considering the nature of the lithologies, it is therefore reasonable to be expecting a wide variation of rock varnish thicknesses among the different rock types." This proposition should be adequately demonstrated, if confirmed, by data gathered in the development of this study. | As shown in the figures (e.g. Figures 4-10 to 4-15), observations so far using scanning electron microscopy confirm that the patina thickness varies both within and among rock types. Patina thickness varies from zero to several hundreds of microns. | Ok. | - |
| 19 | Section 4.2.8 - Comparison with previous work | Check for possible inconsistencies in the different passages, notably page 61 (paragraph 2) vs page 63 (preliminary finding #6), in which the terms "patina" and "rock varnish" are employed. It seems that these are used interchangeably and should not? | Through the 2023 Technical Report "rock varnish" has been changed to "patina", except when describing "patina". | Ok, checked. | - |
| 20 | Section - 4.4.3 Work to date | "It can be seen that the exposed rocks are initially much more acidic than the control rocks, however at the end the solution pH is equivalent." This proposition should be adequately demonstrated, if confirmed, by data gathered in the development of this study, namely taking into consideration what is discussed in Section 7.7.1 - Validation of pH observations. | This statement refers to the chamber studies results and is confirmed by the data shown in Figure 4-25 and is not intended to refer directly to exposed rocks in the field, which is the topic of Section 7.7.1.<br>There are major differences between rocks in the field and the chamber studies rocks, as well as the nature of exposure, so the results are not directly applicable – instead they are intended as the basis of a dose-response understanding of the system. | Ok. While I understand that this was referring to chamber studies, consider make this explanation available in this section. | An expanded explanation has been added to the text. |
| | | | | | |
| 21 | Section 6.2.3 - Global navigation satellite system (GNSS) datum point | "… and was installed as a short star picket or steel spike in the ground that will be permanent for the duration of the Program." Are they subject to displacement (due to vandalism, or animal interference, for instance)? And if so, does it matter? | These control points are considered semipermanent. They can be removed if required. Standard practice for permanent markers is to surround the top in concrete – however this is undesirable at Murujuga. It is unlikely they would move through natural processes and if relocated | Ok | - |

| Item no. | Section | Peer reviewer comment<br>18 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>11 November 2023 |
|---|---|---|---|---|---|
| | | | or removed through interference this can be determined via GNSS. | | |
| 22 | Section 6.2.4 - Local RTK control survey | "Because the true datum coordinates were unknown at this stage." Why? | There was no control or known points on site originally. Instead, a point had to be surveyed in using 2-hour GNSS observations. The observations were later processed using the online service AUSPOS run by Geoscience Australia. Rather than wait for the points to be processed and delaying the real time kinematic (RTK) survey (which would delay it by two weeks or more), an arbitrary coordinate was assumed to the datum mark on site (rough estimate using raw GNSS observations with +/-10 m accuracies). The RTK survey could then take place relative to this coordinate, and then adjusted with a block shift to move the arbitrary coordinates onto the true coordinates (based on the difference between the arbitrary coordinates and the processed coordinates of the datum point for each site). | Ok, consider including this explanation in the text. | This text has been added. |
| | | | | | |
| 23 | Section 7.1.2 - JAZ instrument | "The original manufacturer of the JAZ instrument has been acquired by another company, and the instrument is now discontinued from production and sale." Also considering that expert support for the instrument is no longer provided, won't this negatively impact measurement's reliability and repeatability? Shouldn't a different apparatus from a different supplier be considered to be used in the remainder of the project? | The JAZ has been discontinued, however the supplier, Ocean Insight, offers several comparable instruments using identical componentry in a less portable format. A second instrument has been acquired and will be deployed from November 2023 onwards. It is more reliable to remain with the same manufacturer rather than switch to a technology with differing hardware and acquisition protocols. The new instrument will be calibrated to the JAZ and both will be deployed in the November 2023 campaign to determine the cause of less than optimal results. The failure of the JAZ is a failure to acquire spectra rather than the acquisition of unreliable spectra. | Ok. See also comment #3. | - |
| 24 | Section 7.1.9 - Analysis Results – Data acceptance and validation | This whole subsection points to the conclusion of a reasonably high rate of unreliable data that has been collected. Considering that it is noted in the Executive summary - Summary of key findings to date that "spectral measurement of rock art condition remains a promising approach" special care must be employed in the further development of the project to ensure validity and reliability of gathered data, in all dimensions of the study, but especially regarding photospectrometric colour change measurement. | The project has already implemented a verification protocol from June 2023 that allows the operator to validate the spectra in-field. This allows for the re-acquisition of non-viable spectra to ensure that a full set of targets at each site is acquired. The unreliability of the JAZ is difficult to explain and hence rectify. It has been shown to operate perfectly reliably in the MAC office on days when it has returned sub-optimal results in the field. The unreliability is perplexing in that failures are for an entire set of target readings, | What is noted in your response is troublesome as it reiterates the unreliability of (some) JAZ readings. However, if the sets of target readings that "returned" sub-optimal results have later been able to rectify, by acquiring optimal readings in subsequent visits to the sites, the impact of this issue can be largely controlled, although in a further time-consuming fashion.<br>However, the pointed above (as well as in comment #23), and the need "to | We are now pursuing an even more detailed investigation of the performance characteristics of the JAZ instrument. We have conducted a series of controlled experiments involving exposure of different parts of the system to elevated temperatures under controlled conditions. We have obtained a newer version of the JAZ instrument and are conducting cross-calibration experiments in the field. |

| Item no. | Section | Peer reviewer comment<br>18 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>11 November 2023 |
|---|---|---|---|---|---|
| | | | with the previous and following targets returning consistent results. | ensure validity and reliability of gathered data, in all dimensions of the study, but especially regarding photospectrometric colour change measurement" recommends testing devices produced by different manufacturers? | Further detailed investigation will continue until we are satisfied. |
| 25 | Section 7.2.1 - Background | While it was an adequate strategy to include in the project the measurement of pH on rock surfaces, if this dimension is to contribute effectively to the study, special care must be employed to assure validity and reliability of gathered data. | Agreed – since the 2023 Technical Report the inorganic team has been working to employ techniques that increase the response time and precision of field pH measurements by addition of an ISA (ionic strength adjuster). | Ok. | - |
| 26 | Section 7.6.1 - Correlations between pollution exposure and rock condition | Considering that "Any observed correlations cannot be declared 'statistically significant' using this exploratory analysis. This interim analysis will be discarded once the full suite of data from the chamber experiments and the air quality monitoring is available." And that benefits of conducting such an exercise appear to be limited ("For example, this interim analysis may indicate which gas species are likely to be involved in the causal pathways leading to the degradation of rock patina."), is it worthwhile to include this "interim approach" in the study, namely considering that it "will be discarded once the full suite of data from the chamber experiments and the air quality monitoring is available"? This comment especially considers the potentially argumentative nature of pH impact on the degradation of the rock art, as well noted concerns in using it as an indicator (see comment #30). | I assume this reviewer is arguing for the removal of the entirety of Section 7.6. This section provides analysis that can be followed up in later analysis as more data is collected and provides the initial context for the later analysis. Other reviewers have noted the Ramboll data likely provides a lower bound on the variability in reality and also provides a good one dimensional test for associations with other data such as the pH. Collected gas data will also be compared to the Ramboll data to determine the accuracy of these initial gas predictions in terms of both patterns and quantifying exposure. | Ok, agreed that it is helpful to keep this section on the Ramboll interim approach. | - |
| 27 | Section 7.8.1 - Field measurement of colour | "The protocol developed and adopted for this study has eliminated many of these concerns." So is the magnitude of remaining concerns sufficient to assure the validity of colour measurement results? | The colorimetry procedure is still undergoing careful scrutiny and data validation. At this stage we expect that the colorimetry procedure will be found to be acceptable, subject to certain conditions. The team is not ready to state such conditions precisely, but they will probably include limitations on the wavelengths to be analysed, and conditions on the field operation. | Ok. | - |
| 28 | Section 7.8.1 - Field measurement of colour | "It would also be advantageous to update the JAZ instrument (which is no longer supported by the manufacturer), replacing it by its successor models which have a more accessible software interface..."; "If a new model of spectroscopic sensor is adopted, then the statistical team strongly recommends an experiment to cross-calibrate the two models, in which both sensors | Implemented, however it remains to be established that the unreliability of the JAZ is unique to this instrument or the result of the extreme operating conditions equally affecting any other instrument. | Indeed. See also comments #23 and 24. | - |

| Item no. | Section | Peer reviewer comment<br>18 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>11 November 2023 |
|---|---|---|---|---|---|
| | | are used in the field to measure the same targets."<br>Strongly agreed. | | | |
| 29 | Section 7.8.5 - Ramboll model | "A simple analysis of the Ramboll model outputs, based on annual averages and annual maxima at each spatial location, supports the approach taken in this study, and militates against the idea of treating any site as a 'control'." When gathered data leads to the discard of the interim approach, will this approach continue to be validated? It is noted that while an interesting approach, it is believed that a surrogate strategy such as the Ramboll model does not permit solid conclusions regarding treating, or not, any site as a "control" … | This has been discussed at length in the original research proposal. Since the research team does not have control over the amount of atmospheric NOx, SOx and other gases to which each site is exposed, there are no "control" sites as a matter of principle. A site should not be treated as a control unless it can be guaranteed to have zero exposure. The Ramboll model predictions, while they are only predictions, militate against this assumption. It is in any case unnecessary to assume that control sites exist. The regression approach taken in this study is more general than the "control vs treatment" approach.<br>The statistical modelling and analysis will be undertaken to the highest international standard. This includes model criticism and model validation which will enable scrutiny of all assumptions of the model and will include evaluation of potential weaknesses of the analysis. | Ok. | - |
| 30 | | "Additionally, there are concerns held by the majority of the scientific team as regards the use of pH as an indicator." Again, this must be satisfactorily argued for, and, ideally, established, as other researchers have used pH as an indicator of industrial pollution impact on Murujuga's rock art (Smith et al. 2022). Although this work is cited in the 2023 Technical Report, the relevance of its findings is not exhaustively addressed presently. While it is understood that gathered data is still insufficient to allow addressing them thoroughly, it is precisely important not to present preliminary findings in such a way that it strongly suggests ruling out any indicator, namely pH, in the further carrying out of this research program… | Concerns around pH relate to three main issues:<br>1. The lengthy time taken for equilibration with the rock, so that the pH measured by this study and previous studies is at best, a measure of only the most rapid reactions between water and rock, and at worst, a measure of the pH of distilled water equilibrated with carbon dioxide ($CO_2$) (around 5.6).<br>2. Previous methods used inconsistent amounts of water. The methods state "a few drops" which, while having the advantage of maximising the concentrations of any rock-derived solutes, leads inevitably to issues in summer when small amounts of water evaporate instantly, and potentially leading to a seasonal bias on results. Further, the use of small amounts of water on hot rocks leads to constantly changing concentrations as the water evaporates which exacerbates the issues with equilibration noted above.<br>3. Previously stated trends based on Bednarik and coworkers, and used by Smith, Black and others, do not show a good understanding of the fundamentals of water-atmosphere interactions. For example, rainwater in arid areas is stated to have had a pH of 6.8 in | This is obviously a highly complex matter, as several of the variables analysed by this project, and I appreciate your efforts to resolve issues regarding pH, also acknowledging other reviewers' reserves on its use as a pollution indicator.<br>However, noting that this might be a matter of further debate involving other parties also concerned with and interested in Murujuga rock art preservation and conservation, I reiterate the need to deliver solid conclusions regarding what can and cannot be measured regarding pH and pollution. Perhaps the project will be able to surmount pointed issues, namely regarding season variability.<br><br>In any case, I continue to emphasise that it is "important not to present preliminary findings in such a way that it strongly suggests ruling out any indicator, namely pH, in the further carrying out of this research program". | We agree that it is important not to rule out any indicator, including pH, at this stage.<br>Additionally, given its inclusion in previous studies, and its use as a basis for strong conclusions by previous workers, there will be a comprehensive review of the value and limitations of the technique. |

| Item no. | Section | Peer reviewer comment<br>18 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>11 November 2023 |
|---|---|---|---|---|---|
| | | | previous studies, but rainwater should actually be around 5.6 because the rain equilibrates with CO2 in the atmosphere to form a weak carbonic acid. The small number of analyses of pH values of 6.8 (8 analyses) were made in the 1970s, and it is acknowledged that lightning-derived ammonium might be increasing the pH of those samples. It's a concern that so many subsequent workers have used these data without checking the validity of the source.<br>Our methods avoid the problems inherent in 2., but the issue of what, exactly, is measured remains. It is likely that the measured pH relates to a subset of the rock–fluid interactions that control stability, and include mineral–fluid, microbiome–fluid, and air- or dew-deposited species–fluid interactions. The systems that reach partial equilibrium in the two minutes of pH measurement may vary seasonally. | | |
| | | | | | |
| 31 | Appendix B-2 Target selection and re-establishment | "The 19 rock art surfaces at the RS sites were required to have target areas selected randomly." Why? | As stated in the original project proposal, the RS sites are chosen so as to provide a valid representative sample (in the sense of survey sampling) of the population of rocks on the entire peninsula. This enables us to make statistical inferences about the entire peninsula. | Ok. | - |

**References in peer review**

1 Kolber J (Ed.) (2019). Celebrating the life of John Clegg: Touching rock-art can be a touchy subject. In J Huntley and G Nash (Eds.) *Aesthetics, Applications, Artistry and Anarchy: Essays in Prehistoric and Contemporary Art. A Festschrift in honour of John Kay Clegg: 11 January 1935 – 1 March 2015*. Archaeopress, pp. 143-157.

2 Smith BW, Black JL, Hoerlé S, Ferland MA, Diffey SM, Neumann JT and Geisler T (2022). The impact of industrial pollution on the rock art of Murujuga, Western Australia. *Rock Art Research,* 39(1):3-14.

3 Spribille T, Tuovinen V, Resl P, Vanderpool D, Wolinski H, Aime MC, Schneider K, Stabentheiner E, Toome-Heller M, Thor G, Mayrhofer H, Johannesson H and McCutcheon JP (2016). Basidiomycete yeasts in the cortex of ascomycete macrolichens. *Science*, 353(6298):488–92 doi: 10.1126/science.aaf8287.

## 1.2 Professor Geoffrey Gadd (2023)

| | |
|---|---|
| **Document title** | **Murujuga Rock Art Monitoring Program: Draft Technical Report (March 2022 – March 2023) (Including ADDENDUM: Murujuga Rock Art Monitoring Program DRAFT Technical Report: Corrections to Rev D 16/05/2023)** |
| **Document revision** | **COPP21065-REP-G-101** – Version D (3 May 2023) |
| **Reviewer** | **Geoffrey Michael Gadd** |
| **Date of review** | 15 September 2023 |

| Item no. | Section | Peer reviewer comment 15 September 2023 | MRAMP team response 23 October 2023 | Peer reviewer close-out comment 30 October 2023 | MRAMP close-out response 10 November 2023 |
|---|---|---|---|---|---|
| 1 | General / overarching comments | An extensive well-presented report has been provided supported by detailed methodology statements. A large amount of data has been collected in certain areas of the investigation, and some preliminary conclusions have been drawn in certain areas. Most work is ongoing as are analyses of some data already obtained. Some unanticipated problems have been encountered which has necessitated steps to circumvent them including amendment of the future research plan. The 2023 Technical Report naturally separates the research areas comprising the overall plan but there is rather low integration of findings between the different areas. This will probably improve as the work progresses. For example findings from organic and inorganic geochemistry and the microbiome studies might have obvious linkages. | Agreed. Microbiome and organics studies have yet to return the majority of results (at time of the 2023 Technical Report production), however we anticipate that the 2024 Technical Report will involve significant integration of these results and other datasets, such as air quality and inorganic geochemistry. | Accepted.<br>Integration of the results from different areas should lead to informed conclusions about what processes are occurring and their significance.<br>**The 2023 Technical report has been revised throughout with minor and more substantial corrections and additions. Any further comments I have on the 2023 Technical Report are minor and do not affect the project.** | - |
| 2 | Executive summary | The Executive summary is clear and accurately describes what has been achieved so far, detailing the number of fieldwork campaigns, numbers of samples of the various substrata, soil and biota, and numbers of measurements undertaken or in progress. It is clearly stated that the majority of studies are ongoing and summarises progress to report date submission. Some geological and mineralogical studies and air pollutant monitoring have provided useful information, but further work is still needed, and analyses are ongoing. Referral is made to atypical rainfall patterns over the sampling period which may necessitate some repetition of sampling in the future as well as certain analyses. | Taken as a comment. | Accepted.<br>As has been explained further work and analyses are ongoing, which are likely to involve some repetition of sampling in the future. | - |
| **Introduction** | | | | | |
| 3 | Sections 1.1 to 1.3 – Introduction | The Background is concise and clear concentrating on the work carried out over the first year of study and emphasising that many components are in progress and results are awaited. The full | 16S, internal transcribed spacer (ITS), metagenome and meta-transcriptome sequencing is being done on patina samples in triplicate from each of the sample rocks. In addition, we are | Accepted regarding the microbiome comment, where the molecular analyses will inform on the microbial communities present. Sequencing of the colonies is a routine identification procedure and will | 1. Bioweathering is acknowledged to be a possible component. We have added the term in the 2023 Technical Report to make it clear. We aim to assess the potential bioweathering of the |

| Item no. | Section | Peer reviewer comment<br>15 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | Background to the problem is located in previously produced documents.<br>Section 1.2 outlines objectives of the monitoring studies. I have some minor queries/points:<br>1. "…. with accelerated (anthropogenic) weathering". Weathering due to microbial or other biotic action (termed bioweathering) is not mentioned but could be an important component of the whole deterioration process.<br>2. Examples of which pollutant chemicals or what rock constituents will be used or analysed are not mentioned (though this might be explained in the methodological reports where I will insert any relevant comments about this in the review report form).<br>Section 1.3 Scope of this report: includes the report inclusions (Section 1.3.1) detailing the fieldwork, sampling and analytical measurements to be undertaken. One query:<br>Microbiome. only plate culture/isolation is mentioned with the sequencing/identification still ongoing. Metagenomic and other molecular approaches will be an important part of the microbiome studies, in view of the well known drawbacks of plate culture analyses. One other point is that many rock-inhabiting fungi, especially microcolonial species, are difficult to culture and can be very slow growing so may not be observed through classical isolation techniques.<br>Vegetation. "... vegetation types (both native and weed species) were collected for organic chemical Analysis ...". Although this is likely clearer in the relevant methodological report (where any relevant comments will be directed) I am unclear about what organic chemicals are relevant (there are potentially a huge number in any biota) or how the organic chemical composition of the plants might be connected with the overall rock deterioration problem. There is mention of plant volatiles: is there published information on the significance of this in terms of air composition, and in relation to industrial aerial pollutants?<br>Section 1.3.2 details the 2023 Technical Report exclusions which largely arise from incomplete and ongoing research, and equipment deployment. | sequencing 16S and ITS from the colonies that did grow on the plates, however we completely agree that this is only a very small subset of the microbes present on the rock. | only reveal what species may be successfully isolated using the cultural methods employed. It may be possible to match species names with published information on their capabilities for rock biodeterioration and the mechanisms involved, though for some it may not be possible unless some experimental work is carried out on their bioweathering potential.<br>Other queries/points are not answered.<br>1. Is bioweathering understood to be a potentially significant component?<br>2. Have examples of pollutants/rock constituents been mentioned?<br>3. No response to the vegetation comments here but some relevant points are answered below in the methodology statement. | communities through the metagenome and metatranscriptome data. With such a large amount of samples it is unviable for us to do culture experiments on the microbial isolates.<br>2. Pollutants/rock constituents. The chamber studies section and associated methods documents has expended commentary on this. Nitrogen dioxide ($NO_2$) is the dominant gaseous pollutant in the airshed, however all field and lab studies will analyse a range of pollutants. Metals or ions produced through acid/base dissolution of the rock will be the dominant process considered.<br>3. Vegetation questions – Vegetation types (both native and weed species) were collected for organic geochemical analysis. A range of lipids from plants will be investigated by GC-MS and compound specific isotope analysis to provide a characterisation of lipid distribution and isotopic signature across species growing in the sampling area. |
| 4 | Glossary | Some minor points:<br>Barcoding gene: other organisms also not just bacteria.<br>Biofilm: other organisms also not just bacteria | Barcoding gene: we added fungal ITS and eukaryotic 18S recombinant deoxyribonucleic acid (rDNA).<br>Biofilm: changed to microbial consortium. | Ok.<br>It was the sole use of "bacteria" not the word "biofilm" that was my point (all kinds of organisms can be in rock biofilms). | The Glossary has been updated. |

| Item no. | Section | Peer reviewer comment<br>15 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | Chemoautotrophic: it is manganese not magnesium.<br>Chemoautotrophic/chemolithotrophic: these terms mean the same thing (although there is much semantic confusion in the literature). Better to use chemolithotroph.<br>Weathering: as mentioned in previous review, degradation is a term not used for inorganic substances like rocks but for organic materials like wood. However, the detrimental implication on the substrata considered here is clear.<br>There is no referral to bioweathering here which is an important aspect of the studies to be conducted, where effects can include rock/mineral dissolution and biodeterioration as well as biomineralisation. | Chemolithotrophic/chemoautotrophic is now chemolithoautotrophs.<br>Weathering is now called bioweathering.<br>We agree that cultivation is highly selective and will only just show a fraction of what is alive. This was added later to the proposal as suggested by the reviewers. We will compare the plate cultures with 16S and ITS gene transcripts (complimentary DNA [cDNA]) | The 2023 Technical Report has been revised though the glossary does not adequately define weathering with no reference to biotic influences (bioweathering). | |
| **Study methodologies, verification of competency, and quality assurance** | | | | | |
| 5 | Section 2.1 | Summarises the methodologies employed clearly. | Comment noted. | - | - |
| 6 | Section 2.2 | Specialisms of the research team are listed and a training matrix has been developed to ensure competence with analyses. | Comment noted. | - | - |
| 7 | Section 2.3 | Quality assurance has been considered in depth including reproducibility of sampling and data obtained through analyses, experimental controls, and calibration of analytical equipment. | Comment noted. | - | - |
| **Monitoring Studies undertaken in the field** | | | | | |
| 8 | Section 3.1.2 | Presumably the dashes in Table 3-1 indicate that these samples were not taken. What was the reason for these omissions? (There is a mention of microbiome sampling in campaign 2 and not 3 later because of cooler weather.) | Sampling for microbiome was only planned to take place during the wet and dry season of year one. After the dry season, the rocks were transported to Curtin University for (in)organic geochemistry work. | Clarified. | - |
| 9 | Section 3.2 | Regarding vegetation, was it just above ground foliage that was collected? It is noted that samples were stored in storage bags pending analysis. Depending on timescale there could be some significant chemical changes occurring in the biomass. | Only above ground foliage was sampled.<br>Organic analysis has only been done on subsamples of each plant that were freeze dried and stored in airtight jars. | Clarified partly, but what was the timescale from sampling to freeze-drying? | Samples were stored in an airconditioned laboratory for 30-60 days before freeze-drying. |
| 10 | Section 3.3 | Similar point about soil collection and storage prior to analyses. Significant changes can occur depending on timescale and storage conditions. | The soil samples were collected for plutonium analysis. Plutonium (Pu) will not be affected by storage. | I do not understand the relevance of plutonium analysis or how this could provide any information on changes in soil chemistry and biology.<br>There can be marked changes in organic and inorganic soil components through storage depending on physico-chemical conditions, timescale and the microbiota. | The plutonium analysis is not intended to provide information on soil chemistry or biology. The objectives of the Pu work were to test three hypotheses: (1) that 239Pu was incorporated into soil at Murujuga; (2) 239Pu was incorporated into the patina that the petroglyphs are engraved into; and (3) there are differences in 239Pu levels among patina exposed to high and low amounts of industrial emissions (text from *Monitoring* |

| Item no. | Section | Peer reviewer comment<br>15 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | | | | *Data Studies and Analysis Plan*). To date, it is clear that (1) is correct, from previous work, but the spatial resolution necessary to test (3) is not, at the time of writing, available. |
| 11 | Section 3.4 | Microbiome. Note that the two agar media for bacteria and fungi are to some extent selective, i.e. not all bacteria or fungi will grow on them.<br>It is stated that controls were inoculated on Luria-Bertani plates – why not the tryptic soy agar (TSA) medium for the test isolations? | Agree, these plates will select for a small subset of microbes (mostly non-fastidious). We used the same agar media for samples and controls: Sabouraud agar plates with antibiotics for fungi and TSA for bacteria. In the initial version of the proposal we mentioned LB (liquid broth) but this has changed to the media described above. | Clarified. | - |
| 12 | Section 3.4.3 | Refers to surface bacteria only, but probably other organisms present too such as fungi. Microalgae do not appear to be considered but may also be present on rock surfaces where they may aid biofilm formation, and surface pigmentation, but causing little or no significant rock alteration. | Agree, “surface bacteria” is an incorrect way to reference these samples. They are more accurately “surface samples”.<br>Metagenome sequencing of the patina samples will give us a good understanding of all types of life on these rocks. | Clarified. | - |
| **Laboratory analysis of field samples** | | | | | |
| 13 | | I have no specific comments re: Sections 4.1, 4.2, and 4.4 | - | - | - |
| 14 | Section 4.3.1 | Microbiome – Objectives: should not read “the objectives of the inorganic geochemistry investigations”. | Agree. This has been addressed. | OK. | - |
| 15 | Section 4.3.3 | I am uncertain of the value of colony counts. Was there any specific aim to obtain microbial numbers? This is difficult for all groups. With fungi, spores can result in gross overestimates of their abundance/presence. | Agree, we will not be taking into account colony counts, we will only be looking at the 16S and ITS sequencing from these plates to identify what has grown. Please note that we did not plan to include any cultivation work because of these limitations. This was added later upon request from the external reviewers. We can get all this information far less biased from the parallel molecular studies. | OK, clarified. | - |
| **Air quality monitoring network establishment and operation** | | | | | |
| 16 | | I have no specific comments arising from Section 5 | Comment noted. | - | - |
| **Spatial mapping and surface modelling** | | | | | |
| 17 | | I have no specific comments arising from Section 6 | Comment noted. | - | - |
| **Statistical analysis of combined (dose/response) data** | | | | | |
| 18 | | I have no specific comments arising from Sections 7.1, 7.4 – 7.8. | - | - | - |
| 19 | Section 7.2.2 | The pH fluctuations/variability are thought to arise from seasonal effects or initial equipment operation/operator problems with some indication | One of the objectives of the study is to determine whether industrial emissions affect pH measurements. However, there | OK, clarified.<br>The 2023 Technical report has been amended in relation to the points raised. | - |

| Item no. | Section | Peer reviewer comment<br>15 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | that the latter may have occurred. This is clearly a problem to be clarified, possibly by further sampling campaigns in year two as the team suggests later.<br>Could industrial emissions also have affected pH measurements?<br>Another point is that distilled water is usually acidic and not textbook neutral.<br>Are there any indications that biotic activity may contribute to surface pH values? | are a number of confounding factors, and we are still working our way through these.<br>Distilled water in equilibrium with the atmosphere should indeed have a pH below 7 (around 5.6) and we have taken this into account in our interpretation.<br>It's certainly plausible that biotic activity could contribute to surface pH, but we need to get the results from the organic geochemistry and microbiome work before we can attempt to answer the question. | | |
| 20 | Section 7.2.3 | Chloride. A range of data is presented but I could not see any specific conclusions from the data. | The conclusions are that the data are highly variable and show some evidence of higher chlorine (Cl) in the areas around Karratha, Dampier and Rosemary Island (Section 7.2.3). More complex interpretations are not warranted by the data at this stage. | OK. | - |
| 21 | Section 7.2.4 | Oxidation-reduction potential. As above, I could not discern any definite conclusions. | These data have not been interrogated by the statisticians yet. | OK. | - |
| 22 | Section 7.3 | Referral to equipment problems is made, as in some other sections, regarding different machine brands etc. which may result in inconsistencies in data measurements. Future work should attempt to resolve and eliminate this potentially serious problem. | Every attempt is made to maintain consistency and cross-check between devices where it is not possible to use the same device (e.g., Section 7.3.3). | OK. | - |
| **Progress toward interim EQC (environmental quality criteria)** | | | | | |
| 23 | Section 8.2 | Regarding the detection of change in natural weathering due to anthropogenic activity, it is known that the latter, through e.g. gases, volatiles and particulate deposition) can markedly affect microbial colonisation and biodeterioration of rocks and minerals, as well as the pollutants themselves also chemically contributing to deterioration. Is it possible to determine the relative roles of such processes as data accumulates? | We will aim to undertake this. However, given that no further microbiome sequencing is planned (as the sample rocks have been collected from the field), these effects explored via (a) examining spatial patterns in microbial colonies, compared to long term spatial patterns in air quality; (b) examining spatial and temporal patterns in microbial colonisation of rock cubes located at air quality and weather monitoring stations (AQMs); (c) simplified relationships determined through chamber studies. | I see. Because of the nature of the sampling and sequencing regime this would not be possible to do for the actual site. However, as you say, some relevant information would be obtained from the approaches indicated, especially (b) and (c). | Comment noted. |
| 24 | | I have no specific comments on other parts of Section 8. | Comment noted. | - | - |
| **Key outcomes overall from the first year of scientific studies** | | | | | |
| 25 | Section 9 | It is clear that a large amount of research has been carried out with useful data being obtained in several of the project areas. A variety of unforeseen | Comment noted. | OK. The few points here are answered in other responses. | - |

| Item no. | Section | Peer reviewer comment<br>15 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | problems were encountered which have informed future directions and approaches to eliminate these. Some of the results obtained have also influenced directions of future research. I share the team's reservations about the use of pH as an indicator. Some concrete conclusions have been reached particularly regarding aerial pollutants. Clearly many components of the research are ongoing and further sampling and analysis is necessary to achieve the overall aims of the project. A final point is that the 2023 Technical Report is detailed into the various separate subject headings and possible integration of findings from the different sections was unclear. For example, microbiome studies might be expected to integrate with findings from inorganic geochemistry and vice versa; air pollutant effects on microbiota etc. All the various processes are likely to be interlinked in some way. | | | |
| **References** | | | | | |
| 26 | | There is a brief and selective bibliography. Specific references in relation to rock microbiota are not included. | Original MRAMP proposal has multiple microbiome references. As the one year progress report is updating on progress which we had no data at the time references were not relevant. | OK, accepted. | - |
| **Appendices** | | | | | |
| 27 | | There are extensive appendices relating to drone surveys, spectroscopic analysis and Tescan Integrated Mineral Analyser (TIMA) analysis that include an abundance of well-presented images and data. | Comment noted. | - | - |
| **List of figures** | | | | | |
| 28 | | An extensive list is presented. | Comment noted. | - | - |
| **List of tables** | | | | | |
| 29 | | An extensive list is presented. | Comment noted. | - | - |
| **General** | | | | | |
| 30 | | The Addendum: Corrections to Revision D document do not affect the above comments. | Comment noted. | - | - |

## 1.3 Dr John Henstridge, Data Analysis Australia (2023)

| | |
|---|---|
| **Document title** | **Murujuga Rock Art Monitoring Program – Statistical Review of Technical Report** |
| **Document revision** | **COPP21065-REP-G-101** – Version D (3 May 2023) |
| **Reviewer** | **John Henstridge** |
| **Date of review** | 27 September 2023 |

| Item no. | Section | Peer reviewer comment<br>27 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| 1 | | I have noted that there are many places within the 2023 Technical Report that refer to data and have some simple analyses. However, I have focused on Section 7 where the more critical statistical components appear to be concentrated. | We agree with this emphasis. The policy of MRAMP is that the component studies may include simple data analyses that are customary within the literature of the relevant discipline, but that "definitive" statistical analysis (including analyses involving data from different component studies) will be conducted or supervised by the statistical team. | Noted. I assume that the design aspects have been considered by the statistical team before substantive data is collected so that the definitive analysis is possible. | - |
| 2 | | In many ways the field colour measurements are critical since this was the approach taken by the previous CSIRO (Commonwealth Scientific and Industrial Research Organisation) monitoring.<br><br>(a) The CSIRO had difficulty in maintaining a consistent measurement methodology over time and failed to set up a proper sampling framework in the beginning. It is good to see that the 2023 Technical Report describes a more measured approach that is clearly aimed at establishing a proper working methodology and statistical framework. | We agree. The colour-monitoring activity is very important. In MRAMP, unlike previous projects, the colour monitoring is complemented by other studies which may strengthen the evidence and may permit conclusions to be drawn even if the colour-monitoring data remains inconclusive.<br><br>(a) We appreciate this comment. | A general comment here. The whole area of colour measurement is challenging and it is good that this is acknowledged. However it is clear that much needs to be done.<br>It is good that the need to replace the JAZ instrument is recognized. Clearly the replacement instrument will need to be one that is better documented and ideally overcomes some of the spectral range issues of the JAZ and is better suited for the hot conditions (or an operating protocol enables better performance). Given that one year has passed, this replacement and its integration into MRAMP must be a matter of some urgency.<br><br>- | -<br><br>- |
| 3 | 7.1.2 | An initial focus (Section 7.1.2) is on the JAZ instrument and the processing of its output files: | - | - | - |

| Item no. | Section | Peer reviewer comment<br>27 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | (a) An immediate observation is that the "counts" given in Figure 7-1 are not integer values. Clearly this makes the interpretation difficult since it is difficult to understand the contribution of Poisson like noise. The data in Figure 7-1 (which may not be representative) is suggestive of small counts since the calculated values of P (processed [calculated] reflectivity for the wavelength, reflected as a percentage) are all close to being a multiple of one third. | (a) We have incomplete technical information about the JAZ instrument (at least for the version used for these observations) because it is no longer supported. We believe the numerical values are rescaled counts of detections in a photomultiplier, possibly normalised relative to the exposure time. It would probably be a good approximation to treat these values as having the same variance-to-mean relationship as Poisson count variables. | (a) I agree with this approach, but ideally the nature of the scaling should be better understood. | - |
| | | (b) At the same time, it is assumed that noise is the primary reason why the expected relationship D ≤ S ≤ R (dark field photon for the wavelength ≤ sample sensed photon count ≤ reference [illumination] photon count), (that is, the signal should be between the baseline and the reference) sometimes does not hold. | (b) This is the initial working assumption. | (b) Agreed. | - |
| | | (c) This has led to values of reflectance that have to be truncated into the 0-100% range. | (c) We confirm that this is correct. | (c) Noted. | - |
| | | (d) There seems to be a problem at the spectral extremes where the sensitivity of the instrument is low, outside of the visible range. This is likely to have minimal effect on the (L*,a*,b*) (CIELAB) transformations and the interpretations of visual appearances.<br>Editor's note: the CIELAB transformations described here are coordinates defined by the Commission International de l'Eclairage, where L* refers to lightness, a* refers to the balance between red and green, and b* refers to the balance between blue and yellow. | (d) This appears to be correct. However, if true, it would militate against more sophisticated multivariate analysis of the reflection spectra, which we originally envisaged. | (d) The spectral range problem comes to the essence of what the aim of the colour measurements is. The restricted range might not affect (L*,a*,b*) measures and hence appearances to human eye, but may affect other exploratory methods. | - |
| 4 | | The analysis presented in the 2023 Technical Report is still exploratory, with a focus on producing reflectance spectra plots. | We agree with this assessment. | Noted | - |
| | | (a) The use of generalised additive models is appropriate for producing smooth spectra where smooth spectra are to be expected. | (a) Agreed. | - | - |
| | | (b) I cannot comment upon the appropriateness of the assumption of smooth spectra – I am aware that in some spectroscopic contexts such as emission or florescence spectra, that assumption would not be appropriate. | (b) Agreed. This was noted in Section 7.1.8. | - | - |
| | | (c) Given the problem of the noise and the likelihood that it is in part due to small photon counts, I am curious as to why a more explicit modelling of the Poisson like error was not referenced (if only to say why it was not used). | (c) This approach was envisaged but was not carried out in time for the 2023 Technical Report for operational reasons. | - | - |
| 5 | 7.1.9 | The 2023 Technical Report proceeds to make a number of observations or findings concerning the spectral data ([7.1.9]). In general, I suggest that these findings are premature as they are heavily affected by the clearly spurious measures of reflectance. | We agree with this assessment. The 2023 Technical Report presents the state of exploratory data analysis at the time of preparation of the report. The text attempts to caution the reader that at this early stage of | I look forward to when the statistical team can do this in the way that they intend. | - |

| Item no. | Section | Peer reviewer comment<br>27 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | | the project, any findings are tentative and that conclusions are premature. | | |
| | | (a) I am puzzled by the comment in Section 7.1.9, paragraph 9 that "this suggests that (reflectance) values below 0% are valid and may be a typical trend for rocks at Murujuga". Taken literally, this means that the rocks adsorb more light than falls on them. This is much more likely to be due to instrument or noise problems. (It is easier to find plausible explanations for reflectance greater than 100% but I would still be sceptical.) | (a) The word "valid" was an unfortunate choice. What is meant is that calculated reflectance values less than zero cannot be disregarded, because they occur frequently, and that a detailed explanation is required. The word "valid" has been replaced with "cannot be disregarded". | - | - |
| | | (b) Many of the plots (Figures 7-5 to 7-20) are dominated by negative and other spurious reflectance estimates. | (b) Agreed. | - | - |
| | | (c) The current statistical analysis does not appear to include much information on the instrument itself. Given that the instrument appears to be part of the problem (for example, noise possibly being temperature related), it may have been appropriate to include some analysis of reflectance spectral estimates. | (c) This analysis is now under way. For operational reasons the team was not able to undertake this analysis in time for the 2023 Technical Report. | - | - |
| 6 | | I can understand that using the JAZ instrument in field with may cause greater than ideal problems of thermal noise. This has been a criticism of earlier work at Murujuga. I would seriously question whether the technical problems of keeping the instrument cool and stable have been adequately addressed. | We agree.<br>This has been addressed in two ways. In the short term an on-site spectrum integrity validation protocol has been introduced to ensure that viable spectra are collected for all targets at each site. Where the spectra don't pass the measurements are repeated.<br>Going forward a second Ocean Insight spectrometer will be introduced, comparable to and calibrated to the JAZ. The next campaign will have both run together to ascertain whether the unreliability is instrument specific or due to environmental or operational excesses. | I note the actions to be taken and, as above, recommend they are given high priority. I would question the direction of the calibration – the new instrument might be best considered the standard when going forward. | - |
| | | It is possible that the instrument may work adequately in the visible range, particularly when used to calculate the (L*,a*,b*) values that are most dependent upon the centre of the recorded spectrum where the human eye is most sensitive. | We agree that this is possible. As mentioned in 3(c) above, this would be somewhat unfortunate, as it would militate against a more sophisticated and more sensitive analysis of the spectra. Nevertheless, it would allow statistical analysis of perceptual colour changes. | Noted as above. | - |
| | | The spectra in for example Figure 7-4 suggest that the illumination source may be the origin of the peaks and hence be causing some of the problems. My understanding is that this can be a major issue on the near infrared. It is not clear whether this has been investigated. | This is under investigation. | Noted, with the comment that the new instrument may be relevant here. | - |
| | | If the problems are simply noise, then a more sophisticated analysis may be required that estimates a reflectance constrained to be between 0 and 100% and accounts for the Poisson-like uncertainty in the three measurements D, R and S. | An approach of this kind is being developed for the eventuality that we decide to analyse the full spectral data. The approach will | Noted. | - |

| Item no. | Section | Peer reviewer comment<br>27 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | | involve hierarchical statistical modelling and latent stochastic processes. | | |
| 7 | | My understanding is that the Curtin team recognise that progress on managing this data has not been ideal and they attach some urgency to its improvement. | This is accurate. | Noted. | - |
| 8 | 7.2 | The measurements of these quantities on a rock surface are not straightforward and the team have clearly spent some effort on improving their methods, leading to substantial differences over the four campaigns. The statistical analysis presented in Section 7.2 is essentially exploratory, looking at the data over time, rock types and spatially. | We agree with this description. | - | - |
| 9 | | There is little that can be commented on, although I make the following points:<br>(a) I recommend care be taken in interpreting the initial data. For example in Figure 7-23 is it not possible to assign the changes to the development of the technique or to seasonal trends.<br>(b) It suggests that some time may be needed before the impact of the collection methods is fully understood.<br>(c) In the spatial analysis it appears that the kriging method has ignored the discontinuities of the different rock types. Whilst the spatial displays are used only for exploratory purposes, this is not an issue but when the analysis attempts to link results to emission sources, it will be.<br>(d) The same applies to the multivariate analysis – it would be of interest to know how the correlations relate to (or might be explained by) the rock types. | -<br>(a) Agreed.<br>(b) Agreed.<br>(c) While there are some locations where a major geological discontinuity is evident, these are the exception. In many of the areas visited on Murujuga, individual rocks belonging to each of the four main types are present, sometimes immediately adjacent to one another. We therefore think that it is appropriate to treat rock type as a factor (categorical explanatory variable) such that every level of the factor is potentially available at any location (at a coarse spatial resolution). A spatial regression with a covariate rock-type effect is then appropriate. However, we do agree that great care is required.<br>(d) Agreed. | -<br>(a) Noted.<br>(b) Noted.<br>(c) I can understand this assessment and treating by rock type is appropriate. The fact that the rocks are on the surface and may have moved due to natural processes may mean that the geological discontinuities are now blurred.<br>(d) Noted. | -<br>-<br>-<br>-<br>- |
| 10 | 7.3 | The analyses in Section 7 are also exploratory and not much comment is required.<br>(a) The main analysis used redundancy analysis, which is similar to the earlier canonical correlation analysis, and perhaps better suited when some of the variables being analysed have quite different scales.<br>(b) The effect of campaigns is examined and it is possible that this is significant, although no formal statement is made. | We confirm that these are exploratory analyses in keeping with standard statistical practice.<br>(a) We agree with this assessment.<br>(b) We are cautious about formal conclusions at this early stage. | Noted, everything is at an early stage. | |

| Item no. | Section | Peer reviewer comment<br>27 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | (c) The examination of ratios of certain key minerals follows conventional geological practice, and is again exploratory.<br>(d) The spatial analysis recognises that different rock types need to be considered. | (c) We agree with this assessment.<br>(d) We confirm this. See also response to Section 7.2. | | |
| 11 | | Earlier work with a trial at Curtin demonstrated that there was substantial "random" variation in the performance of the passive samplers, some but not all due to brand differences.<br>(a) It is good that this has been further investigated, focusing on just one of the brands of sampler that performed better than some of the others, so that one source of variation has been eliminated.<br>(b) The controlled trial covered just one month, rather than varying exposure times as used in the earlier trial. It is not clear how this compares with intended use.<br>(c) The results of this trial were described as suggesting the "assay results are well characterised". It is not clear just what this means. My assessment is that the results show substantial variation despite the controlled environment, suggesting that replication of sampling may be required. | We confirm this assessment.<br>(a) Agreed.<br>(b) The IVL passive samplers will be deployed in the field for one-month periods before collection.<br>(c) The text was intended to imply that the probability distributions of the assay values are reasonably well characterised. The assay values can be treated as normally (Gaussian) distributed for all but one of the gases of interest. This is all that is required at this stage for statistical purposes. We note that the two trials of passive samplers (i.e., the first trial which compared three brands, and the second trial which involved only the IVL brand) used techniques of experimental design to determine the placement of the individual samplers within the array of samplers (to avoid bias due to preferential placement, etc.) but that the sampler array was then placed in the field for a month, so that the assayed values include the random effect of environmental exposure, including any differences in atmospheric exposure across the array due to small-scale aerodynamic effects. | (b) I presume that the observation period is being standardised on one month.<br>(c) Noted. | (b) The passive samplers are collected on a standard 4 weekly cycle (13 collections per year). Any variations to the cycle are agreed with the lead statistician and recorded with the data.<br>(c) For clarity we have now written "the statistical distributions of the assay results are well characterised." |
| 12 | | The field trials of the samplers have provided a dataset that again shows considerable variation. No clear findings are made. | See previous comment. | | |
| 13 | 7.6 | The statistical review (Section 7.6) of the Ramboll model outputs amounts to an analysis of simulation output. Given that simulations are usually simplifications of reality it is likely that the Ramboll data provides a lower bound on the variability in reality. | Agreed. This analysis could be considered as a pilot study using the Ramboll outputs as a surrogate for actual observations which are yet to be made. | Noted. | |

| Item no. | Section | Peer reviewer comment<br>27 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | (a) Most of the statistical analysis is exploratory.<br>(b) The main benefit of the Ramboll data is that it provides an estimate of the exposure to industrial emissions and hence provides a good one dimensional test for associations with other data such as the pH measures. | (a) Agreed.<br>(b) Agreed. | | |
| 14 | | This is illustrated in Figure 7-70 where pH data is plotted against Ramboll estimates of emissions (sulphur dioxide [$SO_{2}$], ammonia [$NH_3$], ozone [$O_3$] and particulate matter [$PM_{10}$]) at field sites.<br>(a) This is suggestive of some relationships although it is perhaps more predictive of the scale of variation rather than mean values.<br>(b) The last analysis (bottom of page 148) appears logically unfinished. It works on the hypothesis that manganese (Mn) may be the element most sensitive to acid-forming pollutants such as $NO_2$. This would suggest an interaction between $NO_2$ and Mn on (say) the pH. The plot in Figure 7-71 is given to show that there is no strong relationship between $NO_2$ and Mn, interesting but not relevant to the hypothesis. | (a) Agreed.<br>(b) Agreed. The analysis on page 148 is tentative and speculative. | Noted. | |
| 15 | 7.7 | Section 7.7 considers how certain environmental variables may be affecting the measurement of pH.<br>(a) This is a very useful analysis as, for example, it suggests that during Campaign 1 the weather was qualitatively different from the other campaigns, being hot and humid (as indicated by wet bulb temperature).<br>(b) The relationships between the weather variables are not clear and hence care is required in making findings from a collection of unidimensional analyses. | (a) Agreed.<br>(b) Agreed. | Noted. | |
| 16 | | This section does not actually address dose-response issues despite the heading. | The heading text may have been poorly chosen. | | |
| 17 | | This section summarises statistical conclusions. The general theme is that much remains to be done to establish good measurement processes. | We agree with this assessment. This is also in keeping with standard statistical practice at the current early stage of investigation. | | |
| 18 | | Regarding the colour measurements (Section 7.8.1), I agree with the conclusion that there is much to still to be done to get the processes and perhaps the instrument right.<br>(a) The analysis in the 2023 Technical Report leaves unanswered just how accurate the current instrument is and what might be inferred from its data. Further work is required here on the estimation process.<br>(b) A new instrument, even one from the same manufacturer, will need to be cross calibrated. However colour | (a) Agreed. This is an important priority. In the short term an on-site spectrum integrity validation protocol has been introduced to ensure that viable spectra are collected for all targets at each site. Where the spectra don't pass the measurements are repeated.<br>(b) Agreed. A second Ocean Insight spectrometer will be introduced, | I agree with these actions. It may be worthwhile considering just what checks can be made on-site, or just what are "viable spectra". | Field technique is progressively being improved by adding more checks on the integrity of the data after each measurement. These improvements are driven partly by our exploratory analysis of previously collected data. The checking procedure continues to evolve. |

| Item no. | Section | Peer reviewer comment<br>27 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | measurement in the field can be very sensitive to process and environmental conditions which means that it is necessary to create the cross calibration data in field if it is to be valid. Hence, I agree with the recommendation that such data be collected.<br><br>(c) I agree with the desirability of updating the JAZ instrument, particularly if it then allows in-field quality control. | comparable to and calibrated to the JAZ. The next campaign will have both run together to ascertain whether the unreliability is instrument specific or due to environmental or operational excesses.<br><br>(c) Agreed. | | |
| 19 | 7.8.2 | Regarding the redox chemistry (Section 7.8.2), I agree that further investigation is required into the measurement technique given the evidence of environmental effects on the measurement process.<br><br>(a) This may lead to guidelines as to the time of year of measurement.<br><br>(b) I agree that rock type needs to be more actively considered. | We are continuing investigations into environmental effects on pH, Eh, and Cl measurements and the methods are evolving in response to our findings.<br><br>(a) One of the objectives of this work is to determine seasonal effects and an optimal sampling strategy that will include time of year.<br><br>(b) All five rock types are regularly monitored, and as the data set grows and the sources of random and systematic errors are recognised and eliminated, so far as is practical, it will be possible to perform a meaningful comparison of the data from the different rock types. | | |
| 20 | 7.8.3 | The pXRF data summary (Section 7.8.3) essentially says this is reasonably well measured but there remain problems in “the uncontrolled manual use of the device” and belief that there are “systematic differences between brands”. | After the first field season, we purchased, specifically for the project, a top-of-the-range Bruker pXRF, and in the second field season we compared the two devices to establish inter-instrument comparability. We found that caution should be applied in comparing the data. In addition, by daily monitoring with a secondary standard, we find that absolute percentages are variable. The secondary standard is a tablet of dolerite with a clean flat surface of the fresher rock with a relatively small grain size. The variable measurements are attributed to variation in the contact of the pXRF with the surface of the rock, and, to a lesser extent, potential variation in the local bulk composition of the rock. However, we find that element ratios are consistent, as stated in the text (Section 7.3.3).<br><br>To mitigate these sources of uncertainty, we have (a) reduced the weighting of measurements made with the Olympus in campaign 1, and (b) committed to the use of | I can see that efforts are being made to address this consistency issue. I suspect that continuing effort will be needed, but I recognise that element ratios are likely to be more stable. | |

| Item no. | Section | Peer reviewer comment<br>27 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | | element ratios shown to be robust, based on the daily monitoring of the secondary standard. These strategies are outlined in the text (Section 7.3). | | |
| 21 | 7.8.4 | The validation process for passive samplers is not complete (Section 7.8.4). Significantly more needs to be done here. | While we agree that more could be done to investigate the characteristics of the passive samplers, we do not believe that this would be an efficient use of resources at the current stage of the project. It would be difficult and costly to validate the passive samplers in a trial which simultaneously satisfied both the requirements of a controlled, calibrated experiment and the realities of field observation such as diurnal temperature variation and turbulence. The two trials which have been conducted so far involved placing the samplers in the field. The second trial showed that the IVL samplers have acceptable levels of variability between replicates in the field. In the overall design of the study, the passive samplers are not the only source of information about the environmental atmospheric composition. Other sources include the low-cost real-time monitors, high quality monitors, and fixed weather stations. The definitive statistical modelling and analysis for the project will combine all these data sources with appropriate weighting. | Ongoing work is required here to understand the passive samplers and in an ideal word this would take place before primary data collection. However, I recognise that it may be more appropriate to do some of this in parallel to the primary data collection, providing understanding by the time statistical analysis is required. | |
| 22 | 7.8.5 | I strongly agree with the principle expressed in Section 7.8.5 that the use of a model such as Ramboll is likely to be far more effective than trying to identify control sites. | This is a welcome endorsement of the team's overall approach. | Noted. | |
| 23 | | The dose-response section is minimal, largely because it is premature to consider such analyses while there is insufficient good data. | Agreed. | Noted. | |
| 24 | | I recognise that this is an interim report at an early stage in the project. Hence much of the work – statistical and otherwise – is aimed at establishing a proper data collection process. The magnitude of this process is becoming apparent.<br>(a) There is a risk that time pressure will lead to assuming these data collection methods are "near enough", leading to changes being forced later as the problems are better understood. While to some extent this is unavoidable, every attempt needs to be made to solve these problems before too much is invested in data collection. | Agreed.<br>(a) We agree with this note of caution. We affirm that this is a high priority for the project. | Noted. | |
| 25 | | I have flowed through the R code and find it of a reasonable quality for a project at this stage. | Noted. | Noted. | |

| Item no. | Section | Peer reviewer comment<br>27 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | (a) It is particularly useful to see the test cases in the code comments.<br>(b) The use of GitHub for code management is also good practice. | (a) Noted.<br>(b) Noted. | | |

## 1.4 Dr Ron Watkins (2023)

| | |
|---|---|
| **Document title** | **Murujuga Rock Art Monitoring Program: Draft Technical Report (March 2022 – March 2023)**<br>**(Including ADDENDUM: Murujuga Rock Art Monitoring Program DRAFT Technical Report: Corrections to Rev D provided by Ben Mullins 16/05/2023)** |
| **Document revision** | **COPP21065-REP-–-101** – Version D (3 May 2023) |
| **Reviewer** | **Ron Watkins** |
| **Date of review** | 28 September 2023 |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| 1 | General / overarching comments | I congratulate the authors in producing a report that is free from the inconsistencies of writing style and presentation that were a feature of the previous one that I reviewed. The presentation is of a high standard and the text is almost free of ambiguity and imprecise argument. Typographical errors are few.<br>It is evident that the research team has gone to considerable lengths to report the most complete set of results possible from the first year of field and laboratory work that necessarily involved a learning process and construction and testing of equipment and procedures. In places the conclusions made from limited numbers of results must be considered highly speculative, as is mostly explained in the text, when waiting for a second batch of results from 2023 would have been completely acceptable – no doubt due to the pressure of mandated reporting. Sections indicating a variance from initial work plans were an excellent feature. | Your comments are appreciated. Taken as a comment. | The authors have been very open to modifying the 2023 Technical Report in response to my comments which very often were advisory, less commonly demonstrative. Regarding the latter.<br>I am happy with the actions taken to improve the text. There are instances where typographic/grammatical errors have been corrected where I had commented but persist elsewhere in the report. Not a hanging offence! | - |
| 2 | Executive summary | It is a clear and concise summary of what has been accomplished over the first year of field studies.<br>• Paragraph 3; line 6: “2,594 surface redox measurements (pH, Eh, Cl) combined” is a somewhat unclear statement. Firstly, why are such measurements termed “redox measurements” when this is only one of three independent parameters? Secondly, “combined” might intimate that the 2,594 refers to individual measurements rather than the three parameters representing one physio-chemical record.<br>• As displayed on my PC screen, the geographic background to Figure ES-1 is so dark as to be almost indistinguishable.<br>• A sentence could usefully be added to the summary to describe exactly how the rainfall patterns were atypical during the first year of fieldwork. It took me a while to understand the representation of “cumulative campaign” and “cumulative monthly” and I might not be alone. Firmer indication/labelling of the months may make the cumulative periods/ duration of fieldwork campaigns more explicit. | • We have changed references to “redox” to “electrochemical” both here and elsewhere in the document as appropriate.<br>• Figure ES-1 has been redrawn.<br>• A sentence has been added to describe the weather abnormalities.<br>• Text has been added to the glossary table to clearly define the “cumulative campaign” and “cumulative monthly” terms. | Checked; correction satisfactory.<br>Checked; correction satisfactory.<br>Checked; correction satisfactory.<br>Checked; correction satisfactory. | - |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| 3 | Section 1.1 – Background | Brief but clear statement of the status of work at the time of writing.<br>• Pg 4 Para 3, line 1: component<u>s</u>. | Done. | Checked √ | - |
| 4 | | Further sections are excellently composed and written. Listings (Abbreviations, Chemical terms, Glossary) appear comprehensive and well explained.<br>• Quality assurance and quality control (QA/QC) “Qquality assurance” – remove “q”. | Done. | Checked √ | - |
| | | | | | |
| 5 | | These are presented clearly and are complementary to the detail given in the individual methodology statements. | Comment noted. | - | - |
| 6 | 2.3.1 | • Section 2.3.1 and elsewhere in report: “distilled water” may be incorrect/imprecise. Normally in analytical circumstances the water will be a minimum of deionised water (DI) and possibly Milli-Q standard (> 18.2 Ohm). | Correct, the water used was deionised water or better. | Note “distilled water” remains in this section X | “distilled water” was searched throughout document and replaced with “distilled/deionised”. |
| 7 | | • Page 19; line 11: instrumentation used in this study <u>is</u> regularly …<br>• Page 19; line 33: the data obtained <u>are</u> reliable ... | Done. | Checked √<br>“SEM microanalysis data is” remains X | “SEM microanalysis data is” changed to “SEM microanalysis data are” |
| | | | | | |
| 8 | 3.1.3 | • Page 22; line 9: change “spray” to “aerosols”.<br>• Page 22; line 10: pH and Cl are independent of redox chemistry measurements and the three parameters should not be grouped as one. As a group they may be called physio-chemical parameters.<br>• Page 22; line 11: remove full stop after dates.<br>• Page 22; lines 11-15: this is a better explanation of the figure than appears in the Executive summary. | • “saltwater spray” changed to “salt aerosol”.<br>• The term “redox” has been changed to “electrochemical” throughout the document.<br>• Done.<br>• As mentioned in comment item number 2, further explanation of this figure has been added to the Executive summary. | Checked √<br>Checked √<br>Checked √<br>Checked √ | - |
| 9 | 3.3 | Would it not make sense to have a second field pH, Eh, Cl meter and electrodes. The expense is not great when missing data through malfunction/breakage of the primary unit/electrodes cannot be produced otherwise and may be critical. A dual set will also allow an ability to cross-check values when a temporary error or degradation in quality of results is suspected. | The field kit now includes duplicates for meters, electrodes and other equipment for these purposes. | Satisfactory √ | - |
| 10 | 3.3.1 | • Page 26; line 8: based upon.<br>• Page 26; line 16: ongoing monitoring (OM) is not in the abbreviations table (page 8). | • Done.<br>• OM has been added to the abbreviations table and written in full in the first instance. | Checked √<br>Satisfactory √ | - |
| 11 | | I would make the following general comments on this section:<br>There is a tendency to interweave petrographic and mineral details derived from optical microscope and those revealed by instrumental techniques, namely SEM (scanning electron microscope/scanning electron microscopy) and EDS (energy | It is necessary to integrate information from the different techniques to obtain a comprehensive understanding of the mineralogy. We have edited the text to clarify, and to distinguish between mineral | Checked √ | - |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | dispersive X-ray spectroscopy), and to a lesser extent XRD (X-ray diffraction). Effort should be made throughout to separate information derived from these two different sources. Just one example is the use of an (anorthite) as a compositional calcium (Ca) end-member reported by EDS, as opposed to labradorite, the mineral form actually present in the rock and recognisable under the optical microscope. Numerous other similar examples of the mixing of terms used in the two forms of mineral determination. I have made comments where evident.<br>Initially, a relatively clear picture of the nature and distribution the zones: patina, weathering rind, and underlying rock, is presented with comparison the model of Donaldson 2011. In subsequent descriptions and discussion, however, the picture becomes increasingly confused with respect to the distribution of, and relationship between, the patina, rock varnish, and weathering rind. I have made comments where points of confusion (at least in my head) arise. I believe a sub-section towards the end, or additional point, or points, in the Preliminary findings (Section 4.2.9) could usefully be added to give a clear and detailed summary of the occurrence, character, and inter-relationships of these components. After all, they are central to the nature of the rock art and longevity of the rock art. | end-members, which tend to be TIMA or XRD output and mineral phases, which are observed within the rock.<br>The specific comments have been replied to. However, a comprehensive understanding of the mineralogy and relationships amongst the different components (patina, rind, fresher rock) is the topic of ongoing research and this has been clarified in the text. Our current understanding is summarised in Section 4.2.9. | Checked and accepted √ | |
| 12 | 4.2.1 | • Page 38; line 3: section 0? | The reference to a section in 4.2.1 now says 3.3. | Checked √ | - |
| 13 | 4.2.3 | 1. Page 38; line 10: “spatial” might be added before or in place of “geological”. Mapping and surface observations from 50 m zones alone may go only so far in determining a detailed geology of each of the lithologies (e.g. lateral and vertical variations; structure and interrelations) particularly in the case of the basalt, dolerite and granite.<br>2. Page 38; line 20: replace “to be resolved” with ”to resolve”. | 1. “spatial” added.<br>2. Done. | Checked √<br>Checked √ | - |
| 14 | 4.2.4 | 1. Page 41; line 7: replace “resizing” with “cutting”?<br>2. Page 42; line 9: note that the granophyric texture is believed to relate crystallisation occurring close to the $SiO_2$ – feldspar eutectic and not exclusively relating to a near-surface environments. e.g. occurrence of granophyric intrusions into, and deformed, by enclosing granite.<br>3. Page 43; line 2: re: (anorthite). Gabbro is defined as most commonly containing the plagioclase feldspar labradorite with the Ca end-member anorthite occurring is the far less spatially abundant ortho-gabbro.<br>4. See also my previous general comment. | 1. Replaced.<br>2. Added to the text – though the comment referred to the grainsize not the texture.<br>3. Noted and fixed.<br>4. Noted. | 1. Change not made X<br>2. My comment <u>did</u> relate to grain-size since granophyric texture is inherently relatively finer grained owing to the rapid coprecipitation of quartz and alkali feldspar close to the eutectic T. It was given as advice and I did not expect the text to be included in full. However, it’s OK if the author is happy with such an addition.<br>Checked √<br>3. Checked √<br>4. √ | “resizing” has been replaced with “cutting”. |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | 5. Page 43; line 3: change “orthopyroxes are typically also present” to “orthopyroxenes may also be present”. | 5. Reworded. | 5. Checked √ | |
| | | 6. Page 43; line 5: pedantic it may be point out but “settling” is merely one suggested magmatic process for the formation of “cumulates” in gabbroic magma and it is highly contentious that plagioclase feldspar, in particular, can settle passively in a magma chamber. | 6. Reworded. | 6. Checked √ | |
| | | 7. Page 43; line 6: I am staggered to read that the **main** difference between the gabbro and granophyre lithologies is their provenance! This is specially the case since the origin of the magmas is not decipherable by the laboratory investigation reported. Surely the chemical composition, mineralogy and texture, etc. have an equal, or greater, role in distinguishing the two lithologies? | 7. The reviewer is completely correct. Rewritten. | 7. Kind of you to say. Checked √ | |
| | | 8. Page 43; line 20: you may indeed mean “ubiquitous” although its use can suggest it is present in all samples to some extent, rather than it consistently forms a major portion of the rock, in which case “widespread” and “predominant” may be more correct. | 8. Reworded. | | |
| | | 9. Page 43; line 25: a correct comparison since in granophyre the “spheroidal” texture may be an expression of “quench” devitrification formed relatively shortly after magma cooling. | 9. Added to the text. | | |
| | | 10. Page 43; line 27: this distribution of crystalline quartz as granophyric intergrowths and anhedral crystals in a feldspar-rich matrix may also be related to the wholesale near-tectonic crystallization of the magma. | 10. It’s unclear what near-tectonic means so we haven’t added this. | 10. My mistake (or Microsoft’s). near-tectonic should read near-eutectic. The point is made elsewhere so no need for further revision √ | |
| | | 11. Page 43; line 30: once again, formation of granophyric texture need not reflect a particularly fast cooling rate, rather near simultaneous crystallisation of the two major minerals that form the greatest portion of the rock. Silica ($SiO_2$) rich magmas, such as granophyre, are also prone to delayed crystal nucleation preceding very rapid crystal growth, a result of the very strong network-structure of silica-rich liquids. | 11. Text modified to add the commented information. | | |
| | | 12. Page 44; line 2: I am aware of the earlier use in publications of the term quench gabbro in accounts of the Murujuga rocks, although I have myself not observed it. However, I find it rather counter-intuitive that a quenched (very rapidly chilled) magma would be display a “much coarser (larger) grain size”? It also defies your previous (correct) statement in the case of granophyre that, in general, faster cooling rates produce smaller grain size. Experience of seeing many chilled margins of gabbroic intrusions is that they display fine (basalt) or medium (dolerite/diabase) texture, or when recent in age are commonly glass. | 12. The observations are that the gabbro referred to as “quench gabbro” has very coarse grains, up to 30 cm long, and that it occurs at the contact between the gabbro and the older granite. The textures are reminiscent of spinifex textures, which the reviewer would be familiar with. These form when a magma is cooled below the temperature at which a mineral appears on the liquidus without that mineral nucleating. When the mineral finally nucleates, growth is rapid and forms large skeletal crystals, similar to those seen at Murujuga. Thus, the large crystals are a quench feature. I have clarified this in the text. | 12. Point well explained and I am enlightened. √ | |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | 13. Page 44; line 3: re: "Clinopyroxene is generally the largest phase in the assemblage". Clarify – of greatest abundance or forming the largest crystals?<br>14. Page 44; line 3 and 4: re: "main crystallographic axis". Main? I didn't know degradation graphic axes we so categorised. Also in caption to Figure 4-7 where "long" is used correctly, by is not invariably the case. It is the c-axis or alternatively termed the z-axis.<br>15. Page 44; line 6: Fe (iron) and Fe-Ti (iron-titanium) oxides are not accessory in gabbro since they are included in the definition of gabbro as an essential mineral constituent and are generally present in significant abundance. It is a common mistake to believe that somehow these opaque minerals are always accessory. | 13. Both. Clarified.<br>14. Reworded to refer to the long axis.<br>The reviewer is correct in the comment "Also in caption to Figure 4-7 where "long" is used correctly, by is not invariably the case. It is the c-axis or alternatively termed the z-axis. Reworded.<br>15. Reworded. | 13. Checked √<br>14. Checked √<br>15 Checked √ | |
| 15 | 4.2.6 | The images in Figures 4-9 through 4-15 are extremely illustrative.<br>Page 45; line 7: "Samples presented following are listed according to lithology" ? | Reworded. | Checked √ | - |
| 16 | | 1. Page 53; line 1: re: "the patina within the granophyre and gabbro ". Use of "within" is somewhat confusing when elsewhere in the 2023 Technical Report the patina is described as a surface layer not more than 100 mm in thickness. See general comments on patina and rock varnish.<br>2. Page 53; line 6: the use of "Interestingly" is really redundant and should usually be avoided. Rather: "The rock varnish appears to develop within those portions ……."<br>3. Page 53; line 10: change "much more soluble mineral to weathering alteration" to "is much more soluble in weathering solutions" or alternatively "is far more susceptible to weathering alteration". The sentence may also be at fault in implying that quartz has some degree of solubility during weathering while less than that of potassium-feldspar (K-feldspar), when in fact quartz is imperceptively changed during normal weathering processes.<br>4. Page 53; line 11: omit "calcium" from before plagioclase.<br>5. Page 53; line 22: re: "there is no evidence so far of compositional difference among the patina found in different rock types". This is a most valuable conclusion. However, does it refer to all the (5) rock types, as the text implies? Clarification would be useful. | 1. "within" replaced by "on".<br>2. Removed.<br>3. Reworded.<br>The sentence may also be at fault in implying that quartz has some degree of solubility during weathering while less than that of K-feldspar, when in fact quartz is imperceptivity changed during normal weathering processes.<br>Quartz is soluble in the weathering environment, so we don't exclude the possibility that it is removed by weathering.<br>4. Removed<br>5. The clarification lies in the phrase "so far". I have added "However, examination of rocks not yet fully characterised may alter this conclusion". | 1. Checked √<br>2. Checked √<br>3. Checked √<br>Although Si is present in weathering solutions, I would argue that significant removal of quartz (SiO2) within the timeframe of weathering at Murujuga is highly unlikely. But life's too short to dispute your viewpoint.<br>4. Checked √<br>5. Checked √<br>Satisfactory √ | |
| 17 | 4.2.7 | • Page 55; line 10: "the data **are** graphically ……." | Corrected | Checked √ | - |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| 18 | | • Page 59; Figure 4-10: the interpretation of the XRD spectrum includes sanidine which as a mineral is not usually present in basalt of even the most chemically evolved type. Would I be correct in assuming the sanidine is present not as a primary mineral but as a non-equilibrium low-temperature crystalline state? Some clarification of this is desirable. | Possibly – added to the figure caption (it's Figure 4.17, not 4.10). | Satisfactory √ | - |
| 19 | | • Page 60; table 4-3: ditto, as above. | Added to caption. | Satisfactory √ | - |
| 20 | | • Page 60; line 6: I find the account of the occurrence of sanidine, and also of quartz, to be sloppy and misleading. Whereas sanidine is typically found in rapidly cooled volcanic rocks, it is not characteristic of basalt, in which it does not occur as crystals. True basalt does not contain sanidine, and its presence would indicate the rock to be more felsic – trachybasalt. Unlike the final line of the paragraph might imply, crystalline quartz is abundant in felsic rocks, such as granite and granophyre, but does not occur as a primary mineral constituent of mafic rocks, such as basalt, gabbro, and dolerite. | While there are quartz tholeiites, this is a good point and the text has been altered to read "sanidine is more characteristic of rapidly cooled volcanic rocks, although it would not normally be expected in a basalt, and here may represent a low-temperature alteration phase. Similarly, the quartz noted in sample RS04 is surprising for this $SiO_2$-poor lithology and may have formed during alteration on the seafloor or during weathering." | Satisfactory √ | - |
| 21 | 4.2.8 | • Page 61; line 17: I'm not sure Donaldson described the division between weathering rind and underlying "fresh" rock as being sharp and inter-layer, although the term "sharp" is open to interpretation. | Reworded. | Checked √ | - |
| 22 | | • Page 62; line 11: I find the suggested use of "fresher rock", quite absurd. At best it might be used as a convenient colloquialism amongst members of the current Murujuga investigation. Any suggestion of a broader use would see a revision of what field petrologists have observed and documented over centuries. It is true that distinction can be made between type examples of igneous rocks and those that have been affected by hydrothermal (> 150$^{o}$C) alteration and/or very low-grade metamorphism. Accordingly, a large proportion of igneous rocks of similar age to those exposed at Murujuga can be termed metagabbro or metabasalt, or as being hydrothermally-altered gabbro, basalt, etc. On the other hand, weathering is quite different, although locally it may penetrate to considerable depths in ancient landscapes, such as in the saprolite of Western Australia (WA). My experience of volcanic rocks, notably basalts, is that only very rarely do the primary minerals remain completely pristine, even after relatively short periods of historical time, when simply re-equilibrium can cause phase changes and hydration of minerals, such as pyroxene, especially in fine-grained groundmass, but also phonocrysts. Few coarser-grained intrusives, such as gabbro and granite, seemingly fresh in the field, fail to show such changes in petrographic thin-section. To label all such rocks as not being fresh is obviously erroneous. Cannot the underlying rock of Murujuga weathered exposure simply, and conventionally, be termed "unweathered rock" or "unaltered cores" with the | Rock nomenclature is complex and it is not the purpose of this report to discuss the multiple overlapping and ambiguous terminology used by generations of geologists.<br>Our main aim is clarity so it isn't helpful to use terms that have been previously used with multiple meanings, particularly given the need for international understanding, whereas many terms are applied differently in different countries.<br>The term fresh is inappropriate and clearly erroneous, in that the rocks have undergone hydrothermal alteration. Fresh basalts, and fresh gabbros exist, but the Murujuga rocks are significantly different to those rocks, so it is not helpful to deliberately describe them incorrectly.<br>The terms unweathered and unaltered are difficult to define and apply because the alteration is quite penetrative, and the depth cannot be determined without electron microscopy.<br>The term "fresher rock" was selected, based on the need for a term that hasn't | "Fresh" when referring to a rock, is usually a field term and refers to an absence of perceivable weathering (low temperature reaction on surfaces and in fractures with atmosphere and water). In this context, a hydrothermal deposit or hydrothermally modified rock can very well be "fresh". In the same way that meta-igneous and metasedimentary rocks can be fresh when showing no post-metamorphic low-T (environmental) weathering.<br>I am sympathetic to the author's wish not to use a term that could be misinterpreted. I retain the view, however, that the term "fresher rock" is of little value as a discrete term in a broad/international context. I think an issue here is the perception of "weathering". True, with the aid of electron microscopy, all/many Murujuga rock samples could be deemed weathered and altered.<br>However, there has to be a general interpretation of igneous rocks in the field as being generally weathered (i.e. showing a perceptible degree of surface alteration) and unweathered (displaying | We thank the reviewer for noting that "fresher rock may be quite satisfactory and a useful term in the restricted realm of the Murujuga investigations". |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | understanding that they will contain the products of normal mineral decomposition but free of the profound weathering that clearly is responsible for the surface “patina” and underlying “weathering rind”. | been misused before and that can be defined, applied, and understood for a general international audience that includes specialists and non-specialists. The term satisfies those criteria. | an imperceptible degree of surface alteration) and thus reflecting the condition of the underlying rock. Maybe in the case of Murujuga, “fresher underlying rock” would be the most readily understood term for non-specialists and geologists alike. As I implied in my criticism, “fresher rock” may be quite satisfactory and a useful term in the restricted realm of the Murujuga investigations. | |
| 23 | 4.2.9 | • Page 63; line 4: the second summary point is surprising and, if correct, of extreme importance. Is not the existence and significant proportion of secondary platy minerals – clays such as illite and kaolinite – different that in the unaltered rock beneath? Is it, therefore, the porosity and a “textural variation” alone that accounts for the relative softness and fragility often displayed by the weathering rind, requiring the setting of samples in epoxy resin? Clarification is much needed. | Clarified with text “The weathered rind is not very different in mineralogy from the underlying portions of the rock except for visual (colour difference) and textural (porosity) variations, and minor amounts of kaolinite and illite. | Clarification has been made.<br>Possibly “and the presence of kaolinite and illite” may be better being indifferent to the amount of the platy minerals present? | Corrected as suggested. |
| 24 | | • Page 63; line 6: comment on “fresher rock” as previously made. | Noted. | √ | - |
| 25 | | • Page 63; line 9: having attributed the presence of chlorite and sericite as hydrothermal alteration of pyroxene and K-feldspar, Point 4 begs some mention as to the products and nature of weathering in the “fresher” rock. | Clarified. Weathering alteration in this zone is characterised by some porosity formation below the colour-defined weathered rind. | Satisfactory √ | - |
| 26 | | • Page 63; line 16: in Point 8 the text suggests the patina is developed adjacent to mineral grains in the “fresher rock” without an intervening weathering rind. This may be true in the case of granophyre where, in my experience, a distinct, lighter-coloured, weathering rind is frequently absent, but what of the gabbro where a weathering rind of 5 mm or more thickness is commonly present? In this case, might you mean that the patina is developed upon residual primary minerals of the former gabbro remaining in the weathering rind?<br><br>A clearer picture of the relationships is required. | The point is based on the observations. We do indeed mean that the patina is developed on residual primary minerals, albeit partly dissolved and showing significant porosity. We have referred to a relevant figure in the point to clarify. | OK √ | - |
| 27 | | • Page 63; line 31: use of “dynamic systems” is well chosen. This indicates “which minerals control the pH and Eh” might be changed to “which minerals may buffer the pH and Eh”. Such a change also caters for the possibility that other factors influence the pH when measured in a volume of deionised water introduced to the rock surface. | Changed as suggested. | Checked √ | - |
| 28 | 4.3.3 | • Page 64; line 36: change to “selection of appropriate samples will be undertaken”. | Changed as suggested. | Checked √ | - |
| 29 | 4.4.1 | • Page 64; Figure 4-25: perhaps add to caption the reason why in (d) the experiment was terminated at 50 mins? | The experiment in (d) was terminated earlier than others because this was the first set of experiments, appropriate time points/durations had not yet been determined and it was believed the | Understood √<br>Would a mention of this usefully be included in the figure caption? | Figure caption has been expanded to include this. |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | | measurements were somewhat erratic. We have since significantly revised the protocol for the chamber studies, as per the revised methodology attached. The results are promising and we expect a complete set of results in the 2024 Technical Report. | | |
| 30 | | • Page 69; line 9: clarify what type of "species" is referred to (e.g. chemical, gas, microbiological). | Air pollutant (chemical) species has been clarified in the document. | Checked √ | - |
| | | | | | |
| 31 | 7.2.2 | 1. Page 111; line 4: in Figure 7-21 the range of pH results in campaign 2 appears near equal to that in campaign 1.<br>2. Page 113; line 7: negative trend? Is this evident from values given in the 2023 Technical Report?<br>3. Page 113; Figure 7-25: pH contours values are difficult/impossible to identify especially on islands. | 1. Agreed, the bottom range of pH for both campaigns 1 and 2 are close to 4, apart from the one outlier in campaign 2 which is about pH value of 2. But the highest pH value recorded in campaign 2 is similar to the median (middle line in the box) pH in campaign 1.<br>2. The word "negative" should not have been used here and has been deleted.<br>3. Agreed. However, it was decided to use the standardised pH scale. This decision may be revised in the future, however the data is being made available we understand. | 2. Checked √<br>3. OK √ | - |
| 32 | 7.2.3 | 1. Page 116; line 13: the meaning of quartiles may not be readily understood by readers of the 2023 Technical Report.<br>2. Page 117; line 6: could the overall increase in ranges of values in gabbro and granophyre not be related in part to the different number of samples of each rock type? | 1. Agreed. An explanation has been inserted into the Glossary table 1-3.<br>2. Yes, the range of a dataset is partially dependent on the sample size. | Checked √<br>Is this made clear in the 2023 Technical Report? | - |
| 33 | 7.2.4 | 1. Page 119; line 2: replace "Due to" with "Owing to".<br>2. Page 119; line 3: ditto re: quartiles.<br>3. Page 120; line 1: not sure there is a significantly lower. | 1. Done.<br>2. See above.<br>3. The term "significant" should not have been used here and has been removed. | 1. Checked √ There are a number of similar cases, such as in the following paragraphs, where the conjunction is used incorrectly to commence a sentence. These could be attended to?<br>2. √<br>3. Checked √ | We have attempted to find and correct all such cases. Apologies if any were missed this time. |
| 34 | 7.2.5 | Pages 121-122; Figures 7-32, 7-33, 7-34: the brief captions to these diagrams are insufficient to explain exactly what is displayed. | More explanation has been added to Figures 7-32, 7-33, 7-34. | Checked √ Note that in the amended text on Page 132, line 2: "how" should be "show". | "how" has been replaced with "show". |
| 35 | 7.3 | 1. It may be mental interest to interrogate the pXRF data in terms of rock types as displayed in Figures 7-36 to 7-39 but the variants of analysis are sufficiently numerous to make conclusion highly speculative. | 1. Agreed, as stated in the 2023 Technical Report. | Noted √<br>Noted √ | - |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | 2. I suspect a more definitive outcome may come from other sources such as petrographic observations and electron microprobe.<br>3. I'm not sure what value the use of mineral pairs (7.3.3), such as the demonstrated SiO2:Ti, derived from pXRF pairs would be? Certainly not lithological identification, and special trends within individual rock types are likely to be complicated. To what purpose would such work be put? | 2. Agreed. This is why we are undertaking this work.<br>3. There are element pairs (the text erroneously stated mineral) that do identify the rock type, for example, rubidium (Rb)/chromium (Cr). However, that is not the purpose of the pXRF work. We are testing the use of pairs of elements where one is dominantly hosted by the patina (e.g., Fe, Mn) and one is dominantly hosted by the fresher rock (e.g., Si, Rb, Ca) to investigate whether there is temporal or spatial variation in those ratios that might be attributed to changes in patina thickness. However, the natural and analytical variability may be sufficiently large that a meaningful signal cannot be recognised, even if present. | Yes, inter-element comparison is fine.<br>OK √<br>Noted √ | |
| 36 | 7.3.1 | • Page 122; line 8: is this a reasonable assumption? Meaning of weighted average is unclear. Penetration of the XRF (X-ray fluorescence) beam will be different for each element. I assume this is taken into account by the device's internal algorithm, but complexities much arise with different thickness of each penetrated layer (patina, weathering rind, fresh rock)?<br>• Page 122; line 16: one too many "only"s. | The maximum depth, or range of depths, of pXRF analysis is not known. The vendors (Portaspec) state an approximate depth of X-ray penetration of 5 mm, but lower energy X-rays penetrate less far, so the measured composition includes contributions from the patina, weathered rind, and fresher rock, with a weighting towards elements with higher atomic number, which fluoresce higher energy X-rays, with increasing depth. Therefore, it is reasonable to assume that, unless the rock surface is freshly cut, the pXRF measures a weighted average of the compositions of the patina, weathered rind and interior fresh rock. | I was querying "the "weighted" average, would precisely reflect the thickness of each of the defined layers (patina, weathering rind, fresher rock) for each analyte.<br>Possibly the instrument software and calibrations for each element do allow for such a simple weighting where relative thicknesses of individual layers varies? | Unfortunately, the instrument software does not allow for such a weighting and the presence of variable porosity and density also complicates the relationship between layer thickness and signal strength for any individual analyte, and any straightforward attempt to deconvolute the spectra. The text has been clarified to state this. |
| 37 | 7.6.1 | • Page 140; line 16: I can believe that a low pH may be a measure of the potential for mobilising (leaching) elements from the surface region of the rock profile. I don't however see that the measured pH of a solution produced by addition of deionised water from short-term contact with the rock's surface is a defining measure of the amount of rock surface deterioration? I would like to know how exactly the mineral composition of the surface layer penetrated by the deionised water controls the measured pH, and evidence that other factors, such as residual aerosols or dry deposition on the rock surface, is not a greater influence of the measured pH.<br>• At present, a consistent relation between pH and the state of rock surface degradation, or rate of degradation, is not proven | We agree that the use of pH is highly problematic for a number of reasons, including those mentioned by the reviewer.<br>However, the extensive use of pH by previous workers imposes a necessity that we investigate the relationship amongst pH, other physico-chemical parameters, and the condition of the rocks. | Noted √<br>Noted √ | - |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | and cannot be used as a reliable variable in statistical assessments. | | | |
| 38 | 7.6.4 | • Page 144; line 14: 20203~~3~~ model | Done. | Checked √ | - |
| 39 | 7.7.1 | There are obvious complexities of locality that contrive to invalidate weather as a viable variable. For example, temperature can vary considerably on the surface of a single rock outcrop according to the aspect of the surface, angle of the sun, localised air flow across the outcrop, etc. How this can be related to the general weather and how such small-scale variations can be allowed for across repeated measurements in different campaigns is questionable.<br>The same applies to local humidity, differences in moisture residence times across the rock surface, etc.<br>• Page 149; line 5: I note that "ionic chemistry" is here used for the measurement of pH, Eh and $Cl^-$. This is far superior that the term "redox chemistry" employed in earlier sections of the 2023 Technical Report.<br>• Page 149; line 12: I believe most meters are made such that declining power in the battery does not affect the recorded mV readings until a battery low warning is shown. | Ionic chemistry replaced by physico-chemical parameters.<br>Declining battery removed as a cause of instrument artefacts. | Checked √<br>Checked √ | - |
| 40 | 7.8.2 | • Page 153; line 22: replace "redox chemistry data" with "ionic chemistry data"<br>• Page 153; line one spatial trend or "trends"? | Redox chemistry replaced by physico-chemical parameters (or similar) throughout. | Checked √ | - |
| 41 | 7.8.3 | A very reasonable summary of the outcome and potential of pXRF analysis of in-situ rock surfaces accounting for a question I posed in a previous comment about the purpose of the work. | Comment noted. | √ | – |
| 42 | | • Page 153; line 31: I confirm from my experience that this statement is true, with appreciable bias regarding individual elements presumed at least partly to be a result of variations in the internal computations of the X-ray signals. | Noted. | √ | – |
| 8 | | | | | |
| 43 | | • Page 155; line 16: "the action variable levels" should read "the various action levels"?<br>• Page 155; Figure 8-1: caption "as is data points" should read "as are data points" | • Done.<br>• Done. | Checked √<br>Checked √ | - |
| 44 | 8.3 | • Page 156; lines 20-25: case well made, but a lesser timeframe going back to the date of present landscape formation and rock exposure is probably more appropriate.<br>• Page 156; line 38: why the hyphens in adsorb and absorb which are well known and distinctly different processes? | • Agreed however we are unsure this timeframe has been accurately determined.<br>• Hyphens have been removed. | Noted √<br>Checked √ | - |
| 9 | | | | | |
| 45 | | • Page 159; line 13: "understand the **weathering** system and processes …"<br>• Page 159; line 27: "data **are**". | • Done.<br>• Done. | Checked √<br>Checked √ | |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | • Page 159; line 28: I concur with the disclosure that concerns held by the majority of the scientific team as regards the use of pH as an indicator. The ongoing work to determine more suitable parameters for surface degradation is to be welcomed.<br>• Page 159; line 38: re: “monitoring sites to be stratified between campaigns”. Meaning of “stratified”? | • Comment noted.<br>• This has been clarified in the text. | √<br>Checked √ | |

# 2 Passive air quality sampler validation studies

This section provides the independent peer review undertaken by Data Analysis Australia between June 2022 and October 2023 for air quality passive sampler studies.

An initial study comparing three different brands of air quality passive samplers was undertaken at Curtin University (due to travel restrictions in place at the time, the study could not be undertaken at Murujuga).

Following a review by Data Analysis Australia, a subsequent study was designed and undertaken on site (MAC office air quality monitor [AQM]) in December 2022). This report was reviewed by Data Analysis Australia in 2023 (refer Section 1.3).

## 2.1 Data Analysis Australia – Review of Passive Sampling Tube Evaluation and Testing Report (2022)

1) This is a review of the statistical aspects of the report titled Passive Sampling Tube Evaluation and Testing Report, hereinafter termed the 'Sample Tube Study Report'. It forms part of the Murujuga Rock Art Monitoring Program.
   a) The Sample Tube Study Report considers a number of experimental issues as well as statistical ones. Where an issue contains both, I have tried to focus on the statistical aspects.

2) The work covered by the Sample Tube Study Report is described as a pilot study to 'determine the most appropriate option' for tube use in remote monitoring stations at Murujuga.
   a) The samplers will need to be used at 21 sites spread over the study area and will need to be deployed for extended periods of over 30 days.
   b) The lack of power to many of these sites and the robust conditions limited the choice to passive samplers. These are all described in the Sample Tube Study Report as "tubes" but I understand that they are also termed diffusion tubes or Palme tubes.
   c) I understand that these sensors basically integrate over time the level of atmospheric compound they are designed for through an absorbent pad that is exposed to air in a controlled manner.

3) The main experiment presented in the Sample Tube Study Report considered three brands of sensor – IVL, Gradko and Ranielle.
   a) All of these require to be returned to a laboratory for analysis. IVL and Gradko return to the vendor, it was unclear where Radiello is analysed.
   b) Presumably, the analysis records the change in the absorbent pad and that, together with the knowledge of the time over which the sensor was exposed and the rate at which diffusion can take place can give an estimate of the average atmospheric concentration.
   c) The Sample Tube Study Report does not go into the details of this analysis and the calibration as the pilot was intended to discover how they perform in normal practice. Hence the pilot will be affected by all the events that occur from sensor acquisition through deployment to final results. That is, it considers their 'real life performance'. This is appropriate.

4) The pilot deployed a total of 135 sensors in what is described as a split plot design in an enclosure on the Curtin campus.
   a) The highest level of this design is itself a three-by-three Latin square, a good design to minimise any biases due to the layout in the enclosure.
   b) This design represents good practice in terms of layout and reduces possible biases in the comparison of results for different sensors.
   c) The sensors were deployed on the same date and were then removed in three sets giving sampling times of 8 days, 15 days and 33 days.

5) The design is limited to understanding the differences between the three makes of tubes. In particular there is no 'gold standard' measure for calibration.
   a) Fundamentally this relates to the uncontrolled nature of the exposure of the pilot to the chemical species being measured. If the results for the different brands were substantially the same this might not be a problem, but as they vary substantially (for example for ammonia the Gradko gives results 5 to 10 times the others) it is impossible to know which, if any, are right.
   b) This particularly limits comparisons in regard to the length of time of exposure of the tubes – there is no way of knowing whether the exposure to the chemical species changed over the 33 days of the study. If it did change then it would be impossible to properly compare the results at 8, 15 and 33 days.
   c) This issue highlights the one deficiency of the experimental design – it was not properly balanced over time. For example, over the last 18 days only the 33 day set of tubes was being used. However, it is not clear whether this issue has affected the study significantly.

6) It is said in Section 2.2 of the Sample Tube Study Report that the deployment included 'additional blanks'. No further reference is made to how these were used except that 'blanks returned values below detection limits' with certain exceptions.
   a) It is difficult to fully understand the impact of these exceptions particularly as they seem to seriously affect one of the brands (Gradko).

7) The Sample Tube Study Report records a high proportion of measures below the detection limit (BDL), as high as 37% for the Gradko but still 10% for the IVL that was the best in this respect.
   a) It is not so clear how this depended upon the chemical species involved although some of this can be inferred from the graphs and the tables in Section 3.2.
   b) The tables in Section 3.2 appear to give the standard deviations just for the values that are above the detection limit. As such they are biased. This would be more of a problem if the standard deviations based on so few (2 or 3) measurements were to be taken seriously.

8) Several references are made to unexpectedly high results.
   a) It is suggested that some may be due to contamination although it is not made clear what the evidence is for this. This is clearly a matter of concern and suggests that improved procedures may be necessary.
   b) It also suggests a need for the operational use of these tubes to include replication or some other form of redundancy, both to provide robustness against contamination, to improve precision and to understand just what the precision is. We recognise that this may have cost implications.
   c) In general, the variation is high and should be further investigated. The approach taken in the Sample Tube Study Report of simply tabulating relative standard errors based on samples of size 2 or 3 is far from ideal.
   d) An alternative analysis might be to fit a gamma-log generalised linear model to the standard errors to gain some insights as to the causes of the errors.

9) It is easy to agree with the overall conclusion that out of the three considered, the most appropriate brand to use is IVL. However, this recommendation should be accompanied by some cautions:
   a) The issue of calibration remains as the pilot did not consider this although it provides clear evidence that at least some of the tubes are not properly calibrated. Calibration is critical, if, for example, field monitoring is to be related back to laboratory experiments on the impact of these species on rock surfaces.
   b) Relative standard errors are high, even for the IVL tubes, and the causes of this are not explored. The implications in terms of the numbers of tubes required to achieve necessary precision may be critical to the use of these sensors.

10) Overall, the pilot study gives some insights into this measurement approach and suggests a brand of tube for use. However, whilst the Sample Tube Study Report suggests some issues and potential limitations with the technology, these are not explored. They suggest that, at the very least, further work needs to be done looking into contamination, calibration of the tubes, the high standard errors of results and in turn the sample sizes required.

Dr John Henstridge
Chief Consultant Statistician
21 September 2022

## 2.2 Monitoring program team – Response and proposal for further validation study (2022)

### Response to Data Analysis Australia's Review of Sample Tube Study

This is a brief response, on behalf of the statistical team, to the letter dated 21 September 2022 from Data Analysis Australia (DAA) entitled Review of Sample Tube Study.

1. The statistical team agrees with the comments contained in DAA's review.
2. As we understand it, DAA endorses the selection of IVL as the preferred brand of sample tubes and endorses the decision to proceed with the monitoring study using IVL tubes.
3. We agree with DAA that further work is required to exclude the possibility of contamination of the tubes, to calibrate the assay results, and to characterise the statistical distribution of the assay results.
4. In an effort to characterise the statistical distribution of assay results obtained from field observations, we will do the following:
   (a) A second study of sample tubes will be performed, very similar to the design of the previous study, but using only IVL tubes. This second experiment will provide eleven-fold replication of each observation.
   (b) Historical field observations of air quality on Murujuga using IVL sample tubes, recorded by Woodside and recently provided to us, will be analysed with a view to selecting appropriate statistical models (e.g. probability distribution, appropriate transformation of data).
   (c) Detailed information will be requested from the manufacturer about the assay procedure that is performed on IVL sample tubes, with a view to determining an appropriate model of the occurrence of values 'below detection limit' (BDL), and in particular to decide whether left-censoring would be an appropriate model.
5. Regarding the calibration of assay results, we shall initially seek information from the supplier of IVL tubes about validation trials that may already have been performed. A decision whether to perform calibration experiments will be made in the light of such information. Reasons for deciding to perform our own calibration experiments might include the absence of studies that cover the environmental conditions (e.g. temperature) encountered on Murujuga.

Professor Adrian Baddeley
29 November 2022

## 2.3 Data Analysis Australia – Close-out comments

I agree with Adrian Baddeley's proposed steps forward. It is clear that the tube method of measuring air quality is not without problems and it is critical that the strengths and limitations be understood before too much is invested in the approach. (I don't know if there are alternatives.) I think the proposed further study and the obtaining of further manufacturer information are both appropriate and essential.

John Henstridge
Chief Consultant Statistician
7 December 2022

# 3 Methodology Statements

This section provides the independent peer review reports undertaken between June 2022 and October 2023 for the component study methodologies (Methodology Statements):

- Preparation of rock cubes for AQMs
- Passive air quality monitoring (AQM) installation and commissioning
- Passive air quality monitoring (AQM) sample collection, maintenance and context observations
- Unmanned aerial vehicle and spatial mapping
- Inorganic monitoring (pH and portable X-ray fluorometer)
- Microbiome field sampling
- Representative vegetation sample collection
- Photospectrometric colour change measurement
- Microbiome laboratory analysis
- Organic geochemistry of rock surfaces, dust and particulates
- Inorganic geochemistry laboratory analysis
- Sample rock collection
- Chamber exposure studies.

The final methodologies will form the standard operating procedures for the ongoing monitoring program.

## 3.1 Dr António Batarda Fernandes (2023)

| | |
|---|---|
| **Document titles** | **Murujuga Rock Art Monitoring Program: Methodology Statements**<br>1. COPP21065-PRO-G-101 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: PREPARATION OF ROCK CUBES FOR AQMS<br>2. COPP21065-PRO-G-102 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: PASSIVE AQM INSTALLATION AND COMMISSIONING<br>3. COPP21065-PRO-G-103 (Rev 1) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: PASSIVE AQM SAMPLE COLLECTION, MAINTENANCE AND CONTEXT OBSERVATIONS<br>4. COPP21065-PRO-G-105 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: UNMANNED AERIAL VEHICLE AND SPATIAL MAPPING<br>5. COPP21065-PRO-G-106 (Rev. 1) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: INORGANIC MONITORING (PH AND PORTABLE X-RAY FLUOROMETER)<br>6. COPP21065-PRO-G-107 (Rev. 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: MICROBIOME FIELD SAMPLING<br>7. COPP21065-PRO-G-109 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: REPRESENTATIVE VEGETATION SAMPLE COLLECTION<br>8. COPP21065-PRO-G-110 (Rev 1) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: PHOTOSPECTROMETRIC COLOUR CHANGE MEASUREMENT<br>9. COPP21065-PRO-G-112 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: MICROBIOME LABORATORY ANALYSIS<br>10. COPP21065-PRO-G-113 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: ORGANIC GEOCHEMISTRY OF ROCK SURFACES, DUST AND PARTICULATES<br>11. COPP21065-PRO-G-114 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: INORGANIC GEOCHEMISTRY LABORATORY ANALYSIS<br>12. COPP21065-PRO-G-115 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: SAMPLE ROCK COLLECTION<br>13. COPP21065-PRO-G-117 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: CHAMBER EXPOSURE STUDIES |
| **Reviewer** | **António Batarda Fernandes** |
| **Date of review** | 18 September 2023 |

| Item no. | Section | Peer reviewer comment<br>18 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>11 November 2023 |
|---|---|---|---|---|---|
| 1 | General | A general comment to be made regarding the application of methodologies in the field has to do with, especially considering the envisioned aim of making possible for future work, notably involving measurements, to be made by non-specialists after the current project is over, is if calibration, measurement, and reading procedures can be simplified? | We are implementing a formal training program for the MAC Rangers who are currently working with us and will be leading the monitoring post-end 2025. We are also keeping in mind the principles the reviewer states, to simplify field monitoring techniques wherever possible, however more replicates are required before this can occur. | Ok. | - |
| 2 | General | Also considering comments #1 and 2 above on the 2023 Technical Report, in each of the statements below, if applicable, the need to consider if applied methodology involves non-invasive methods for rock art panels will be noted. | Addressed in other comments. | The issue here has to do with the fact some relevant statements noted applying non-invasive methods for rock art while other also relevant (in the sense that these implied the collection of samples) statements did not. For instance, see comments #4 and 5 below. Hence, the statements, when relevant, should be coherent on this matter? | A statement has been added to each methodology document, stating if the method was invasive or not, the samples to which it was applied and the multiple approvals required. A general statement has been added to the Executive summary. |
| **METHODOLOGY STATEMENT: UNMANNED AERIAL VEHICLE AND SPATIAL MAPPING** | | | | | |
| 3 | Section – 1.1.1 Marks and monuments | (See also Comment #21)<br>“This will likely take the form of one of the following:<br>• a small star iron/picket driven into the ground | In practice, we used existing survey monuments as control points where possible and at sites where none were present, utilised a 300 mm steel Y-post unless the ground was too rocky, in which case we used a 250 mm steel survey nail. | Ok, so should this be included in the text? | This text has been added, with some slight changes to be in third person and present tense. |

| Item no. | Section | Peer reviewer comment<br>18 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>11 November 2023 |
|---|---|---|---|---|---|
| | | • concrete post/mark on the surface with a spike or brass tube placed in the middle for centring<br>• concrete paving slab (ideally the AQM installation), with a drill hole or nail in the middle for centring equipment".<br>It is believed that it should briefly justified when and why each of these methods will be used, as it is mentioned "one of the following". | | | |
| **METHODOLOGY STATEMENT: INORGANIC MONITORING (PH AND PORTABLE X-RAY FLUOROMETER)** | | | | | |
| 4 | Section 1 – Purpose and scope | It is acknowledged that this statement adequately notes that "The data will be collected and interpreted as outlined in the sections on 'Non-invasive monitoring of rock art'". | Comment noted. | See comment #2. | A statement has been added to each methodology document, stating if the method was invasive or not, the samples to which it was applied and the multiple approvals required. A general statement has been added to the Executive summary. |
| **METHODOLOGY STATEMENT: MICROBIOME FIELD SAMPLING** | | | | | |
| 5 | Section 1 - Purpose and scope | It is believed that it should be noted if methodology involved non-invasive methods for rock art panels. | No microbiome sampling was done on the rock art panels, only the representative sample rocks. | Ok, so should this be included in the text? See comment #2. | A statement has been added to each methodology document, stating if the method was invasive or not, the samples to which it was applied and the multiple approvals required. A general statement has been added to the Executive summary. |
| **METHODOLOGY STATEMENT: PHOTOSPECTROMETRIC COLOUR CHANGE MEASUREMENT** | | | | | |
| 6 | Section 1 - Purpose and scope | It is believed that it should be noted if methodology involved non-invasive methods for rock art panels. | Spectrophotometry is a non-contact non-destructive technique that requires no sampling and has no physical impact on the surface, unlike some other non-contact techniques such as Raman spectroscopy that heats the surface. The light source is of such low intensity and heat generation and for such shorth duration that there will be no colour change induced by the procedure. | Ok, so should this be included in the text? See comment #2. | A statement has been added to each methods document, stating if the method was invasive or not, the samples to which it was applied and the multiple approvals required. A general statement has been added to the Executive summary. |
| 7 | Section 3 - Equipment, consumables and training required | "If that is their wish to incorporate such scientific procedures into their ongoing custodial role" – it is suggested to consider the need to use this sentence (and the gist of the following paragraph) in each of the statements which imply the continued gathering of data after the current study is completed. | In 2023 the project has acquired an instrument that will remain with the Murujuga Aboriginal Corporation beyond the current project. This instrument, by the same manufacturer, will be calibrated to and work alongside the JAZ instrument for the first 2-3 campaigns. The assigned MAC Rangers have already mastered the operation of the JAZ instrument and will, by the completion of the current project, be familiar with the basic physics governing reliable spectral acquisition. | Ok. | - |
| 8 | Section 3 - Equipment, consumables | Can it be expected that in the foreseeable future colour change will cease to be "a viable measure of industrial impact"? | Colour change, as part of the overall spectral change queried by the JAZ spectrophotometer, will remain a useful metric of change for any length of time. It needs to | Ok, so should this be included in the text? | This text has been added. |

| Item no. | Section | Peer reviewer comment<br>18 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP close-out response<br>11 November 2023 |
|---|---|---|---|---|---|
| | and training required | | be emphasized that the photospectrometer is not only determining colour and its change, but equally importantly, is being applied in spectral mineralogy mode to determine mineralogical change, that may not translate as colour change. Spectral mineralogy does not speciate the minerals by determining their colour but rather by their spectral signature unique to that mineral. The spectral change issue is not whether time makes the measurement technique redundant but rather how long it takes to get meaningful change data. Some commentators have suggested the engraving may disappear within decades. Such rapid change will be detectable by the spectrometer within six months. On the other hand others have suggested that the return to a surface appearance matching undisturbed adjacent rock may take in excess of 20,000 years. Such gradual change may not be discernible in the spectrometer for 20 years. A more realistic scenario is one where colour change is cyclical through changing seasons. It is important to measure such seasonal changes to isolate them from long term industrial impact trends. | | |
| **METHODOLOGY STATEMENT: MICROBIOME LABORATORY ANALYSIS** | | | | | |
| 9 | Section 1 - Purpose and scope | "Which microbes carry the genetic machinery that can potentially form or deteriorate rock patina and which of these genes are actively expressed and potentially translated into enzymes that carry out these processes?" Is it possible that microbes carrying genetic machinery to potentially form or deteriorate rock patina do both, according to variables changing, say for instance, dry/wet season succession? | Yes, this is the case. We hope to see if there is any difference in what genes are being transcribed between the sample seasons (dry and wet). We can also test if differences in the metadata collected with the patina samples has any significant correlation on what genes are being transcribed. | Ok, it will be interesting to check results of this line of research. | Comment noted. |
| **METHODOLOGY STATEMENT: ORGANIC GEOCHEMISTRY OF ROCK SURFACES, DUST AND PARTICULATES** | | | | | |
| 10 | Section 1 / 2 | It is believed that it should be noted if methodology involved non-invasive methods for rock art panels. | No organic geochemistry analysis was performed on rock art panels. Rocks from the same rock type collected close to the rock art panels were used as sample rocks. | Ok, so should this be included in the text? See comment #2. | A statement has been added to each methodology document, stating if the method was invasive or not, the samples to which it was applied, and the multiple approvals required. A general statement has been added to the executive summary. |
| **METHODOLOGY STATEMENT: SAMPLE ROCK COLLECTION** | | | | | |
| 11 | Section 1 - Purpose and scope | It is acknowledged that this statement adequately notes "destructive analyses of non-petroglyph rock samples of the Monitoring Studies Data collection and Analysis Plan." | Comment noted. | See comment #2. | A statement has been added to each methodology document, stating if the method was invasive or not, the samples to which it was applied and the multiple approvals required. A general statement has been added to the Executive summary. |

## 3.2 Professor Geoffrey Gadd (2023)

| | |
|---|---|
| **Document titles** | **Murujuga Rock Art Monitoring Program: Methodology Statements**<br>1. COPP21065-PRO-G-101 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: PREPARATION OF ROCK CUBES FOR AQMS<br>2. COPP21065-PRO-G-102 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: PASSIVE AQM INSTALLATION AND COMMISSIONING<br>3. COPP21065-PRO-G-103 (Rev 1) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: PASSIVE AQM SAMPLE COLLECTION, MAINTENANCE AND CONTEXT OBSERVATIONS<br>4. COPP21065-PRO-G-105 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: UNMANNED AERIAL VEHICLE AND SPATIAL MAPPING<br>5. COPP21065-PRO-G-106 (Rev. 1) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: INORGANIC MONITORING (PH AND PORTABLE X-RAY FLUOROMETER)<br>6. COPP21065-PRO-G-107 (Rev. 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: MICROBIOME FIELD SAMPLING<br>7. COPP21065-PRO-G-109 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: REPRESENTATIVE VEGETATION SAMPLE COLLECTION<br>8. COPP21065-PRO-G-110 (Rev 1) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: PHOTOSPECTROMETRIC COLOUR CHANGE MEASUREMENT<br>9. COPP21065-PRO-G-112 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: MICROBIOME LABORATORY ANALYSIS<br>10. COPP21065-PRO-G-113 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: ORGANIC GEOCHEMISTRY OF ROCK SURFACES, DUST AND PARTICULATES<br>11. COPP21065-PRO-G-114 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: INORGANIC GEOCHEMISTRY LABORATORY ANALYSIS<br>12. COPP21065-PRO-G-115 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: SAMPLE ROCK COLLECTION<br>13. COPP21065-PRO-G-117 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: CHAMBER EXPOSURE STUDIES |
| **Reviewer** | **Geoffrey Michael Gadd** |
| **Date of review** | 15 September 2023 |

| Item no. | Section | Peer reviewer comment<br>15 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| 1 | General | Methodology statements usefully followed a common template and were clearly written and presented, often containing informative appendices. | - | - | - |
| **METHODOLOGY STATEMENT: PREPARATION OF ROCK CUBES FOR AQMS** | | | | | |
| 2 | | Straightforward procedures for preparation of rock cubes from the five predominant rock types. This aspect could provide some useful information about microbial colonisation of the different rock types, and the main species involved.<br>Some queries/points are:<br>• I infer that most of the cubes will have newly-exposed surfaces resulting from cutting up of the rock. Will any consideration be given to colonisation of sterilised rock surfaces that have previously been weathered through natural abiotic/biotic processes over time? | • As the rocks are on the order of billions of years old in general, the interior surfaces, while not patinated, contain some alteration or weathering. E.g. the basalt rock cubes contain weathered fissures or cracks throughout. This should provide a spectrum of chemical and morphological elements for microbial colonisation. | • OK, but the interior surfaces will still be quite different to the exterior surfaces that have received exposure to the atmosphere. | • We agree that the interior surfaces are different, however this is analogous to the weathering of a fractured or deeply engraved rock. We also had concerns whether it was possible to sterilise the surface patina properly. Geochemical studies have shown nearly closed cavities below the surface |

| Item no. | Section | Peer reviewer comment<br>15 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | • The rock cubes will be placed inside the air monitoring systems. How will this affect potential exposure to the atmosphere and surface inoculation? Would it be more relevant if cubes were fully exposed to the atmosphere? Surfaces are inoculated by aerially-deposited propagules and any restriction of this might reduce colonisation.<br>• The sterilisation procedure seems very rigorous (450ºC, 8 hours, twice) – is this a standard used procedure?<br>• Is it known whether such a strong treatment can alter or affect rock structure, mineral and other chemical components?<br>• Will rock cubes be rehydrated after the heat treatment or will further water absorption rely on atmospheric conditions?<br>• Only bacteria are mentioned as possible contaminants, but fungi are also important to consider especially because of the aerial spore dispersal of many species. | • Since epoxy resin will be used to locate the stainless steel mounting hardware in the base of the rock cube, we no longer use heat sterilisation. Instead, we will submerge the cubes in 70% ethanol for 10 minutes and flame sterilise subsequently.<br>• Rehydration will rely on atmospheric conditions.<br>• This must have gone lost in translation since we agree that fungi should definitely be mentioned as potential contaminants. | • The highlighted comment has not been addressed/clarified.<br>• OK.<br>**The methodology statement has been amended.**<br>• OK.<br>• OK. | which appear to have microbial deposits.<br>• Regarding the rock cube exposure to air. All the solar powered stations are a cage with an open top. So the rock cubes will be freely exposed to air/dust and airborne microbiome (or wildlife interaction).<br>Likewise, for the powered stations, the rock cubes will be placed on the roof of the monitoring station. While the elevated position is perhaps less than ideal, it was desired to minimise the risk of contamination by humans during routine monitoring and maintenance. |
| **METHODOLOGY STATEMENT: PASSIVE AQM INSTALLATION AND COMMISSIONING** | | | | | |
| 3 | | I have no specific comments regarding this very detailed summary of the components and assembly. However despite the detail and the diagram, I still cannot envisage what it actually looks like. What are the panels – are they a kind of open mesh? Is the cage top open to the atmosphere? A 3D diagram or image would be helpful. | The AQMs have an open top and mesh sides with 50 x 50 mm opening. A 3D drawing has been added to the document. | OK thank you.<br>**The methodology statement has been amended.** | - |
| **METHODOLOGY STATEMENT: PASSIVE AQM SAMPLE COLLECTION, MAINTENANCE AND CONTEXT OBSERVATIONS** | | | | | |
| 4 | | I have no specific comments on this detailed methodology except, as above comment, some images or a video of how everything is in place would be helpful (to me, anyway!). | We are preparing videos as part of the MAC Ranger training program, and can make these available in the near future. | OK. | - |
| **METHODOLOGY STATEMENT: UNMANNED AERIAL VEHICLE AND SPATIAL MAPPING** | | | | | |
| 5 | | I have no specific comments on this detailed methodology. | Comment noted. | - | - |
| **METHODOLOGY STATEMENT: INORGANIC MONITORING (PH AND PORTABLE X-RAY FLUOROMETER)** | | | | | |
| 6 | | I have no specific comments on this detailed methodology. | Comment noted. | - | - |
| **METHODOLOGY STATEMENT – MICROBIOME FIELD SAMPLING** | | | | | |

| Item no. | Section | Peer reviewer comment<br>15 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| 7 | | The methodology is detailed and broadly follows standard procedures used in other environmental sampling studies. Some comments/queries:<br>• What was the rationale for only sampling in the wet season?<br>• What is the "preservation solution" referred to in Section 1? Is it the DNA/RNA Shield solution?<br>• There is little detail on the procedures for soil sampling and treatment.<br>• Will there be any attempt to quantify microbial populations present in the rock microbiome or is this not possible with the analyses to be conducted?<br>One technique for non-destructive sampling of surfaces, that has been used in rock cultural heritage studies, is the use of various adhesive tapes to pick up removable surface propagules which can then be observed, cultured or analysed later. In fact many rock cultural heritage studies use similar approaches to those described here and for the same purposes, i.e. what organisms are there, their origins, and what are their effects on the rock – such studies could beneficially inform the work in this project. | • We have sampled during both wet and dry seasons, however the "wet" season was abnormally dry and the "dry" season was abnormally wet. However, ultimately we have collected two sets of samples under different climatic conditions and one being post-recent rainfall.<br>• We always used DNA/RNA Shield solution which is a commercial solution from ZymoBIOMICS (Zymo Research) that ensures the integrity of RNA and DNA for a minimum of 7 days at ambient temperature, and indefinitely at -20$^{o}$C.<br>• One gram of soil samples were mixed with 5 mL of DNA/RNA Shield solution. In the field, the samples protected by the solution were kept in eskies filled with frozen blue ice packs and stored at -20$^{o}$C at the MAC office. They were then shipped to Curtin by air inside a dry shipper at -196$^{o}$C and kept at -80$^{o}$C at Curtin. The DNA/RNA miniprep from Zymo Research is completely compatible with their DNA/RNA shield solution so we simply follow their protocol.<br>• We will not be quantifying microbes on the rock surface. Given the porous nature of the rock this would be a difficult task to do accurately.<br>• Through sampling the close by rocks facing the same way and with the same slope we are able to get a sample of not just the surface, but also the deeper layers. This allows us to get enough sample for successful sequencing but also get a more complete understanding of the microbial community. As you mentioned just getting a sample from the surface for cultivation would be too selective. | All the points have been clarified.<br>**The methodology statement is satisfactory.** | - |
| **METHODOLOGY STATEMENT: REPRESENTATIVE VEGETATION SAMPLE COLLECTION** | | | | | |
| 8 | | • What might be the time period from actual plant sampling to the analytical phase? As mentioned above, the chemistry of natural samples can change significantly after collection. Is anything known about this for plant material?<br>• Presumably in the natural location released volatiles from the plants or present in smoke from bush fires reflect contributions from all the species present which occur in differing proportions and biomass | • We are really focusing on the higher-molecular-weight lipids not volatiles from the plants only volatiles from burning.<br>• Yes. | OK. I see. Points have been clarified.<br>**The methodology statement is satisfactory.** | - |

| Item no. | Section | Peer reviewer comment<br>15 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | production. Is there any desire to address this and correlate results from the individual plant species samples to mixed plant populations at the site?<br>• Does the overall chemical composition of plant material vary widely between different species, and are there large differences in the potential volatiles that may be produced by different plant species? | • Yes, we are analysing individual plants for their higher molecular-weight lipids – these won't change – they will represent different plant species – different lipid profiles. Yes we also measure d13C and dD of individual compound classes – reflects pathway of photosynthesis and different biosynthetic pathways. | | |
| **METHODOLOGY STATEMENT: PHOTOSPECTROMETRIC COLOUR CHANGE MEASUREMENT** | | | | | |
| 9 | | I have no specific comments on this detailed methodology. | - | - | - |
| **METHODOLOGY STATEMENT: MICROBIOME LABORATORY ANALYSIS** | | | | | |
| 10 | | The methodology is based on modern DNA-based molecular approaches and associated bioinformatic analysis with some aspects of standard isolation and culture methods.<br>Inference of microbial activities will be made through identification of functional genes, and which of these might be expressed. It is usual to complement such an approach with some experimental analysis of key microbial isolates and the processes that they are capable of, e.g. mineral dissolution, biomineralisation, redox transformations, etc. Are any such studies contemplated?<br>Section 1:<br>**1c** Many key processes are not directly mediated by enzymes but rather by excreted metabolites such as $CO_2$, organic acids, etc. There are biochemical pathways involving enzymes in their production, but direct enzymic involvement is only found in some metal redox transformations, e.g. of iron (Fe), Mn, by certain bacteria.<br><br><br><br><br><br>**2b** I am unclear as to the relevance of identifying ancient DNA (aDNA) to the study.<br><br>**2c** The growth rate of patina-associated microorganisms may be very slow. Is there published | We unfortunately don't have the capacity to do microbial experiments on these colonies. The cultivation of the rock surface microbes has led to the growth of hundreds of colonies. We have roughly 300 plates with multiple colony types on each plate. To identify key microbes on these plates would be a task too large for the scope of the study and based on logistics we had to freeze the plates and cannot maintain cultures. Given these limitations we are planning to do 16S and ITS sequencing on these plates to identify what has grown. If bioinformatic analysis finds key microbes, we could attempt to isolate and further study their cellular abilities in the future.<br>**1c.** While this is true, we can gain an understanding of a lot of different cellular capabilities through bioinformatic analysis. Many microbes in the dataset may be unculturable so bioinformatics is the best way to get an understanding of the whole microbial community rather than a selected number of culturable microbes.<br>The capacity for organic acid production can be found in the genome. Through comparing what we find in the bioinformatics and working with the organic geochemists and geologist we hope to get an idea of both the biotic and abiotic process affecting the rock surface.<br>**2b**. As stated in the original proposal, the aDNA study is basically the use of a bioinformatics tool (mapDamage) to identify post-mortem modification to their genomic DNA. It is an added bonus.<br>**2c**. As stated in the original proposal: We will use another bioinformatics tool to calculate growth rate | OK, I understand the problem.<br>The other points/queries have been clarified.<br><br>**The methodology statement has not been amended in response to points/queries, but I do not think this is necessary.** | - |

| Item no. | Section | Peer reviewer comment<br>15 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | information on this for other rock patina/crust systems? Also is there always a patina on the rocks, which implies associated mineral formation, or are general microbial biofilms also present?<br>**3** Cultivation techniques to follow seasonal changes but sampling only took place in the wet season for this report? Will more sampling take place subsequently therefore?<br>As previously mentioned, and as is well known, cultivation experiments may only reveal a fraction of the organisms present and distortion of numbers obtained using plate counts by bacterial and fungal spores and mycelial fragments make quantification difficult if not impossible. Only basic conclusions may be reached for those organisms that can be isolated using the procedures employed. The best outcome of isolation methods is obtaining of strains that can be explored in later physiological studies.<br>What are the pristine field samples? Are these the rock slabs and the rock cubes?<br>**4** Initial colonisation of rock surfaces will be by deposition of cells, spores, particles, etc. resulting in colonial/biofilm formation. The timescale to form an actual patina might be very long and needs to involve significant rock and mineral transformations.<br>**5** What are the key pollutants that might be used? Some examples should be provided. Will the same molecular approaches and cultivation experiments be used to assess effects?<br>Integration of the molecular biological datasets with mineralogy, organic geochemistry, spectral, and air quality metadata is desired although the listed questions that might be answered through such integration appear solely to depend on the microbiome studies. Some of these answers are already known from many other studies, e.g. the mechanisms behind the long-term survival of extremophiles that colonise desert rocks, the significance of soil and air as inoculum sources, and the microbial species capable of rock transformations and the mechanisms involved.<br>“How do the members of these complex microbial ecosystems interact at individual to whole community levels?” – this is an extremely complex task and might be unattainable in the present study.<br>“At what rate do patina-forming bacteria and fungi colonise the patina-free rock slab surfaces, and in what order?” – not all the colonising microorganisms will be capable of patina formation, and, as mentioned, patina formation may be a very slow process. | based on the shotgun metagenomic datasets. It may not be sensitive enough, but it can do this for microbes that comprise at least 0.2% of the population.<br>**3** This question was raised above and has been answered already (we did repeat the plating during the dry season, and we agree with the selective bias involving cultivation, but we will compare the living and active fraction of bacteria and fungi from 16S and ITS transcripts/cDNA sequencing).<br>**4** Possibly, but we won’t know until we try.<br>**5** Nitrate and volatile organic compounds (VOC). Yes (same sampling/approaches and analysis as for the field samples). Network analysis from the ITS and 16S (both genomic and reverse-transcribed ITS and 16S) can be done to look for microbial interactions. For logistic reasons we cannot perform a detailed time-series experiment so it will be t=0 (blank), t=2 years wet/dry seasons). We will identify those taxa involved in metal cycling from the shotgun metagenomic datasets. | | |

| Item no. | Section | Peer reviewer comment<br>15 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>30 October 2023 | MRAMP team close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| | | **Section 2** – Some of the above comments also apply here.<br>**Section 5 –** The molecular and bioinformatic approaches are modern and well described in detail.<br>**5-11** Some examples of the organic/inorganic pollutants are not provided.<br>**5-11** Not all members of the rock viable community will be culturable, so species obtained using plating methods may reflect only a small proportion of the actual natural population. | **Section 5**: It will also include the dead stuff as answered above (hence the need for aDNA work). We will compensate for the obvious limitations of the selective growth of non-fastidious taxa on the plates with the molecular tools (cDNA sequencing of reverse transcribed ITS and 16S as outlined earlier). | | |
| **METHODOLOGY STATEMENT: ORGANIC GEOCHEMISTRY OF ROCK SURFACES, DUST AND PARTICULATES** | | | | | |
| 11 | | I have no specific comments on this detailed methodology. | Comment noted. | - | - |
| **METHODOLOGY STATEMENT: INORGANIC GEOCHEMISTRY LABORATORY ANALYSIS** | | | | | |
| 12 | | This aspect is well supported by a range of modern and appropriate analytical technologies. I have no specific comments. | Comment noted. | - | - |
| **METHODOLOGY STATEMENT: SAMPLE ROCK COLLECTION** | | | | | |
| 13 | | I have no specific comments on this straightforward methodology. | Comment noted. | - | - |
| **METHODOLOGY STATEMENT: CHAMBER EXPOSURE STUDIES** | | | | | |
| 14 | | Regarding the combustion chamber, what are the operational details – temperature and time? | We are still finalising the protocol for the chamber studies, however the attached methods document has been significantly updated. We have now split into separate protocols for geochemical processes and microbial processes. For the geochemical processes, we have settled on one hour exposure, followed by 23 hours of incubations, both at 60$^{o}$C. With repeats of up to six times. For microbiome experiments, we are likely conducting experiments using monocultures or simplified colonies which have been green fluorescent protein (GFP) labelled, permitting pre- and post-exposure measurements using confocal microscopy. These experiments will obviously include clean air exposures as negative controls and likely be shortened duration than the geochemical exposures. We welcome any further comment on this preliminary method. | OK, thank you for the clarification.<br><br>**The methodology statement has been updated and amended.** | - |

## 3.3 Dr Ron Watkins (2023)

| | |
|---|---|
| **Document titles** | **Murujuga Rock Art Monitoring Program: Methodology Statements**<br>1. COPP21065-PRO-G-101 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: PREPARATION OF ROCK CUBES FOR AQMS<br>2. COPP21065-PRO-G-102 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: PASSIVE AQM INSTALLATION AND COMMISSIONING<br>3. COPP21065-PRO-G-103 (Rev 1) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: PASSIVE AQM SAMPLE COLLECTION, MAINTENANCE AND CONTEXT OBSERVATIONS<br>4. COPP21065-PRO-G-105 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: UNMANNED AERIAL VEHICLE AND SPATIAL MAPPING<br>5. COPP21065-PRO-G-106 (Rev. 1) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: INORGANIC MONITORING (PH AND PORTABLE X-RAY FLUOROMETER)<br>6. COPP21065-PRO-G-107 (Rev. 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: MICROBIOME FIELD SAMPLING<br>7. COPP21065-PRO-G-109 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT – REPRESENTATIVE VEGETATION SAMPLE COLLECTION<br>8. COPP21065-PRO-G-110 (Rev 1) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: PHOTOSPECTROMETRIC COLOUR CHANGE MEASUREMENT<br>9. COPP21065-PRO-G-112 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: MICROBIOME LABORATORY ANALYSIS<br>10. COPP21065-PRO-G-113 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: ORGANIC GEOCHEMISTRY OF ROCK SURFACES, DUST AND PARTICULATES<br>11. COPP21065-PRO-G-114 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: INORGANIC GEOCHEMISTRY LABORATORY ANALYSIS<br>12. COPP21065-PRO-G-115 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: SAMPLE ROCK COLLECTION<br>13. COPP21065-PRO-G-117 (Rev 0) Murujuga Rock Art Monitoring Program METHODOLOGY STATEMENT: CHAMBER EXPOSURE STUDIES |
| **Reviewer** | Ron Watkins |
| **Date of review** | 28 September 2023 |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP Team close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| 1 | General | All methodology statements were reviewed. They are for most part clear well conceived and uncontroversial statements of well-established techniques of field study and laboratory practices and analysis. Comments are made only where questions or typographic errors occur, or where I have particular expertise. | - | - | - |
| **METHODOLOGY STATEMENT: PREPARATION OF ROCK CUBES FOR AQMS** | | | | | |
| 2 | 101 | Will not the use of clean freshly-cut surface provide an environment unlike the natural weathered exteriors of rock outcrops?<br><br>Will not placement of cubes at height within the enclosures disallow natural mechanisms of microbial recruitment that occur on the ground (e.g. by movement of animals or from vegetation litter)? | The rock cubes were included in response to microbiology reviewer's requests. Due to the age of the rocks they are not completely devoid of weathering and alteration, even on the cut surfaces. The basalt in particular has minor weathered cracks and fissures throughout.<br>Placement at the top of the cage was to avoid contamination from the human microbiome so far as possible. Time will tell regarding colonisation, however the cubes will experience significant dust deposition as well as likely contact with fauna. | Noted √ | - |
| 3 | | • Page 4; line 10: "frock" replace by "of rock".<br>• Page 5; line 23: "where to rock was attached" replace with "where the rock was attached". | Done. | Checked √ | - |
| **METHODOLOGY STATEMENT: UNMANNED AERIAL VEHICLE AND SPATIAL MAPPING** | | | | | |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP Team close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| 4 | | Page 4; line 21: “A (semi) permeant mark” replace by “A (semi) permanent mark”. | Done. | Checked √ | - |
| **METHODOLOGY STATEMENT: INORGANIC MONITORING (PH AND PORTABLE X-RAY FLUOROMETER)** | | | | | |
| 5 | | Proposed procedures are well explained and appear sound.<br>Will revisiting of precise location of measurement in the case of pH give concern? If so, how will the coincidence with points of past measurements be avoided? | pH will not be measured on the precisely same location each time. Instead, a similar type of patina will be monitored. We take pictures each time so points of past measurements can be avoided. This has been added to the methods. | Satisfactory √ | - |
| **METHODOLOGY STATEMENT: INORGANIC GEOCHEMISTRY LABORATORY ANALYSIS** | | | | | |
| 6 | | Describes in detail well-established techniques and methodologies. Employs an extensive range of instrumentation with appropriate awareness of the strengths and limitations of each. As with each new research initiative, time and testing will tell what works on the Murujuga samples and what does not. | Comment noted. | - | - |
| 7 | | • Page 7; line 7: “weather ring” replace with “weathering rind”.<br>• Page 10; line 14: “Tom’s Office” is rather informal. (May not be familiar to a new user?)<br>• Page 11; line 27: “…. of evaporation to do not incur in charging effects” requires rewrite. | “Tom’s Office” to be replaced by more comprehensive statement around chain of custody.<br><br>Grammar issues addressed. | Checked √<br><br>√ | - |
| **METHODOLOGY STATEMENT: SAMPLE ROCK COLLECTION** | | | | | |
| 8 | | • Page 4; line 11: “A number of 64 rock samples” replace with “Sixty-four rock samples”.<br>• Page 4; line 16: re: “to prevent contamination of the samples with organic material” add “from hands”, since the wearing of gloves does not prevent transfer of organic substances between samples or from other sources.<br>• Page 4; line 27: “sledge **hammer**” – I don’t expect snow will be encountered!<br>• Page 5; line 5: “Sharpies” is a not universally known brand name. Replace with “permanent marker”.<br>• Page 5; lines 17 and 21: replace “sledge” with “sledge hammer”. As no doubt will be discovered, use of a geological hammer is often more effective and practical than using a sledge hammer. | Fixed. | Checked √ | - |
| **METHODOLOGY STATEMENT: CHAMBER EXPOSURE STUDIES** | | | | | |
| 9 | | The aims could have been better explained. They are clearly not related to human health issues.<br>Is there any plan to assess inorganic chemical changes or microtopographic changes at the cube surfaces? | The document has been significantly revised. The revised methodology is focused on measuring inorganic chemical dissolution from the rock surface, as well as pH and hopefully also microtopographic changes. The microbiome studies are however very closely aligned conceptually and functionally with the health/toxicology studies for which the chamber was originally designed. | Noted √ | - |

| Item no. | Section | Peer reviewer comment<br>28 September 2023 | MRAMP team response<br>23 October 2023 | Peer reviewer close-out comment<br>31 October 2023 | MRAMP Team close-out response<br>10 November 2023 |
|---|---|---|---|---|---|
| 10 | | Page 8; line 2: “Samples will undergo post exposure pH samples and then ….” replace with “Samples will undergo post exposure pH measurement and then ……”. | Done. | Checked √ | - |

## 3.4 Dr Jillian Huntley (2022)

Dr Huntley was engaged in 2022 to review early versions of *Methodology Statement: Inorganic Monitoring (pH and Portable X-Ray Fluorometer)* and *Methodology Statement: Photospectrometric Colour Change Measurement*. The next versions of the methodology statements were reviewed by Dr António Batarda Fernades in 2023, refer Section 1.1.

| | |
|---|---|
| **Reviewer** | Dr Jillian Huntley with quality assurance/internal review by Professor Lynley Wallis (Wallis Heritage Consulting) |
| **Document titles** | 1. Murujuga Rock Art Monitoring Program: Methodology Statement: Inorganic Monitoring (pH and Portable X-Ray Fluorometer) (Rev 1)<br>2. Murujuga Rock Art Monitoring Program: Methodology Statement: Photospectrometric colour change measurement (Rev 1) |
| **Document revision** | Revision 1 |
| **Date of review** | • 25 July 2022 – Initial peer review<br>• 13 September 2022 – Contractor response to peer review<br>• 16 November 2022 – Addendum to contractor response to peer review<br>• 22 November 2022 - Peer reviewer close out<br>• 04 August 2023 – Contractor response to peer reviewer close out<br>• December 2023 – DWER additional comment (Item 11). |

| **Item no.** | **Section No.** | **Peer reviewer comment** 25 July 2022 | **MRAMP team response** 16 November 2022 | **Peer reviewer close-out comment** 22 November 2022 | **MRAMP team close-out response** 4 August 2023 |
|---|---|---|---|---|---|
| 1 | Both documents: Throughout | The methodology documents do not have standardised content:<br><br>The Inorganic Monitoring (pH and Portable X-Ray Fluorometer) document tabulates the instrumentation and consumables to be used, listing the supplier and storage for the equipment throughout the program. I suggest this information and tabulation is also added to the Photospectrometric colour change measurement document. I further recommend that this table include the date of manufacture or expiration date for any consumables listed.<br><br>It would be useful for Tables 1 to 5 in the *Inorganic Monitoring (pH and Portable X-Ray Fluorometer)* methodology document, and for tables inserted into the *Photospectrometric colour change measurement* document, to contain manufacture/purchase dates for equipment, given that one of the most likely sources of introduced error are instrumental/consumable drift/failures. | Manufacturer/purchase dates and other requested information added to the method document. | Accepted.<br>No further comments. | Previous acceptance noted.<br><br>As discussed in item #9, a second spectrometer is now being purchased by the MRAMP team. Details of this instrument will be added to the next revision (rev. 2) of the methodology document. |

| Item no. | Section No. | Peer reviewer comment<br>25 July 2022 | MRAMP team response<br>16 November 2022 | Peer reviewer close-out comment<br>22 November 2022 | MRAMP team close-out response<br>4 August 2023 |
|---|---|---|---|---|---|
| | | The "Purpose and scope" section of the *Inorganic Monitoring (pH and Portable X-Ray Fluorometer)* document outlines how the methods correlate to the relevant sections of Calibre's MSDCAP. I recommend that this detail is added to the Purpose and scope section of the *Photospectrometric colour change measurement* document. | | | |
| 2 | Both documents | More detail is needed in the *Inorganic Monitoring (pH and Portable X-Ray Fluorometer)* document regarding assay locations.<br><br>The *Photospectrometric colour change measurement* document gives a detailed procedure for precisely (re)locating the data acquisition points on the stone surfaces in the field. In contrast, the *Inorganic Monitoring (pH and Portable X-Ray Fluorometer)* lists "transparencies to aid location of spots for measurement" in Table 4, but scant detail is given about the (re)location of the spots to be analysed other than in Section 5.3 where it states: "Locate three spots for analysis. Usually these will represent the different types of patina present on the rocks. Make a sketch in the notebook indicating the locations for analysis". Given the critical importance of (re)sampling the exact same locations over time I suggest the methodology documents are revised for clarity and to ensure exact re(sampling) is indeed possible.<br><br>I note that Section 3.2.3.ii of Calibre's MSDCAP explicitly states that "the XRF study will examine the same surfaces as those from which colour measurements are being taken", yet this is not mentioned in either methodology document. It is important for the methodology documents to stand alone, not requiring the user or those following the progress of the project, to have to refer to the separate | Spatial relocation for pXRF (portable X-ray fluorescence) added to Section 3(i)(a), and reason for not relocating pH (potential of hydrogen), Eh (oxidation-reduction potential), Cl (chlorine) measurements exactly given. | Accepted.<br>No further comments. | Closed. |

| Item no. | Section No. | Peer reviewer comment<br>25 July 2022 | MRAMP team response<br>16 November 2022 | Peer reviewer close-out comment<br>22 November 2022 | MRAMP team close-out response<br>4 August 2023 |
|---|---|---|---|---|---|
| | | (and much longer) MSDCAP in order to find necessary details.<br><br>Section 1.7.2 (Elemental distribution) of Calibre's MSDCAP states that "The XRF studies will also explore spatial elemental distribution of visual variability across a surface to give deeper interpretation of the composition of the variously coloured surfaces." With the exception of the quote above about the representation of "different types of patina" on the rocks being selected, no guidance about pXRF assay location is given in the method document. | | | |
| 3 | Both documents: Throughout | I remind Calibre of their obligations with regards to DWER's aspiration that the initial five-year program undertaken by the contractor will underpin a longer-term monitoring program with field data collection *to be undertaken by Murujuga's Traditional Owners via MAC*. I suggest that the training sections of both methodology documents be revised with this in mind. These sections should incorporate how the field data collection programs will build capacity for MAC field staff, guaranteeing their training for competency in undertaking the field data collection. | "Required training" section revised in line with the reviewer's comments. | Accepted.<br>No further comments. | Closed.<br><br>*Editor's note: No comment 4 provided by peer reviewer.* |
| 5 | Inorganic Monitoring (pH and Portable X-Ray Fluorometer)<br><br>Title | I suggest changing "Fluorometer" in the title of the Inorganic Monitoring (pH and Portable X-Ray Fluorometer) document to "Portable X-Ray Fluorescence". Whilst it is technically correct that the commercial pXRF instruments are spectrofluorometers, most lay people (including archaeologists and rock art specialists, rather than archaeological scientists) will only know these instruments as pXRF spectrometers and the added specificity currently in the title could lead to confusion. | Change made. | This change has not been made to the title. | We apologise for the omission in the updated (revision 1) document. The change will be captured in the next document update (to revision 2). |

| Item no. | Section No. | Peer reviewer comment<br>25 July 2022 | MRAMP team response<br>16 November 2022 | Peer reviewer close-out comment<br>22 November 2022 | MRAMP team close-out response<br>4 August 2023 |
|---|---|---|---|---|---|
| 6 | Inorganic Monitoring (pH and Portable X-Ray Fluorometer)<br><br>Table 5 and Section 5 | Workflow for pXRF measurement should be improved and an explanation of the comparability of data collected using two different manufactures given.<br><br>Table 5 lists an Olympus pXRF instrument, in addition to the Bruker Tracer 5G. Section 5, specifically 5.1.1 and 5.2.4, do not list the instrument parameters for either instrument, with 5.1.1 not mentioning the Olympus at all. The analysis type to be used on the Tracer (GeoExploration) is not noted until Section 5.3.1. Assay duration (30, 60, 90, or more seconds?) is not specified for either pXRF such as it is for the pH testing (where number of minutes for the probe in solution etc. are stated). No details for the start-up procedure (password, etc.) or analytic perimeters are given for the Olympus at all (presumably it too has variable selection in uA and kV). All of these issues must be addressed by Calibre. | New text:<br>At selected localities, repeat the measurement with the Olympus pXRF and cross-check the results. This is done to ensure that data from the sample selection field season (Nov/Dec 2021), which used the Olympus only, can be compared with data from subsequent field seasons where the Bruker is used. These data are provided in a separate report. The Olympus uses a GeoExploration calibration, analysis duration is 60 seconds (2x30s measurements). The other parameters are set within the calibration. | Accepted.<br>No further comments. | Closed. |
| 7 | Inorganic Monitoring (pH and Portable X-Ray Fluorometer)<br><br>Table 5<br>Section 3 | Table 5 lists a Bruker 5G helium kit. Presumably the use of the helium instrument atmosphere is important with regards to the measurement of sulphur as outlined in Section 3.2.3.ii of Calibre's MSDCAP. Yet, the use of helium is not mentioned in the workflow. This inconsistency must be addressed. | The helium (He) monitoring methods are still in development. It requires some fairly onerous changes to the set-up of the pXRF and transport of a heavy helium cylinder within the field, which has some safety implications. It is not clear that the advantage of this technique, which is the capacity to monitor sodium, outweighs the additional time required to employ the technique and the issues with carrying the cylinder. A final decision will be made after the results of monitoring for the first two seasons without He are compared and the value of sodium assessed in the light of those results.<br><br>Helium is only necessary where sodium is being detected. Sulphur is sufficiently detectable under normal operating conditions. | This was a typographic error on my part – I meant sodium, not sulphur. I realise sulphur can be reliably measured in air, especially where there is an option for vacuum atmosphere in the instrument (as is the case for instruments used herein).<br><br>It is completely understandable that the methods are "living documents" in the sense that they can be updated as the MRAMP progresses.<br><br>Perhaps it would be valuable to add a statement to this effect in the Purpose and scope or Description of tasks and/or activities (Sections 1 and 2, respectively) of the methodology statements. | Noted and agreed. We will add this to the next revision of the methodology statement. |
| 8 | Inorganic Monitoring (pH and Portable X-Ray Fluorometer)<br><br>Section 5 | Section 5.2.4 outlines internal standards to be measured at the start of each analytic session, to be checked against certified reference values (CRVs). I strongly recommend the known composition of these internal standards (the CRVs) is appended to the methodology document, which will | The standard data has been appended to the document as an appendix. | Accepted.<br>No further comments. | - |

| Item no. | Section No. | Peer reviewer comment<br>25 July 2022 | MRAMP team response<br>16 November 2022 | Peer reviewer close-out comment<br>22 November 2022 | MRAMP team close-out response<br>4 August 2023 |
|---|---|---|---|---|---|
| | | presumably be kept with the field equipment as a "user guide". | | | |
| 9 | Photospectrometric Colour Change Measurement<br><br>Section 3 | Only one analyst is listed in the "Training required" section, and therefore there are no training requirements. Whilst Andrew Thorn is unquestionably qualified and experienced to undertake the monitoring activities outlined in this methodology document, this leaves no redundancy in MRAMP (if something were to happen to him). I recommend a backup analyst, familiar with the equipment and methodology, be identified as a contingency. | The MAC Rangers have been incrementally trained by A. Thorn, such that they can now perform the measurements independently. A study on the influence of operator (if any) on the measurements is planned for the next field campaign (i.e. A. Thorn and the two MRAMP Rangers will each independently repeat measurements on the panel/s).<br><br>Furthermore, A. Thorn's relocation accuracy has been independently verified in tests at Curtin on preliminary sample rocks (via both real time kinematic (RTK) laser and image analysis) to <0.1 mm. A report on this validation is in preparation and will accompany the amended method.<br><br>If necessary, A. Thorn can provide a person fully familiar with the equipment he uses and operating methods. However, the redundancy issue is being addressed through MAC training. By the next field season at least one Ranger will be fully up to speed on all remaining field procedures. This Ranger has acquired a high level of competency in target location in a very short time and the next season will see him equally capable on the spectrometer and environmental instruments. The environmental data gathering will be simplified to a data logger requiring no site setup other than simply placing it in a suitable location. | I am not sure the Calibre team grasp the substance of my concern here. Doubtless Andrew Thorn is eminently qualified and has designed a robust and highly accurate data collection method for the colour monitoring.<br><br>The Calibre response goes part way to addressing my concern – i.e., it is heartening to see that the MAC Rangers have been trained in data collection and an assessment of the degree to which the operator influences measurements is planned.<br><br>But, who else apart from Thorn can/would **evaluate and interpret** the data collected in his absence? A contingency plan should exist for this possibility. | Photospectrometric data evaluation and interpretation is already being undertaken by members of Curtin's statistical team.<br><br>The data files downloaded from the spectrometer used by Andrew Thorn are text files with a ".jaz" file extension. These files can be analysed using the commercial software package "OceanInsight" provided with the instrument to display reflectivity spectra as graphical plots and convert a spectrum to perceptual colour coordinates (L, a, b values). This is the approach used by Andrew Thorn.<br><br>However, a more rigorous approach is required for MRAMP to account for sources of variability and fully explore potential exposure vs response relationships in conjunction with MRAMP's other component studies. The statistical team, with support from the Curtin Institute for Computation, have analysed the spectral data contained in the text files directly.<br><br>Section 7.1 of the 2023 Technical Report contains a comprehensive explanation of the work undertaken by the statistical team on evaluating and interpretating the photospectrometric observations.<br><br>It is worth noting that the MRAMP team is purchasing a second spectrometer, being the current model of the instrument being used by Andrew Thorn. Cross validation between the two instruments is planned for the fourth quarter of 2023 following receipt of the new spectrometer. Access to two cross-calibrated instruments for field measurements provides a further level of contingency planning for this |

| Item no. | Section No. | Peer reviewer comment<br>25 July 2022 | MRAMP team response<br>16 November 2022 | Peer reviewer close-out comment<br>22 November 2022 | MRAMP team close-out response<br>4 August 2023 |
|---|---|---|---|---|---|
| | | | | | part of MRAMP in the event that one or the other fails. |
| 10 | Photospectrometric Colour Change Measurement<br><br>Section 4 | Point 10 in the "Detailed Procedures" section of the Photospectrometric Colour Change Measurement document states that the time stamp of the spectral files and the image files for spectra location will be used to provenance the data. Given the time signatures of the equipment are critical, I recommend the document include a start procedure that checks the clocks on the equipment are synchronised. | This has been performed as a matter of course. The sequence of measurements is also separately recorded in triplicate – i.e. the sites and panels covered each day and the sequence for each panel. This has been clarified in the methods.<br><br>All time critical instruments are synchronised at the beginning of each field session and remain accurate over the five-week data acquisition. The methodology has been amended to note this. | Accepted.<br>No further comments. | |

| Item no. | Section No. | Peer reviewer comment<br>25 July 2022 | MRAMP team response<br>13 September 2022 | Peer reviewer close-out comment<br>22 November 2022 | MRAMP team close-out response<br>4 August 2023 | DWER additional comment<br>December 2023 |
|---|---|---|---|---|---|---|
| 11 | Photospectrometric Colour Change Measurement<br><br>Section 1 | The sentence "sites have been selected to give a statistically meaningful distribution of sites that embraces all rock types and various orientations and exposures" should also specify that a representative sample of the known rock art assemblage has been sampled in the MRAMP. I remind Calibre that they need to include in the MRAMP rock art sites that are *representative of the relative rock sequence and archaeological features and its relevance in the regional rock art sequence* in order to meet the terms of their commission (DWER103118 MRAMP Tender Document [VERSION 011018] Section 2.4.1 and 2.4.2) (DWER103118 Request for Tender Document). In order for the sample of rock art sites to be | This issue was raised during review of the study design (documented in the MSDCAP) and the statistical team provided a response to those earlier review comments at the time. As noted previously, a representative sample is not in fact required to satisfy such conditions, and that attempting to satisfy such conditions at Murujuga would work against the representativeness of the sample.<br><br>DWER's statistical expert peer reviewer provided a comprehensive review and commentary on the proposed study design and selection of rock art panels, and subsequently approved the sampling design as being suitable to fulfill the intended contractual requirements.<br><br>The purpose of the Photospectrometric Colour Change Measurement Methodology provided for review here is to document the colorimetry technique being used for the project. The methodology is intended to provide a detailed description of a particular component study of the overall program to ensure its repeatability for quality assurance purposes. As such, it is not intended to contain definitive statements of the statistical sampling design. The quoted sentence "sites have been selected to give a statistically meaningful distribution of sites | As with previous iterations of peer review for the MRAMP, we are at cross purposes here as the Calibre team seem to not grasp the substance of my concern. In my role as a peer reviewer, I am trying to ensure the MRAMP fulfills the requirements of the original Tender Document issued for MRAMP, the scope of works for which now forms the contractual obligations that Calibre must meet.<br><br>Specifically: "In the selection of additional monitoring sites, the Contractor must give appropriate consideration to:<br>The representativeness of the rock art selected for monitoring in terms of its archaeological features and its relevance in the regional rock art sequence".<br>(DWER103118 Request for Tender Document, Sections 2.4.1 and 2.4.2 pages 15 and 16) .<br><br>I take representative as intended by DWER to mean that each of the known archaeological characteristics the Murujuga rock art assemblage (even if it were only a single instance) be captured in MRAMP. This is clearly distinct from statistically | Thank you for further clarifying the nature of your concern regarding compliance or otherwise with the terms of the MRAMP contract in selection of the rock art panels for monitoring.<br><br>We agree with your understanding that one of the five criteria for consideration in selection of monitoring sites required by the Clause 2.4.1 of the current DWER101621 Request for Tender Document remains "the representativeness of the rock art selected for monitoring in terms of its archaeological features and its relevance in the regional rock art sequence".<br><br>The scientific team carefully considered this criterion, and we believe that it has been given "appropriate consideration" as mandated by the contract, for the following reasons:<br>• The DWER101621 Request for Tender Document and its guiding principles for designing the monitoring studies program and selecting the sites for monitoring were informed by the best known information at the time. | Both DWER and MAC are satisfied that the study design (MSDCAP) meets the contractual requirements for representativeness of the rock art.<br><br>The heritage report referred to in the peer review includes culturally sensitive images and descriptions of rock art that senior knowledge holders have not consented to release in a public forum.<br><br>The report was commissioned to ensure there was no material impact on heritage matters from the project and to support heritage permits under the *Aboriginal Heritage Act 1972.* The report forms part of MAC's cultural and intellectual property as defined under the DWER-MAC Partnership and Funding Agreements. |

| Item no. | Section No. | Peer reviewer comment<br>25 July 2022 | MRAMP team response<br>13 September 2022 | Peer reviewer close-out comment<br>22 November 2022 | MRAMP team close-out response<br>4 August 2023 | DWER additional comment<br>December 2023 |
|---|---|---|---|---|---|---|
| | | considered representative, not only stone types, but also relative chronology of the motifs, engraving technique(s) and petroglyph density need to be accounted for. | that embraces all rock types and various orientations and exposures" is a brief, non-technical but fairly accurate precis of the sampling design, intended to improve readability of the colorimetry methodology.<br><br>The rocks at Murujuga have many attributes, including those attributes mentioned by Dr Huntley (rock type, motif chronology, engraving technique, nearby petroglyph density) but also patina condition, surface dip and strike angles, shading, post-engraving history (breakage, movement down slope), water runoff exposure, and so on. Many of these attributes could indeed be important for the study. For that reason, these attributes were carefully considered in the original MSDCAP document under the heading of Sources of variability. However, many of these attributes cannot be measured directly, and require scientific interpretation (for example, time (age) of engraving is not measured directly; relative chronology is inferred from motif and engraving technique). Since only a small portion of the population of all petroglyphs at Murujuga have been studied, there is no reliable information about the overall population.<br><br>The sampling design that we have specified involves stratification over strata that can be easily identified (such as spatial location) and for which the population size is known. This sampling design is valid (unbiased) and should be relatively accurate (efficient).<br><br>A correct random sampling procedure is expected to produce a sample which contains a broad spread of attributes (e.g. with regard to contrast state, motif and technique) without the imposition of quotas.<br><br>Professor McDonald and a colleague from UWA's Centre for Rock Art Research and Management (CRAR+M) logged selected rock art study panels and those adjacent which were required to be recorded for approvals purposes during the study design | representativeness, as I have pointed out in previous peer reviews.<br><br>Calibre is correct that what is known about the rock art assemblage is limited. However, as all knowledge is cumulative, it seems unscientific to suggest that we not act on the best available data to hand (while acknowledging its limitations). Furthermore, I did not design the tender document and hence the scope of works for the MRAMP. However, as peer reviewer it would be remiss of me not to point out that it has not yet been demonstrated if the requirements of the MRAMP are being meet.<br><br>The validity of the statistical methodologies being implemented in the MRAMP are a moot point in regard to the concern I raise about DWER's requirement that representativeness of the rock art be captured in the MRAMP. That is to say that I am well aware of the history of the CSIRO program and the critical need for statistical validity of the sampling strategy that underpins the MRAMP (and, as stated in previous peer reviews, I am satisfied of this).<br><br>I am not suggesting, nor have I ever suggested, that Calibre implement an alternative statistical (stratification) methodology. I am simply reminding Calibre and DWER that the current iteration of the MRAMP is yet to provide evidence that it has meet its contractual requirement to ensure the MRAMP include sites that are representative of the relative rock sequence and archaeological features in relation to what is known about the regional archaeological sequence (DWER103118 Request for Tender Document Section 2.4.1 and 2.4.2, pages 15 and 16).<br><br>I raise this here again because the previous response provided by Calibre | • The detailed development of the MRAMP MSDCAP by the scientific team elaborates on, or reframes, some of the stated general principles. For example, Clause 2.4.2 requires reference sites (control sites) to be established that are "un-influenced" by anthropogenic emissions in the area. Through analysis of modelling commissioned by the Environmental Protection Authority (EPA) for the *Study of the Cumulative Impacts of Air Emissions in the Murujuga Airshed* (Ramboll, 2021) while developing the MSDCAP, we have determined that this is not possible as all locations in Murujuga are exposed to anthropogenic emissions to a greater or lesser degree. This discovery – together with the contractual requirement that the study design must have adequate statistical power – entails that the selected sites must exhibit a range of different levels of exposure to anthropogenic emissions.<br>• If all sites were selected so as to achieve a full range of levels of exposure to anthropogenic emissions, they would not automatically provide a representative range of archaeological features. Consequently, the scientific team determined that it would be necessary to select two separate sets of monitoring sites: air quality (AQ) sites and representative sample sites. This two-part design could be viewed as a further departure from the original specification in the DWER103118 Request for Tender Document, but it was developed precisely in order to satisfy the general principles of the DWER103118 Request for Tender Document and was subsequently approved. | |

<table>
<tr><th>Item no.</th><th>Section No.</th><th>Peer reviewer comment<br>25 July 2022</th><th>MRAMP team response<br>13 September 2022</th><th>Peer reviewer close-out comment<br>22 November 2022</th><th>MRAMP team close-out response<br>4 August 2023</th><th>DWER additional comment<br>December 2023</th></tr>
<tr><td></td><td></td><td></td><td>development. Rock art panel attributes recorded during site selection: dimensions (length/width/depth), colour, desert varnish (presence/absence), condition, type (bedrock/block/vertical surface), contour and dip. Individual rock art motifs were also recorded using the CRAR+M taxonomy (class, subject, attributes, traits) plus condition, depth, contrast state, form, technique, and whether there was superimposition (two or more motifs depicted on the same part of the panel) (McDonald and Beckett, 2022).<br><br>As an example, the table below summarises the frequency of different motifs and contrast states in the petroglyph panels which have been recorded as part of the MRAMP fieldwork. A heritage report containing more detail on the CRAR+M methodology and information tabled below was submitted to MAC and DWER for approval purposes prior to finalising the MSDCAP.<br><br>Table 1: Site selection observations - contrast state and motif.
<table>
<tr><td>MOTIF</td><td colspan="7">CONTRAST STATE</td></tr>
<tr><td></td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>NA</td><td>TOTAL</td></tr>
<tr><td>Anthropo-morphic</td><td>3</td><td>15</td><td>30</td><td>38</td><td>5</td><td>8</td><td>99</td></tr>
<tr><td>Geometric</td><td>10</td><td>53</td><td>75</td><td>72</td><td>10</td><td>29</td><td>249</td></tr>
<tr><td>Other</td><td>2</td><td>7</td><td>13</td><td>24</td><td>4</td><td>54</td><td>104</td></tr>
<tr><td>Tracks</td><td>1</td><td>24</td><td>25</td><td>33</td><td>5</td><td>9</td><td>97</td></tr>
<tr><td>Zoo-morphic</td><td>0</td><td>22</td><td>36</td><td>28</td><td>10</td><td>14</td><td>110</td></tr>
<tr><td>TOTAL</td><td>16</td><td>121</td><td>179</td><td>195</td><td>34</td><td>114</td><td>659</td></tr>
</table>
The occurrence of a motif type or contrast state in this table does not make the sampling design any more or less representative. For example, the fact that one cell of the table is empty does not mean that the sampling design had inadequate coverage of this combination of</td><td>which restates their statistical methodology for monitoring site selection has not addressed my concern. How a representative sample of the rock art assemblage is captured in the MRAMP is a moot point — it is a contractual requirement between DWER and Calibre that it is.<br><br>Therefore, all I have ever suggested is that (with MAC's permission) DWER and the peer reviewers of the MRAMP be provided with information regarding which attributes of the rock art assemblage are being captured in MRAMP to identify if there are any omissions from the known archaeological characteristics of the rock art assemblage. In the unlikely event that omissions in the characteristics of the known rock art sequence were present in the MRAMP, then DWER would need to work with Calibre to ensure they apply their statistically robust methodologies until such time as any identified gap was closed.<br><br>The discussion of other site attributes in this response such as patina condition, surface dip and strike angles, shading, post-engraving history (breakage, movement down slope), water runoff exposure, and so on is irrelevant and distracting. The stipulation made by DWER in the DWER103118 Request for Tender Document was that the characteristics of the relative rock sequence and archaeological features relating to the regional archaeological sequence be captured in the MRAMP – this is mutually exclusive of these other attributes listed in Calibre's response (which are covered in a separate, subsequent points in the DWER103118 Request for Tender Document on page 16).<br><br>The information provided in Table 1 is a reassuring start, but further detail is</td><td><ul><li>In designing the selection procedure for the representative sample sites, the scientific team assessed the information available on the known and recorded rock art on Murujuga and identified a number of concerns and constraints. Classification of individual petroglyphs (by age/sequence, style, engraving technique, etc.) is not universally agreed and - more importantly - requires close inspection of the individual petroglyph, so that it would be extremely difficult to select a pre-specified number of each type of petroglyph from across Murujuga. Any such "quota" sample would probably result in a sampling bias, which would imply that the selected petroglyphs and their host sites were not representative of the Murujuga population of petroglyphs in other respects.</li><li>Accordingly, the scientific team has determined that it would be infeasible and statistically indefensible to select sites to achieve a specified quota of each type of petroglyph. The randomised selection procedure adopted ensures that all characteristics of the petroglyphs are correctly represented - including, but not limited to, the desired representation of the age sequence and engraving technique.</li></ul>In our view, the sampling design has been developed with "appropriate consideration" for "the representativeness" of the selected rock art with respect to "its archaeological features and its relevance in the regional rock art sequence".<br><br>We agree that it is worth separate consideration to confirm that the work</td><td></td></tr>
</table>

| Item no. | Section No. | Peer reviewer comment 25 July 2022 | MRAMP team response 13 September 2022 | Peer reviewer close-out comment 22 November 2022 | MRAMP team close-out response 4 August 2023 | DWER additional comment December 2023 |
|---|---|---|---|---|---|---|
| | | | motif and contrast state.<br><br>This example reassures us that the sampling technique in the study design has captured a wide range of types of petroglyphs for these attributes, while also ensuring statistical validity required for the study design. | **required to ensure the substance of my comment is addressed**. | being undertaken by Calibre and Curtin fulfils contractual obligations to DWER's satisfaction, however we reiterate that this concern relates to compliance of the MRAMP design with contract requirements and not the specific methodology for colour change measurement provided for review here.<br><br>The methodology was provided for review under Clause 2.4.3 of DWER101621 Request for Tender Document, especially with reference to sub-clause 4, vis:<br>"All monitoring methodologies must be appropriate and robust for consistently collecting reliable and reproducible data in remote, exposed locations in rough terrain, often at high temperatures."<br><br>We contend that the methodology COPP21065-PRO-G-110 Photospectrometric Colour Change Measurement satisfies the contractual requirements for a monitoring methodology stated in DWER101621 Request for Tender Document, Clause 2.4.3 and respectfully request the peer review to be closed. | |
| | | | | **Potential conflicts of interest**<br>I am curious as to why work documenting and interpreting the rock art assemblage is being undertaken by Professor McDonald rather than Calibre's rock art specialist, who I understood from the authorship of the MSDCAP to be Dr Robert (Ben) Gunn. In the DWER103118 Request for Tender Document, Section 3.1 – Required Skills and expertise, page 19) DWER required that "the Contractor will have a multi- and inter-disciplinary team of Specified Personnel with highly specialised skills, qualifications and expertise in the following minimal requirements … 3. Rock art recording, interpretation and analysis, including the regional and local-scale physiographic conditions and the | **Potential conflict of interest**<br>The rock art expert engaged by Calibre at commencement of the Contract was unable to undertake the rock art documentation and interpretation work required to support the site selection process due to WA State Government COVID-19 travel restrictions in place at the time.<br><br>At the time of undertaking the time-critical fieldwork required to obtain Elder approval for MSDCAP in the fourth quarter of 2021, strict interstate travel protocols existed. Dr Robert Gunn was not able to commit to the prolonged stay in WA (plus additional quarantine periods) that would have been required for him to undertake this work, and he therefore declined to | **Conflict of interest management**<br>Both DWER and MAC are satisfied that the conflict of interest was declared and managed appropriately.<br><br>The MRA SRG is an advisory body and does not have an oversight or decision-making role in relation to MRAMP.<br><br>Potential conflicts of interest for Professor McDonald were addressed by her standing down from her role on the MRA SRG for the duration of her involvement on the |

| Item no. | Section No. | Peer reviewer comment 25 July 2022 | MRAMP team response 13 September 2022 | Peer reviewer close-out comment 22 November 2022 | MRAMP team close-out response 4 August 2023 | DWER additional comment December 2023 |
|---|---|---|---|---|---|---|
| | | | | regional archaeological record". This implies that it is a requirement of the MRAMP that Calibre have their own "in house" rock art expert.<br><br>Professor McDonald is unquestionably a world leading expert on the rock art and archaeology of Murujuga; however, she is also a past member, now observer, of the Murujuga Rock Art Stakeholder Reference Group (MRA SRG) who oversee the MRAMP, and I understand her substantive position as the Rio Tinto Chair in Rock Art Studies at the University of Western Australia (UWA) is funded by industry stakeholders who have ongoing operations contributing to the emissions that are the catalyst for the MRAMP (Rio Tinto also hold membership of the MRA SRG).<br>Therefore, several conflicts of interest may occur through Professor McDonald's direct participation in the MRAMP.<br><br>In summary, I am not satisfied that my concern has been understood, and it is certainly yet to be addressed.<br><br>I recommend that DWER seek further clarification from Calibre as to what rock art is being monitored and how that compares with the known archaeological attributes of the Murujuga rock art assemblage. This additional report should be prepared by a suitably qualified and experienced rock art specialist. | participate. At the time, there was no anticipated end for Coronavirus travel restrictions in WA and an alternative consultant needed to be found to allow MRAMP to move forward.<br><br>Following consultation with DWER and MAC, UWA's CRAR+M was invited to submit a tender for the rock art documentation and heritage impact assessments, and was subsequently awarded a contract for the work by Calibre.<br><br>Protocols were established to manage conflicts of interest during the term of Professor McDonald's engagement by Calibre, including her standing down from the MRA SRG for the duration of the contracted work. The services of Professor McDonald (and her assistant Emma Beckett), were paid for directly by Calibre under the MRAMP contract independent of her role as Rio Tinto Chair in Rock Art Studies at UWA.<br><br>Again, we note that this is a contractual matter between DWER and Calibre that is unrelated to the validity of the methodology COPP21065-PRO-G-110 Photospectrometric Colour Change Measurement. As such, we respectfully request the methodology peer review to be closed. | MRAMP. This was discussed and agreed with the then-Chair, Dr Ron Edwards, in accordance with the Terms of Reference, and MRA SRG members were advised of this decision. Professor McDonald resumed her role as an observer on the MRA SRG in 2022 once the heritage services were completed, and the declaration remains on the record.<br><br>Professor McDonald is employed by UWA, not Rio Tinto. The Rio Tinto and UWA research memorandum of understanding (MoU) is funded by Rio Tinto's Conservation Agreement with the Commonwealth to research the values of the Murujuga National Heritage Listed Place.<br><br>Professor McDonald agreed to undertake the heritage documentation of the MRAMP when, due to COVID-19 restrictions, the project's rock art expert Dr Robert (Ben) Gunn, was unable to travel to WA. MAC have further advised that it does not support the peer reviewer's recommendation for an additional external review. |