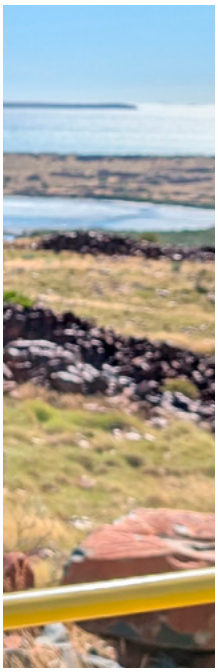
Government of **Western Australia**
Department of **Water and Environmental Regulation**



Murujuga Rock Art Monitoring Program: Research Summary

Year 2

The Murujuga Rock Art Monitoring Program is the most extensive scientific study to examine the impact of industrial air emissions on the marni (rock art engravings) of Murujuga, an area covering the Burrup Peninsula and Dampier Archipelago in Western Australia.

The monitoring program is led by the Murujuga Aboriginal Corporation (MAC) and the Department of Water and Environmental Regulation (DWER). This report summarises key learnings from the second year of research studies, which sets the initial levels of safe air quality for the rock art. In the final years of research, the scientists will refine and determine final safe air quality criteria. These will be monitored to ensure the long-term protection of the rock art.

MAC, DWER, and project contractors WSP and Curtin University recognise the Traditional Owners and Custodians of Murujuga. We pay respect to the past, present and future generations of Ngarluma, Yindjibarndi, Yaburara, Mardudhunera and Wong-Goo-Tt-Oo, who are the five groups collectively known as Ngarda-Ngarli. We thank them for their ongoing care for Murujuga's land and sea and their support for this significant research program.

In the first two years of research, the monitoring program has:

- completed 30 weeks of fieldwork, monitoring 54 rock art panels across the five rock types
- collected 18 months of air quality data from 21 stations located across Murujuga
- recorded over 66,000 rock surface colour, elemental, porosity and electrochemical measurements
- characterised the physical, chemical and geological composition of 64 sample rocks using specialist equipment at Curtin University
- collected 484 microbial samples for microbial composition (DNA/RNA) analysis

The data collected provides an important information source on air quality and rock art condition. This information has been subject to careful analysis by expert scientists and statisticians as well as independent peer review.

This information has been used to set the first ever interim Environmental Quality Criteria – the initial levels of ambient air quality that are safe for the rock art.

The research studies are being completed over four years and include integration of research in specialist areas such as rock microstructure, organic chemistry and geochemistry, rock surface microbiology, air quality and local climate conditions.

Year two results

Air quality data collected over the past 18 months generally aligns with previous modelling

- Average ambient levels of nitrogen dioxide and nitric acid are generally lower than predicted.
- Average ambient levels of ozone and ammonia appear to be higher than predicted.
- Sulphur dioxide is considerably lower around Dampier, however is occasionally higher than modelled on outer islands, depending on wind direction.

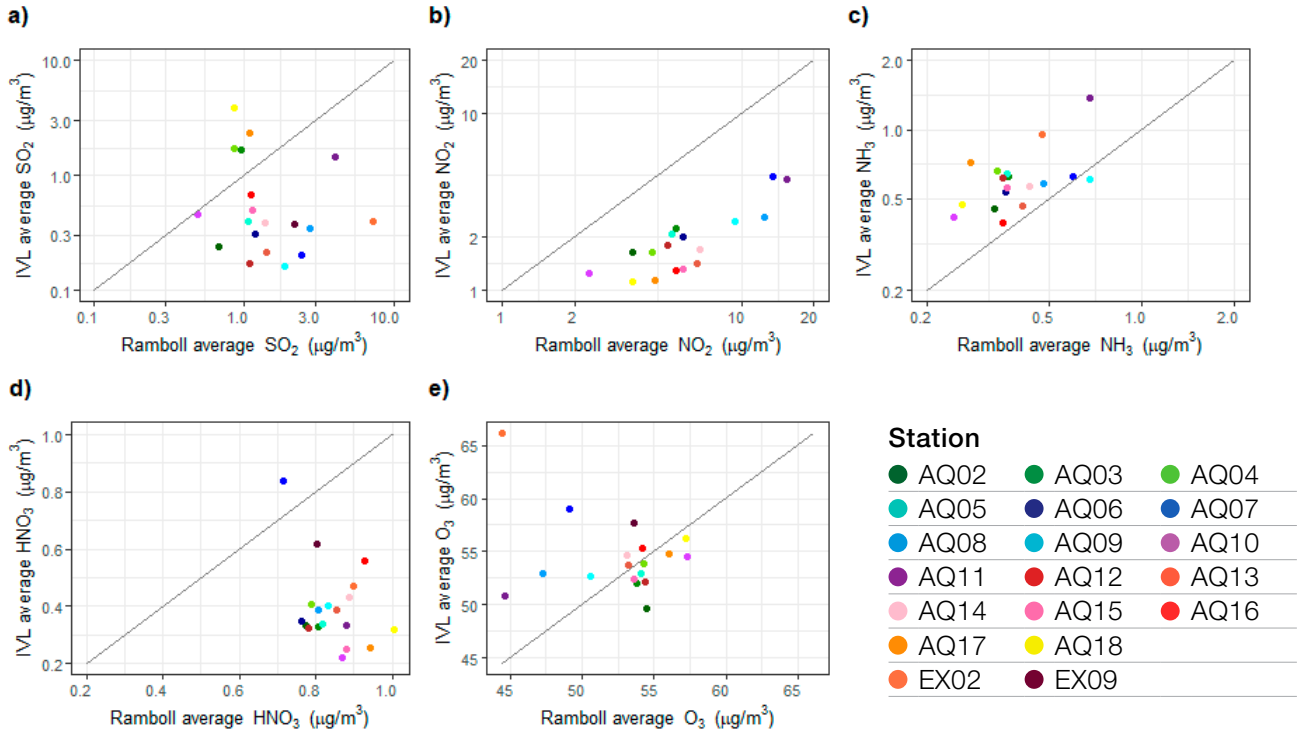


Figure 1: Comparison of observed (passive samplers) to modelled (Ramboll, 2022) air quality, averaged for all year 2 data by station. Gases shown are (a) sulphur dioxide (b) nitrogen dioxide (c) ammonia (d) nitric acid and (e) ozone.

The acid rain/deposition theory proposed by earlier researchers is not supported by data from this program

- Measurements of rainfall and deposition over the past two years are neutral or slightly alkaline.
- Rock surface pH is not a reliable indicator of rock degradation.

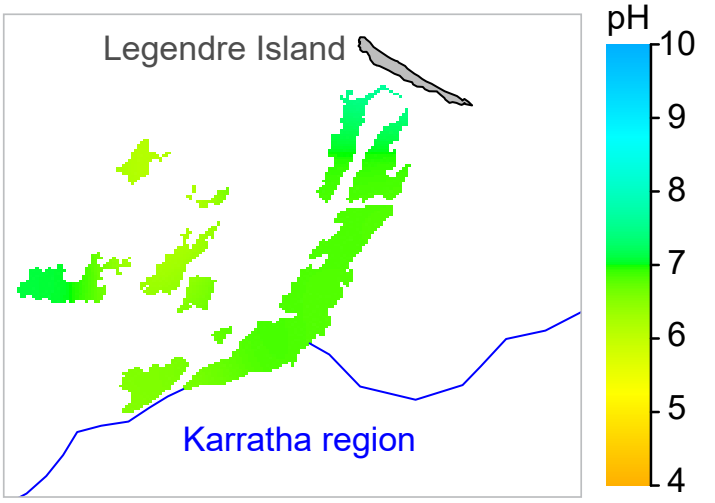


Figure 2: Spatially smoothed deposition sampler pH (February 2024)

The upper layer of granophyre rocks, one of the five rock types being investigated, has elevated porosity (the open spaces in rocks) in a region close to Dampier

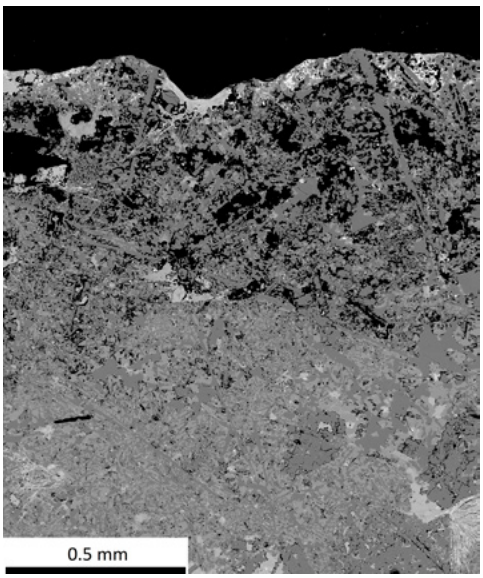


Figure 3: An image of one of the granophyre rock samples analysed using scanning electron microscopy. The dark areas near the rock surface represent (micro) pores.

- This is likely to be a response over many years, and possibly most accelerated when estimated industrial emissions were two-to-three times higher in the 1970s.
- The processes that lead to porosity are complex, involving natural weathering, microbial activity and chemical or chemo-microbial acceleration.
- Further investigations into these processes and the potential link to historic emissions are underway.
- Work is ongoing to confirm whether the observed surface porosity is now stable, and this is a key focus for the third year of research.

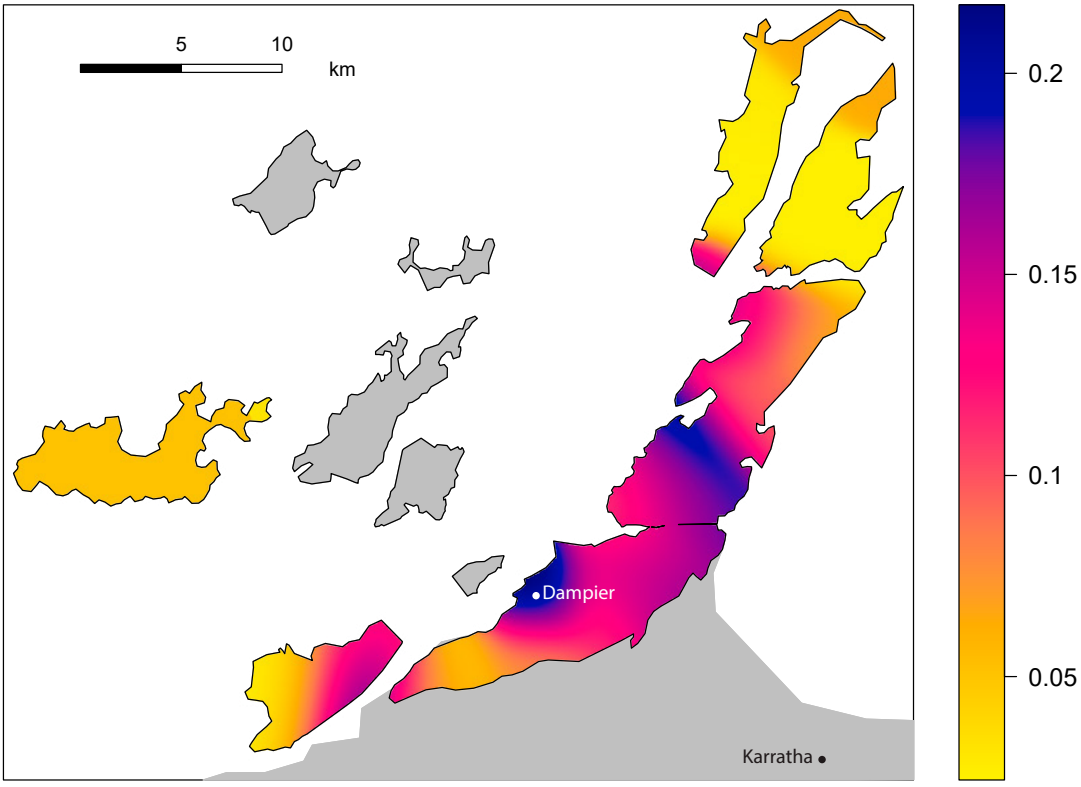


Figure 4: Spatially smoothed index of subsurface porosity in granophyre rocks across Murujuga study area.

Colour and photogrammetric monitoring of rock art is ongoing, however major or systematic change in the rock art surface has not been identified to-date

What are EQC, and what do they mean for Murujuga's rock art?

Environmental Quality Criteria (EQC) are risk-based benchmarks for air quality monitoring data. The EQC sit within an Environmental Quality Management Framework (EQMF) that is set out in the Murujuga Rock Art Strategy. The scientists have recommended interim EQC for nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and ammonia (NH_3).

Under the EQMF, the EQC consist of a lower guideline level which serves as an early warning indicator and a higher standard level which is the threshold at which there is a risk of unacceptable change in rock art condition, linked to industrial emissions.

Emissions measured to date are below the interim EQC, so there is currently a low risk of impact to the rock art. Now that we have interim EQC, the research team is monitoring against the EQC and exceedances will be reported to DWER and MAC.

The interim guidelines and standards are based on the first two years of studies and will be refined over time as research progresses. The results and data from the final two years of research studies will inform the final, scientifically robust guideline and standard values that support implementation of the management framework.

The research indicates that the current levels of the pollutants of most concern for the rock art are lower than the interim guideline levels (Table 1). Current evidence suggests that changes to rock porosity occurred in the past when emissions from industry were higher than they are now. Ongoing monitoring and application of the EQMF is essential to ensure air quality is maintained at levels that ensure the protection of rock art.

Table 1: Interim EQC.

Air pollutant	Annual average concentration ($\mu g/m^3$)	EQC type	Application
Nitrogen dioxide (NO_2)	5.5	Interim Guideline	combined (NO_2 & SO_2)
Nitrogen dioxide (NO_2)	45.6	Interim Standard	single species
Sulphur dioxide (SO_2)	4.3	Interim Guideline	combined (NO_2 & SO_2)
Ammonia (NH_3)	5.2	Interim Guideline	single species

Scientists have observed some interactive effects of nitrogen dioxide and sulphur dioxide, and the interim guideline EQC for these pollutants has been developed as a combined measure. This means that there must be an exceedance of both species at the same site to trigger a guideline exceedance. Further research will seek to develop individual criteria for these pollutants.

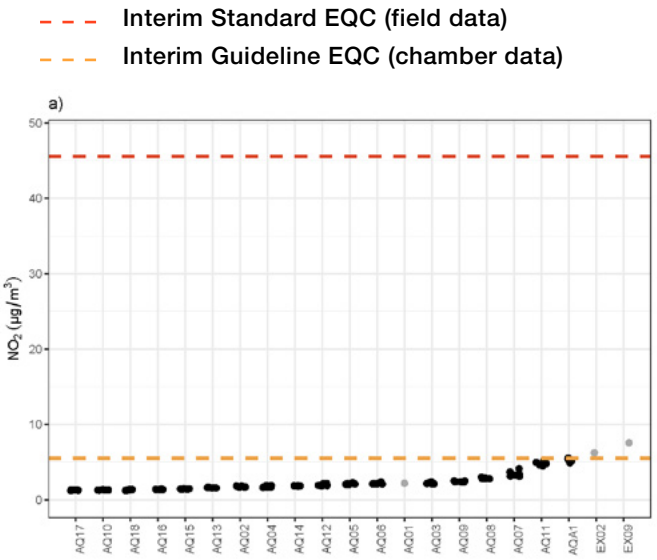


Figure 5a: Interim standard and guideline EQC for nitrogen dioxide (NO_2) and average passive sampler levels for NO_2 at each monitoring station (Nov 2022–April 2024).

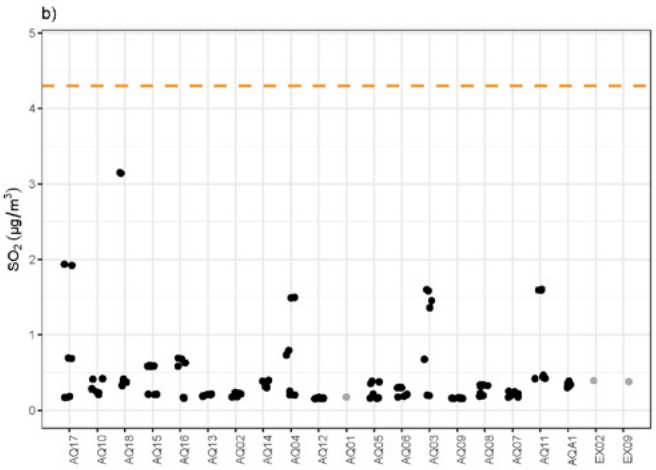


Figure 5b: Interim guideline EQC for sulphur dioxide (SO_2) and average passive sampler levels for SO_2 at each monitoring station
(Nov 2022–April 2024).

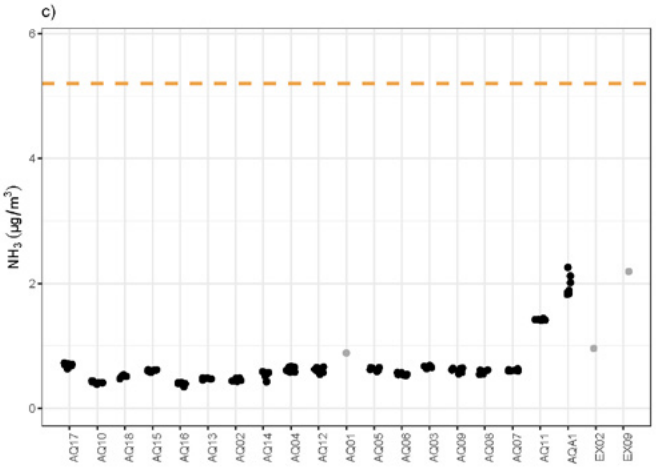


Figure 5c: Interim guideline EQC for ammonia (NH_3) and average passive sampler levels for NH_3 at each monitoring station (Nov 2022–April 2024).

Ongoing monitoring and management

When research is complete, the ongoing monitoring program will be jointly managed by MAC and DWER. MAC will be primarily responsible for implementing the long-term monitoring, and DWER will continue to support the ongoing monitoring and management. To enable this, the program includes capability-building elements, including specialised training for MAC Rangers.

The MAC Rangers are completing specialist micro-credential training through Curtin University, and will continue to build skills in air quality, rock condition and inorganic geochemistry monitoring and work health and safety. Micro-credentials are completed on Country and involve theory and practical assessments focused on the methods and equipment utilised across the program.

Future research

This project represents the largest and most reliable data set of air quality, rock surface, rainfall and deposition pH measurements at Murujuga. Data fusion and rigorous statistical assessment provides certainty in the results and recommendations.

The scientists are continuing to investigate how dust, organic chemicals and microorganisms impact each other and the rock art, with results expected in future reports. Complex relationships are emerging between porosity, microbial abundance and pollutants.

Additional research has been added to years three and four to confirm the porosity findings and investigate whether porosity is now stable. This will include additional sampling and field measurements on all rock types.

The scientists will continue to use accelerated weather chamber studies to refine and update the interim EQC, which underpin ongoing monitoring.

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Publications related to the Murujuga Rock Art Monitoring Program are available from the Department of Water and Environmental Regulation and the Murujuga Aboriginal Corporation. View at www.wa.gov.au/murujuga

The Murujuga Rock Art Monitoring Program is a joint initiative of the Murujuga Aboriginal Corporation and the Department of Water and Environmental Regulation. It is being delivered by WSP and Curtin University, with the assistance of consultants from ArtCare, University of Wollongong, University of Melbourne, and L & K Engineering.

The full reports for the year two research studies and interim EQC are available online:

- Murujuga Rock Art Monitoring Program: Monitoring Studies Report 2024 (Curtin University, 2024)
- Murujuga Rock Art Monitoring Program: Interim Environmental Quality Criteria Report (Curtin University, 2025)

Reference: Ramboll (2022) Study of the cumulative impacts of air emissions in the Murujuga airshed. Technical Report. Prepared for DWER. Government of Western Australia.