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

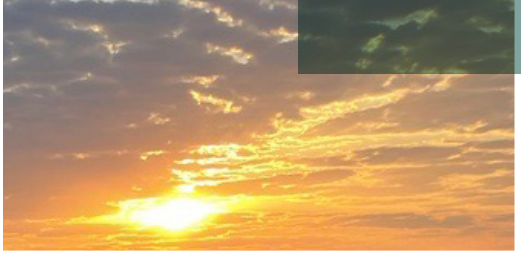
Murujuga Rock Art Monitoring Program: Summary Monitoring Studies Report 2023

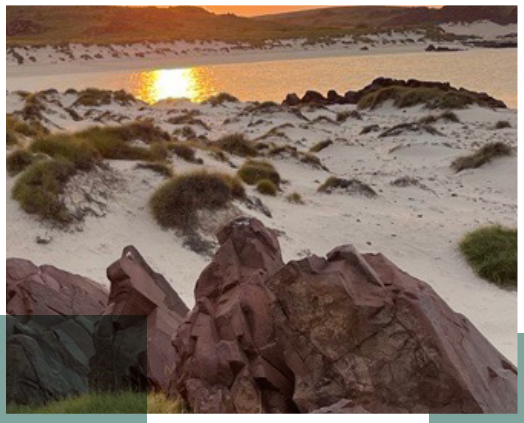
The Murujuga Rock Art Monitoring Program is the most extensive scientific study to date to examine the impact of industrial air emissions on the rock art engravings of Murujuga, an area covering the Burrup Peninsula and Dampier Archipelago in Western Australia.

This report summarises the first year of results from the research being undertaken to establish acceptable and unacceptable air pollutant exposure levels to protect the Murujuga rock art.

The Murujuga Aboriginal Corporation, Department of Water and Environmental Regulation, Calibre 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.

The Murujuga Rock Art Monitoring Program is being led by the Murujuga Aboriginal Corporation (MAC) and the Department of Water and Environmental Regulation (DWER).





Key messages

- The program will develop air quality standards applicable to the protection of the rock art.
- The program is the largest of its kind in the world in terms of the number of study sites and the number of measurements being recorded.
- Spatial trends have been observed for some air pollutants in the work to date, but longer-term data are still needed.
- Where possible, the research builds on data collected in previous smaller studies at Murujuga.
- Data collected in the first year of observation do not permit any firm conclusions to be drawn about trends in rock surface condition and any relationship to air quality over time. Each successive year of data collection greatly increases the statistical power of the study to detect such trends.
- Laboratory studies exposing rock samples to air emissions will allow air quality standards to be developed in a shorter time than would be possible from field data alone.

Program context

Murujuga provides one of the oldest and most continuous records of human culture, thought and creativity on the planet. The area contains one of the world's most significant and dense collections of ancient petroglyphs, thought to be up to 65,000 years old. For the Ngarda-Ngarli, the collective term for Traditional Owners and Custodians who look after Murujuga today, these engravings are not just ancient art but are also a deep time record of Ngarda-Ngarli's interaction with the landscape since the Creation. The environmental management framework being developed through the Murujuga Rock Art Monitoring Program will inform future stewardship of the area and help ensure that natural weathering of rock engravings is not accelerated by human activity.

The Burrup Peninsula has seen significant industrial development over the past 60 years, which has generated concerns about the potential for accelerated weathering of the petroglyphs. Previous studies have been conducted to understand the impact of these industrial emissions, but the results and their interpretation have been a matter of debate as they have not provided conclusive evidence of causation.

Scope of studies

The research studies will investigate all plausible scenarios associated with anthropogenic activity that could result in a measurable degradation of the rock art. This includes all air pollution sources and any other human-induced effects such as future climate change impacts, but it excludes acute impacts such as vandalism.

Findings to date

Geochemical studies have identified important compositional and structural variations in the rock surface (patina) and near-surface (weathered rind). Some features are related to rock type and others show consistent trends across multiple rock types and are therefore likely a result of environmental weathering (both natural and potentially human-induced). Scientists are still gathering and interpreting results; however, these studies are a promising source of key information with which to understand the weathering processes of rocks at Murujuga. For example, dissolution of key minerals has been identified as a process responsible for forming a high porosity outer layer of the rock. Further work is required to determine if this is caused by human factors or natural weathering.

Some spatial trends in electrochemical parameters (such as pH, see Figure 1) and rock surface elemental composition have been found. Spatial trends are also appearing for several measured air pollutants (such as nitrogen dioxide [NO_2], see Figure 2) that are generally consistent with earlier air quality modelling by Ramboll Australia.

Spatial correlations were identified between pH and the modelled levels of NO_2. However, much more work is required to determine causal relationships for these trends as relationships were

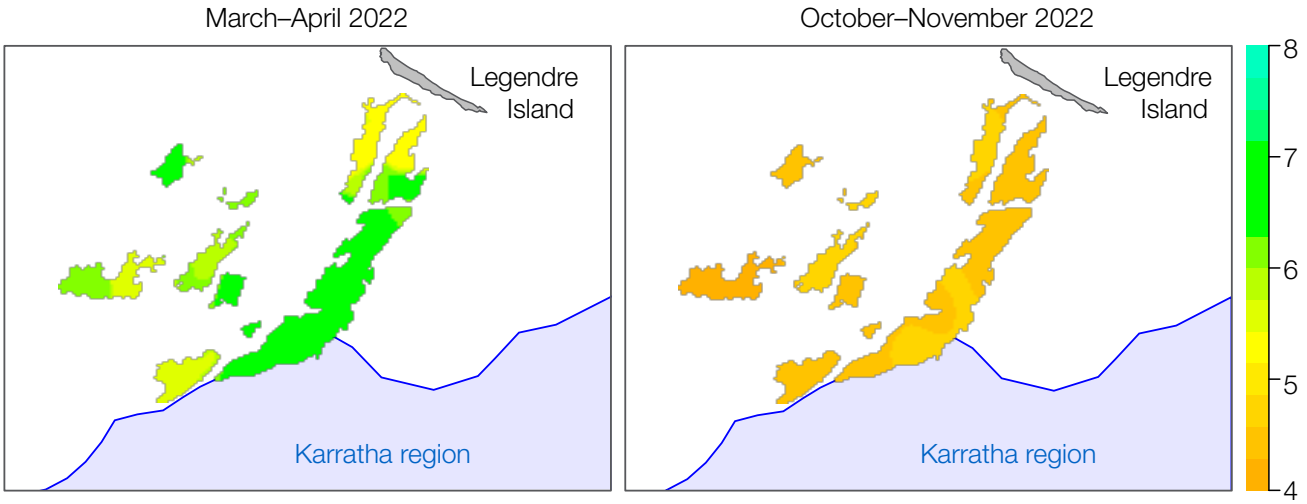


Figure 1: Spatial trends of the pH measurements on rock art panels during March–April 2022 and October–November 2022

not as expected. In Figure 1 and Figure 2, similar trends exist for the pH measurements taken in March–April 2022 and the measured NO_2 levels generally. Interestingly, this relationship is the reverse of what would be expected to confirm the acid deposition hypothesis in previous literature: our research has found pH values in March–April 2022 were highest where NO_2 concentrations are highest; whereas with acid deposition, pH would be lower where NO_2 is higher, as NO_2 is often a precursor to the formation of nitric acid, which has a low pH. Neutral pH is around 7, with low pH indicating potentially acidic conditions.

Data collected in the first year of studies do not permit any firm conclusions to be drawn about trends over time. However, each successive year of data collection will greatly increase the statistical power of the study design to detect temporal trends.

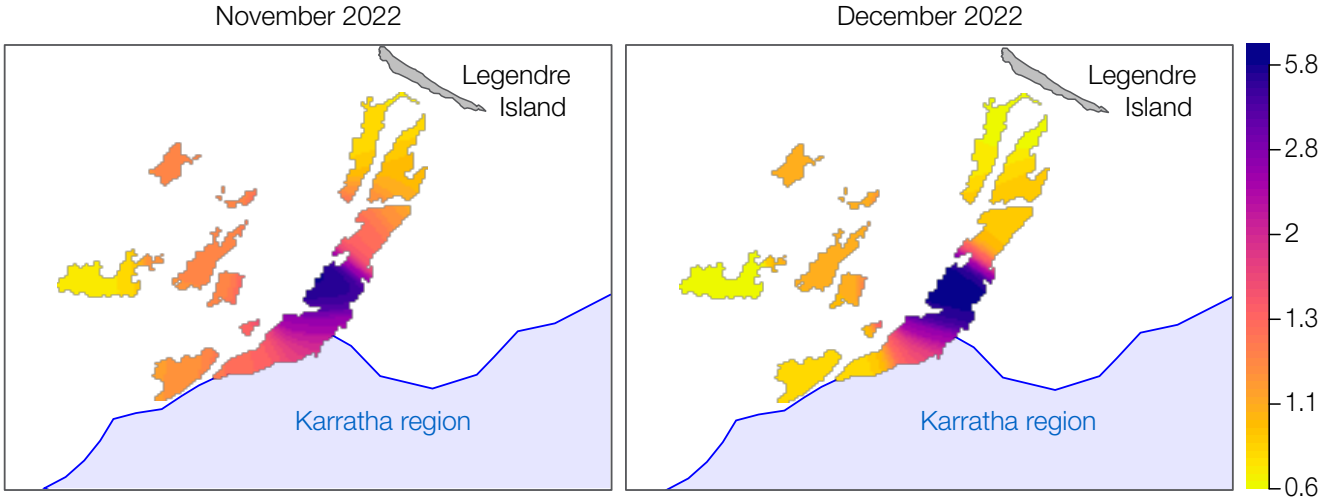


Figure 2: Spatial trends of the NO_2 (mg/m^3) gas measurements (IVL passive sampler) from the air quality monitoring sites for November and December 2022

Study design

The research study design and methods have undergone extensive independent peer review by international scientists with relevant fields of expertise. The full study design is available online.

Fieldwork sites (Figure 3) were selected during the study design phase in 2021 and approved by the Murujuga Circle of Elders for inclusion in the research studies. Sites were selected using all available data on geology, rock art and air quality to provide maximum statistical power to detect pollutant effects. Site selection models were optimised at the Pawsey Supercomputer Research Centre in Perth.

A network of air quality monitoring sites was designed to provide accurate air quality maps across the entire region. This network includes 18 new solar-powered monitoring stations and three new mains-powered stations. The solar-powered monitoring sites have a weather station and a mix of unpowered samplers and low power instruments. The three mains-powered monitoring stations include additional reference-grade real-time instruments, such as those used for air quality monitoring in urban and regional areas throughout the world. One station contains specialist instruments to assist in better understanding short term or transient air pollution events in the region. Data from other industry monitoring programs are also being considered.

A fundamental component of this study is the development of rigorous methods to explore the quality of data collected during the study and its statistical analysis.

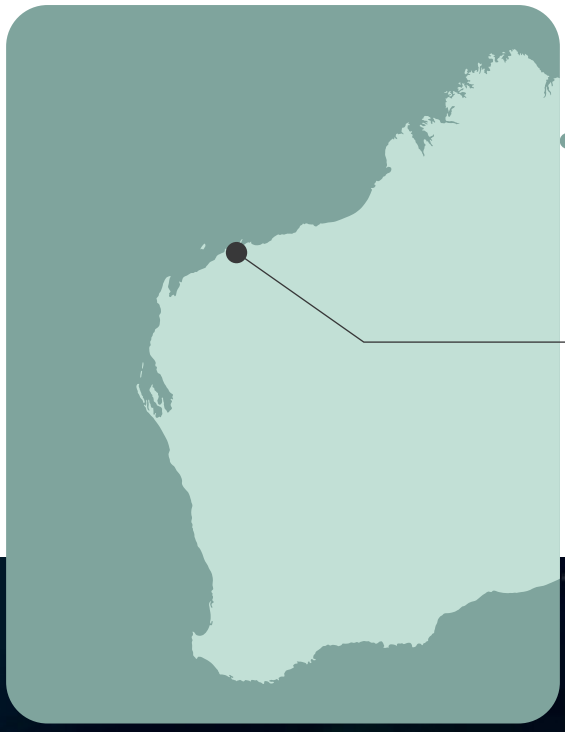


Figure 3: Murujuga Rock Art Monitoring Program study region and selected study sites

The first year of field and laboratory research studies has involved...

Air quality monitoring: Fabrication and deployment of the air quality monitoring network has been a major focus of the first year of studies. At the end of March 2023, 18 solar-powered stations were operational in the field.

Seasonal field monitoring of rock art condition and rock sample collection: Four fieldwork campaigns (18 weeks total duration) were undertaken between March 2022 and March 2023. Fieldwork included monitoring 54 rock art panels and 64 selected, weathered rock surfaces across the five rock types found in the study area.

Spectral (colour) measurement of rock art: A methodology has been developed that will enable highly precise and repeatable measurements on the rock surfaces over many years and be used to establish measurement points on 54 rock art panels. Many thousands of measurements have been taken at these points but work still needs to be done to establish the spectral measurement procedures, specifically in the ultraviolet and the near infrared ranges. It is believed the technical issues with the instrument can be overcome, particularly with a newer version of the instrument, and it should provide a means of examining long-term trends in the rock (art) surface.

Electrochemical and elemental measurements: Approximately 2,600 surface electrochemical measurements (pH, Eh, Cl) and more than 3,000 surface elemental analyses were made on the 64 rock samples and 54 rock art panels. These are being used to assess possible acid deposition and better understand the surface chemistry and reactivity of the rocks.

Sample collection for laboratory analysis: 484 microbial samples from 64 rock samples (triplicate samples from rocks and surrounding soil, lichen, etc. for two seasons) were collected for laboratory DNA/RNA sequencing and analysis as bacteria and fungi can be key to the formation and possibly degradation of the rock (art) surface.

In July 2022, the 64 rock samples were collected for more detailed analysis in organic geochemistry and geology laboratories at Curtin University. This work will allow the composition of the surface patina and underlying rock to be better understood. It will also help us understand how the rocks will react when they come into direct contact with air pollutants or receive rainfall containing trace amounts of pollutants.

Twenty-nine vegetation samples were collected for biomass organic chemical analyses and chamber combustion studies. This work will allow us to understand the effects of smoke from bush fires.

Measurements on rock art panels used non-invasive techniques to safeguard the petroglyphs. All sample collection was conducted far enough away from rock art or other cultural sites to avoid impacting cultural heritage values and was supervised by Murujuga Aboriginal Corporation Elders and Rangers

Spatial mapping and computational fluid dynamics (CFD): High resolution spatial mapping of some 3,200 ha of land has been completed at air quality monitoring sites. Detailed digital surface models have been created for CFD modelling of air quality to evaluate local-scale transport of air and pollutants over rock surfaces at the study sites.

Next steps

Work has continued both in the field and the laboratory to collect data and investigate potential biogeochemical mechanisms.

With the assistance of the Department of Biodiversity, Conservation and Attractions, monitoring was conducted during a mosaic vegetation burn at Murujuga to help assess the impact of natural air pollutants.

Curtin University is conducting accelerated weathering studies on Murujuga rock samples, exposing them to various simulated air pollution scenarios. These study results will be used to establish dose response curves and hence Environmental Quality Criteria (EQC) for all key air pollutants (see Figure 4).
During year 1, exploratory studies were undertaken to inform the design of the chamber studies. The design has now been finalised using field geology and microbiology information and trial laboratory exposures. Separate accelerated weathering studies are planned for purely geochemical processes, followed by studies incorporating live microbes on the rock samples.

Additional field monitoring and results of both chamber-exposure and other laboratory studies data are required to establish that the observed correlations are evidence for causal relationships, which can then form the basis for EQC.

The monitoring program will continue to incorporate all new data that becomes available, either directly from the program or from other concurrent studies.

The research team is confident that the current study design and approaches are appropriate overall in terms of techniques and statistical power. As more research data are obtained, this study will provide information to enable true mechanistic relationships to be confirmed and EQC developed.

The monitoring studies will deliver an Environmental Quality Management Framework (EQMF) and EQC for air pollutants that need to be monitored on an ongoing basis due to their potential to degrade the rock art.

The EQC will specify acceptable, unacceptable, and intermediate “Stop/Act” air pollution levels related to air quality measurements (dose) and measurements obtained on rock art and rock samples (response) see Figure 4.

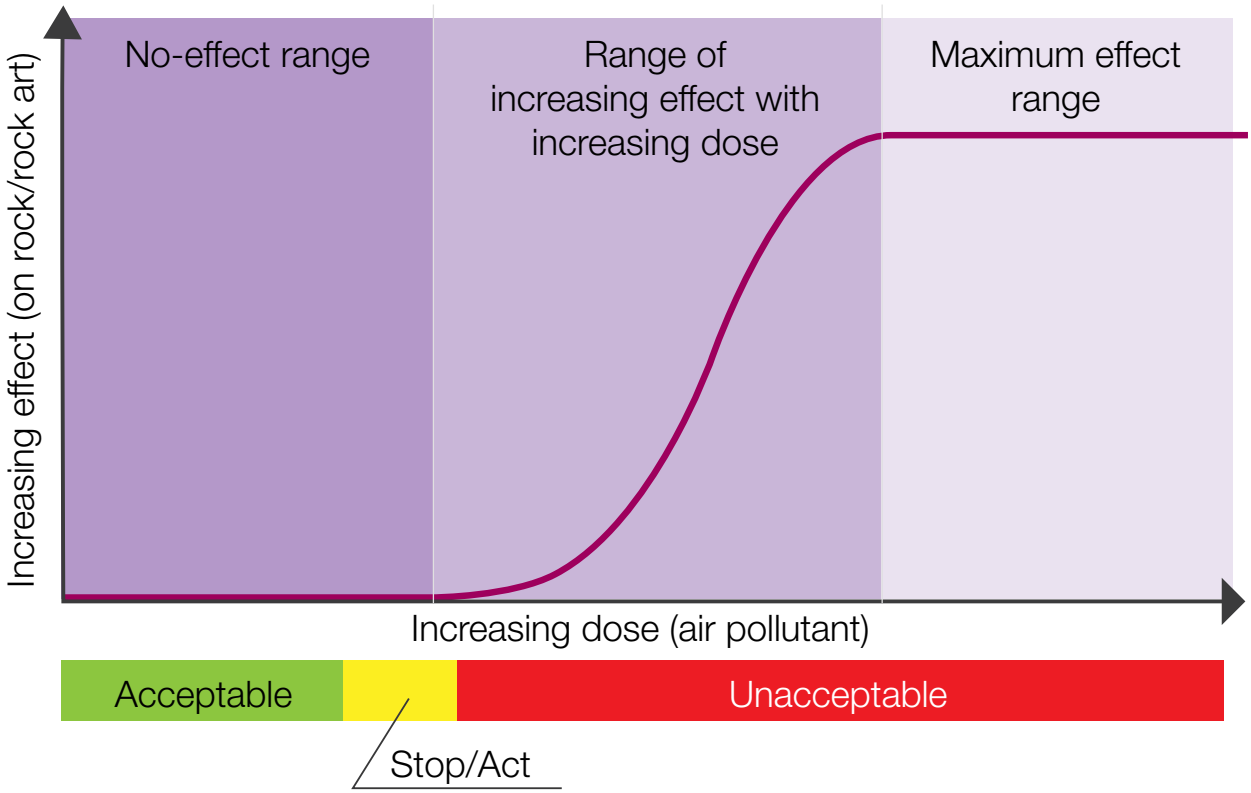


Figure 4: Dose – response model concept for development of Environmental Quality Criteria

Interim EQC will be released as soon as available throughout the program. As the studies continue and EQC are established, work will be progressively handed over to the Murujuga Aboriginal Corporation and the WA Government for long-term monitoring against the EQMF (Figure 5). Murujuga Rangers from the Murujuga Aboriginal Corporation are already embedded into field monitoring teams, and formal training is underway to provide skills needed for the transition in program delivery.

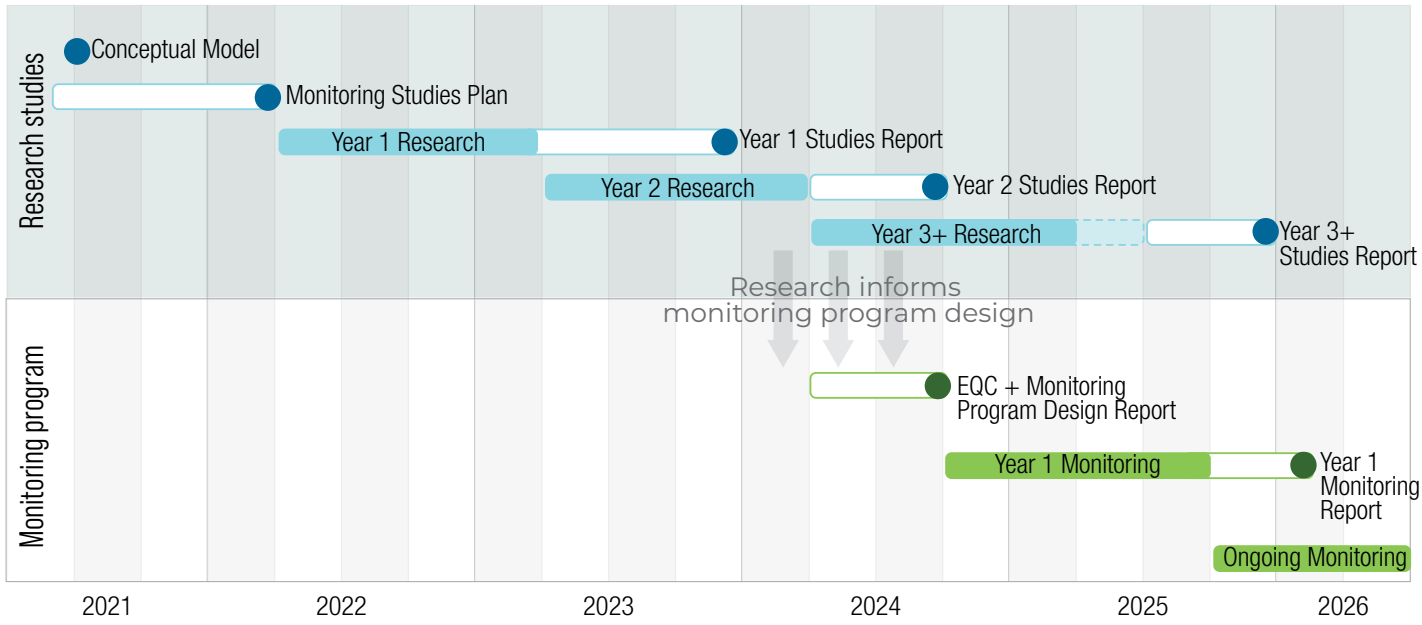


Figure 5: Key program activities and stages

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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 Calibre Group and Curtin University, with the assistance of consultants from ArtCare, University of Wollongong, University of Melbourne, and L & K Engineering.

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