Written questions for Professor John Black

1. What are your recommendations for limiting emissions from shipping?

   Sulphur dioxide formed from ships burning high sulphur fuel oil, when combined with water from fog or rain forms sulphuric acid. The outer surface patina on Burrup rocks is rapidly degraded by sulphuric acid. Maintenance of the patina is essential for continuing existence of the rock art. A ship burning high sulphur bunker oil produced about 5,000t/year of sulphur dioxide. The current Australian national limit for sulphur content of bunker oil is 3.5%. However, for the most sensitive environments, such as Sydney Harbour, the limit for fuel oil sulphur is 0.1%. The high sensitivity of rock art on Burrup Peninsula to acid makes this environment one of the most sensitive in Australia.

   Recommendations:
   - The maximum sulphur content of fuel oil for ships entering the Port of Dampier should be 0.01%.
   - The Port of Dampier authorities must take a sample of fuel oil from each ship entering the Port and analyse it for sulphur content.
   - If the content of sulphur in fuel oil from a ship is above 0.1%, the ship owners should be fined a substantial fine (say, $200,000) for the first offence.
   - A repeat offence should result in the ship being banned from entering the Port of Dampier.
   - The Port of Dampier authorities are required by the Western Australian State and the Federal Governments to measure continuously wet and dry sulphur dioxide deposition at the Port of Dampier, at five locations on the west coast of Burrup Peninsula from King Bay to the tip of Gidley Island, and at one location each on the east of East Lewis Island, the northern tip of West Lewis Island and Malus Island.

2. Is there evidence of changes to the environment from pollution on the Burrup Peninsula?

   Three examples of industrial pollution and its effects on the environment were included in my Public submission to the Inquiry:
   - The high level of air pollution demonstrated through the Bureau of Meteorology radar vision on Burrup Peninsula indicating it is 'raining' every day, despite an average of only 20 days per year when rain is recorded.
   - Photographs of pitted paving bricks with black surrounding (presumably from microbial growth stimulated by nitrogen emissions) where rain and dry acid has fallen between two roof-lines at the Woodside Visitors Centre.
   - Green algal bloom in a stream at Geo's Gorge adjacent to the Woodside plant taken in July 2016 compared with a photograph of a stream on Burrup Peninsula taken in July 2010.

   Other evidence has been located showing deleterious effects of emissions on rock art and the environment.
   - Airborne emissions are deposited in dry form and in wet form in rain, fog or dew. The majority of acid forming pollutants are deposited on Burrup Peninsula in dry form because of the few days of rain per year (average of 20). These pollutants accumulate, particularly on the foliage of plants, where they remain inactive until mixed with water. Tree canopies can retain large amounts of

deposited acid-forming NO_x and SO_x compounds because of their many layers of foliage. Rain water falling through the foliage concentrates these acid forming chemicals. Bednarik (2007) collected the 'through-fall' rain under trees at sites on Burrup Peninsula and found it to be highly acidic with pH as low as 3.2. Evidence in my submission to the Inquiry (Black et al. 2017) and now accepted for publication in an international peer reviewed journal, the *Journal of Archaeological Science: Reports*, shows from electrochemical theory, that the rock patina required for maintenance of the integrity of the rock art would be dissolved by acid.

Figures 1 and 2 are photographs taken from Bednarik (2007) and show complete removal of the rock patina below a tree adjacent to the Woodside site on Burrup Peninsula. These photographs were taken in 2004, before the Yara Fertiliser plant was established. Further acid emissions from the new Ammonium Nitrate plant will simply hasten the removal of the desert varnish patina on rocks throughout Burrup Peninsula and the destruction of rock art.

Figure 1. 'Bleaching' of patina under a tree near the Woodside Northwest Shelf plant, Dampier. (From Bednarik, 2007).

Figure 2. Comparison of 'bleached' and 'unbleached' rocks at the location shown in Figure 1. (From Bednarik, 2007).

Other evidence showing the dissolution of rock patina in desert environments by surface acid comes from Bednarik (1979), where the patina disappeared under bird droppings where the average pH was 5.9 across 30 sites in an area adjacent to Burrup Peninsula. Similarly, Engel and Sharp (1958) and Dragovich (1986) showed that desert varnish was not present beneath growing lichen, because of accumulated organic acids secreted by the lichen.

Bednarik (2002) has been photographing rock sites on Burrup Peninsula since the mid 1960's. He used the International Federation of Rock Art Organisations

standard colour assessment system to show marked changes in colour from pre-industrial times to 2002. Based on these observed changes, Bednarik (2002) predicted the petroglyphs would disappear during the second half of the 21st century at the then current levels of acid emissions and by around 2030 if emissions trebled (Figure 3). In 2014, Woodside released 22,400 tonnes of acid load into the environment (Woodside 2016) and, in the same year, the Yara Pilbara fertiliser plant released 13,600 tonnes of acid into the environment (Yara Pilbara 2016). These are extremely large amounts of acid forming emissions.

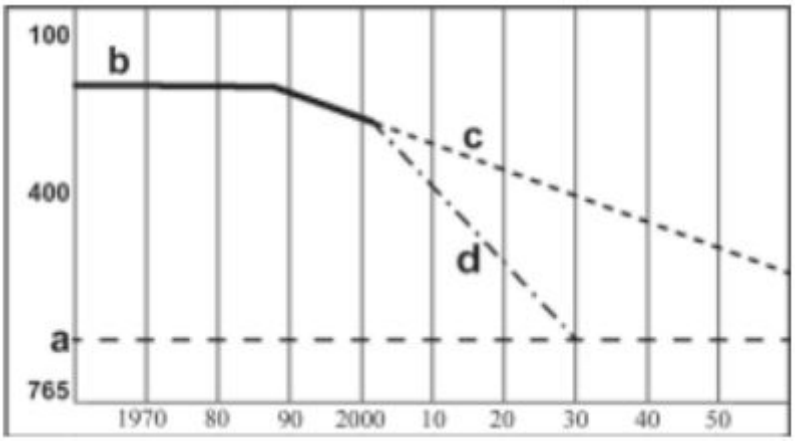

Figure 3. Deterioration of ferruginous crust on Murujuga rock surfaces as determined by measurement (b); as predicted at the present level of atmospheric pollution (c); and as predicted in the event of a trebling of the ambient air-shed pollution (d). The average value of the buff-coloured substrate, the threshold at which the rock art becomes imperceptible, is indicated by (a). From Bednarik (2002, Fig 5).

There is irrefutable empirical and theoretical evidence that any increasing acid accumulation on the surface of rocks on Burrup Peninsula is now destroying and will completely dissolve the desert varnish patina. These processes will result in the destruction of the petroglyphs within the next 20-30 years at the current rate of acid emissions.

- Evidence of the impact of NO_x on vegetation. A "WITHDRAWN" WA EPA 2004 report on the impact nitrogenous emissions have on vegetation on Burrup Peninsula is revealing. (ENVIRONMENTAL PROTECTION AUTHORITY 2004 Cumulative impacts of oxides of nitrogen emissions from existing and proposed industries, Burrup Peninsula, Environmental Protection Authority, Perth, Western Australia<edit.epa.wa.gov.au/EPADocLib/Burrups16e-archived-280115.pdf>)

  Plant species are known to be vulnerable to NO_x exposure. WHO guidelines for critical loads for impact of NO_x on plant species are 36.5 ppb for 24 hours and 14.6 ppb for annual exposure. Emissions from the dispersal models used in 2003 for the Woodside plant alone show that these concentrations were already exceeded by that time. The dispersion model used by Burrup Nitrates Pty Ltd (undated) for establishment of the new ammonium nitrate plant show concentrations of NO_2 ranging from 43 to 85 ppb, with an 'assessment criteria' when action will be taken of 120 ppb. This figure does not include other NO_x compounds, ammonia or sulphur dioxide. Modelling of cumulative emissions from all industry on Burrup Peninsula is required as well as continuous monitoring of emissions over time at many locations.

  Vicki Long (Principal Botanist Ecologist), who has identified plant species on Burrup Peninsula and found them to be unique to that restricted environment, has told me that no studies have been conducted on Burrup Peninsula to monitor

the effects of emissions on vegetation health. However, important evidence can be obtained from studies in other parts of the world (Nilsson and Grennfelt 1988). Figure 4 shows the impact of parent rock on the critical loads of nitrogen and sulphur for forests in Europe. The slower degrading granite rock has lower buffering capacity and therefore lower critical loads than the faster degrading limestone. The lower extremes of the bars in Figure 4 represent unmanaged forests. The critical nitrogen load for undisturbed European forests growing on granitic soil was from 3-5 kg/ha/year (15 to 25 meq/m^2/year) depending on the sulphur load. Since the rocks on Burrup Peninsula are extremely slow degrading and do not produce soils sufficient to maintain substantial plant growth, the critical loads would be below the bar for granite in the graph.

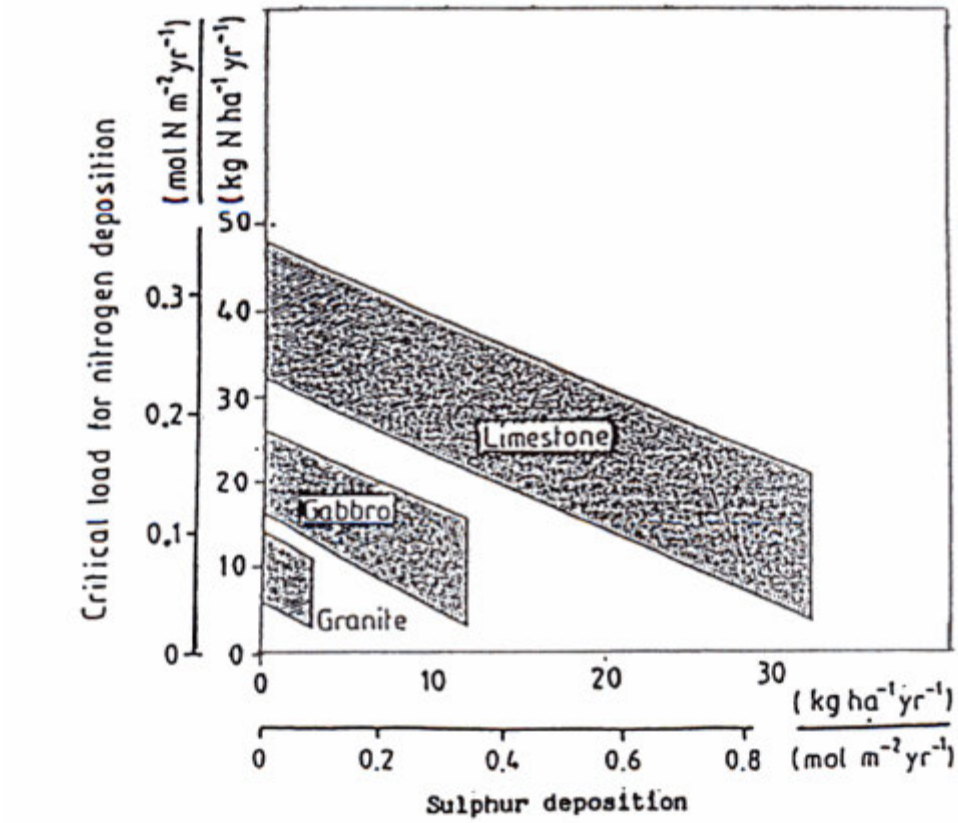

Figure 4. Nitrogen and Sulphur critical loads for European forests growing on soils formed from different base rock types. (From Nilsson and Grennfelt 1988, Fig 1).

In summary, there is substantial evidence showing that the levels of nitrogen emissions on Burrup Peninsula will damage vegetation, but no systematic measurements of changes in plant health have been conducted.

3. Who is currently monitoring emissions from the AN plant and the Burrup area as a whole?

There has been no independent monitoring of gaseous emissions on Burrup Peninsula since the work of Gillett in September 2008 (Gillett 2008).

An air quality monitoring program is required to be undertaken by Yara Pilbara under clause 9 of the Australian Government Approval of the Proposed Technical Ammonium Nitrate Production Facility (EPBC 2008/4546).

Air quality monitoring is to be conducted at three sites used in the CSIRO colour/mineralogy project: Site 5 (Burrup Road), Site 6 (Water tanks), Site 7 (Deep Gorge). Measurements of atmospheric ammonia, nitrogen oxides, sulphur oxides and total suspended solids were to be undertaken from the beginning of construction for 24

months to provide 'background' readings and then continued for a further 5 years following operation of the plant. Measurements were to be made at least four times during each 12 month period. The report on 'background' emissions was to be delivered to the Government within 12 months from the completion of construction or following 24 months of 'baseline' readings, whichever is the shorter.

Construction of the TANPF commenced on 17 February 2013 (Yara Pilbara, 2014), which means the first report with background readings should have been provided to the Australian Government on 17 February 2015. No record of emissions measurements was included in the Yara Pilbara 2016 report to the Government, which is a non-compliance issue. Yara Pilbara state these measurements will be included in their 2017 report. The 2017 report is not available on the company website.

Under the Western Australian Government Ministerial, M870 Section 5.2, Yara Pilbara is to implement an air quality monitoring program prior to construction. However, in the 2016 M870 Compliance Report, Yara Pilbara state "*Ambient air quality monitoring was not effectively implemented during the reporting period*."

I have not studied in detail the regulations for the Woodside plants. They are required to monitor NO_x, SO_2 and carbon monoxide. There is a maximum limit on NO_x of 100 mg/m^3, which is extremely high at approximately 53,190 ppb.

In summary there appears to be no effective monitoring of emissions from industry on Burrup Peninsula.

- Are these measurements made public?

  These measured emissions from Yara Pilbara are to be made public in reports to the government that are placed on their respective websites.

  Woodside publishes annual mean valued and total acid load emissions on their website.

  Woodside state in their 2016 report that acid emissions in 2014 were 22,400 tonnes.

  Yara Pilbara Fertilisers state in their 2016 report that acid emissions were 13,600 tonnes.

- How reliable are they?

  Yara Pilbara measurements provided for PM_{10} (total suspended solids) in the M870, 2016 report are totally unreliable with values ranging from 112,020.5 $\mu g/m^3$ to a minimum value of -90,649.28 $\mu g/m^3$, when the national limit is 25 $\mu g/ m^3$: negative values are impossible.

4. How satisfactory do you regard the limits to emissions set by State and Federal Governments?

The acid load emissions proposed by Yara Pilbara Nitrates in their Air Quality report accepted by Governments is the highest in the international scale for critical loads at 200 meq/m^2/year. This limit is totally unacceptable and will certainly result in destruction of rock art on Burrup Peninsula. Reasons for these limits being unacceptable are given in answer to question 6. Reduction in acid load emissions requires reduction in all nitrogen and sulphur containing gases from industrial plants on Burrup Peninsula.

There are no limits set on ammonium nitrate particles in either the Australian or Western Australian Government regulations for the TANPF. However, the concentration of PM_{10} dust particles (which could include ammonium nitrate particles) allowed in the Western Australian Works licence, W4701/2010/1, is 15 milligrams per cubic metre (mg/m^3). The standard set in the Agreed Statement from a meeting of Australian Environment Ministers on 15 December 2015 for PM_{10} particles in the air is 25 micrograms per cubic metre ($\mu g/ m^3$), with it being lowered to 20 $\mu g/ m^3$ in several states and territories. The standard set for airborne particles for workers on Burrup Peninsula is almost 1000 times higher than has been accepted for the general public of Australia.

The fertiliser effect of ammonium nitrate particles landing on rock surfaces and the impact on growth of microorganisms and lichen were not considered by either the Western Australian or Australian Governments when setting conditions for the ammonium nitrate plant. As stated in my submission, there is evidence from the research of MacLeod (2005) of a logarithmic increase in microbial growth with increasing rock surface nitrate. An increase in microbial growth was related to a logarithmic increase in acidity and a logarithmic increase in mobilisation of manganese and iron compounds from the rock patina. No ammonium nitrate particles should be allowed to escape from the TANPF if the rock patina is to be preserved.

5. Do you have knowledge of modifications to license conditions made by the WA and Federal Governments when conditions have not been met?

   Yes.

   - A renewal to the licence to operate the Fertiliser plant (L7997/2002/11), through the 7997 Yara-Ministerial Statement 586, was granted on 16 April 2015 by Jonathon Bailes from the Department of Environment Regulation (DER). The attachment to Ministerial Statement 586 outlines the capacity and outputs from the Fertiliser plant for ammonia production. The Decision Table on page 8 of the Decision Document appended to the licence states that '*Yara has been liaising with the Environmental Protection Authority (EPA) to progress an amendment to MS586 or remove the limits contained in MS586.*' A modification to the licence dated 20 April 2016 lists only two emissions limits, both for NO_x of 130 mg/m^3 averaged over 60 minutes from the Primary Reformer stack and 350 mg/m^3 from the Package Boiler stack.
   - Approval for construction and operation of the TANPF was granted by the Federal Government on 14 September 2011 (EPBC 2008/4546). The approval included many conditions applied under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999. These conditions were established to protect the rock art, fauna and flora. In relation to the rock art, condition 8 d) (i), stated that a suitably qualified person must survey the rock art sites within a two kilometer radius of the project site from the time construction commences. This condition was not immediately implemented and it has now been amended twice (18 December 2013 and 10 February 2014) on request by the company, to reduce the level of surveillance. The company has notified Federal Government in its 2016 Annual Compliance report under EPBC (2008/4546) that it will seek a further change to Condition 10 of the EPBC approval, because of non-compliance.

6. What limits do you believe should be placed on emissions from the ammonium nitrate plant to prevent damage to the rock art?

- Total acid load emitted from the plant should be as low as possible and definitely < 25 meq/m^2/year.
  Justification for this limit comes from i) scientific principles and empirical evidence showing acidity below neutral dissolves manganese and iron compounds from the rock patina, and ii) critical acid loads set for other environments around the world.
  - Scientific principles showing dissolution of rock patina commences once pH falls into the acidic range. The acidity of rock surfaces on Burrup Peninsula was pre-industrialisation around neutral (pH 7) and is already down in the strongly acid pH range of 4-5. This acidity is already causing the patina to become thinner or disappear and be lighter in colour.

  - Critical load is an estimate of an exposure to one or more pollutants below which significant harmful effects on specified elements of the environment do not occur. Critical load relates to a specific pollutant for a specific risk on a nominated target such as trees, fish or people. Consequently, critical acid load for rock art on Burrup Peninsula is one specific application of this principle: the effect of acid on rock patina.

    No measurements of critical acid load for rock patina on Burrup Peninsula have been made, because the buffering capacity of the rock surfaces has never been measured. Thus, there is no empirical evidence for critical acid load for rock surfaces on Burrup Peninsula.

    The value of < 25 meq/m^2/year is derived from comparisons of critical loads for other parent rock types and ecosystems. The rocks on the Burrup Peninsula are igneous and formed under great pressure to make them extremely hard. Pillans and Fifield (2013) showed these rocks to be among the slowest eroding rocks anywhere in the world. Consequently, little soil is formed where petroglyphs occur. Erosion rate of parent rocks is strongly related to buffering capacity. Figure 4 (above) shows critical acid loads around 15 to 25 meq/m^2/year for forests growing on granite soils in Europe. The slower erosion rate of rocks on Burrup Peninsula would create critical loads less than those found for granite rocks. Hence, the recommendation of a limit for critical acid load on Burrup Peninsula of less than 25 meq/m^2/year.

- There should be zero emissions of ammonium nitrate particles.

  The limit of zero ammonium nitrate particle emissions is set because these particles will accumulate over the years the TANPF is operating. The nitrate will stimulate growth of organisms that out-compete the varnish forming organisms and the patina will be destroyed. There is strong supporting evidence quoted above from theoretical electrochemical principles where acid secreted from lichen and bird droppings dissolves the varnish patina from rocks in desert environments.

7. What is the need for and what would be the benefits from a more comprehensive research project on the Burrup Peninsula for saving the rock art?

Research studying the impact of pollution on petroglyphs in arid regions is almost non-existent in the world. Research on the weathering of rocks in a cultural heritage context

has focused on buildings and provides data that are mostly inapplicable to rock art (cut stones, use of coatings, impact of other materials such as iron or cement, research usually done in an urban environment). There is, therefore, no tool to predict long term cumulative impact of pollution on rock art conservation and no existing standards for pollution emission to manage industrial development without threatening the conservation of rock art.

No reliable measurements are being made of levels of emissions at rock art sites on Burrup Peninsula. No measurements have been made on the buffering capacity of the surface patina of Burrup rocks to determine critical acid loads. Few measurements have been made on the rate of dissolution of manganese or iron compounds within rock patina under different acid levels. Few measurements have been made on the types of microorganisms that will be stimulated by atmospheric nitrogenous compounds on Burrup Peninsula and how these compete with patina forming organisms.

There is an urgent need for an independent scientific study to provide a sound scientific basis to understand current pollution levels, their short-term and long-term effects on the rock art and to design recommendations on how best to mitigate the expected impacts of pollutants and manage industrial development in the area. If we are to protect Murujuga rock art for future generations then this study is needed now, before the damage is irreversible.

Consequently a new, open and independent research program is needed. Friends of Australian Rock Art, the Murujuga Aboriginal Corporation and the University of Western Australia Centre for Rock Art Research and Management have set out the research required and identified scientists for each component of the program. Funds are currently being sought for this program through philanthropic and citizen donations. There may be an opportunity for the Western Australian Government and the Australian Government to contribute to this research. Funds from industries located on Burrup Peninsula are not being sought. However, the program will collaborate with these industries to gain their cooperation in saving the petroglyphs.

Question on Notice from Senator Dean Smith: Hansard.

What is the empirical research supporting the claim you are making that the acid capacity of the Burrup rock is 25 milliequivalents per square metre per year?

The answer to this question is covered in the answer to 6 above.

Critical load is an estimate of an exposure to one or more pollutants below which significant harmful effects on specified elements of the environment do not occur. Critical load relates to a specific pollutant for a specific risk on a nominated target such as trees, fish or people. Consequently, critical acid load for rock art on Burrup Peninsula is one specific application of this principle: the effect of acid on rock patina.

No measurements of critical acid load for rock patina on Burrup Peninsula have been made, because the buffering capacity of the rock surfaces has never been measured. Thus, there is no empirical evidence for critical acid load for rock surfaces on Burrup Peninsula.

The value of < 25 meq/m^2/year is derived from comparisons of critical loads for other parent rock types and ecosystems. The rocks on the Burrup Peninsula are igneous and formed under great pressure to make them extremely hard. Pillans and Fifield (2013) showed these rocks to be among the slowest eroding rocks anywhere in the world. Consequently, little soil is formed where petroglyphs occur. Erosion rate of parent rocks is strongly related to buffering capacity. Figure 4 (above) shows critical acid loads around 15 to 25 meq/m^2/year for forests growing on granitic soils in Europe. The slower erosion rate of rocks on Burrup Peninsula would create critical loads less than those found for granite rocks. Hence, the recommendation of a limit for critical acid load on Burrup Peninsula of less than 25 meq/m^2/year.

At this time, this claim is the closest available to having the empirical evidence for the rocks on Burrup Peninsula. In the absence of that direct evidence it is by looking for sameness or equivalence in other empirical evidence that a limit can be found. To set any higher critical acid load is ignoring the available evidence that can reasonably be applied to the specific situation of the rocks on Burrup Peninsula.

Question on Notice from Senator Siewert from last page of the Hansard record of the in-camera session.

Question: In relation to the Arizona work "CSIRO said, 'No, that was a bad abrasive dust'. Do you have a response to that?"

I was citing work reported in 1998 from Professor Dorn's book, "Rock coatings". In more recent correspondence with Professor Dorn he stated "*The various pinnacles and depressions are not normal. This is a very strange texture due to the acid fog*." One would expect dust abrasion to cause the surface of the desert varnish to be made smoother rather than increasing the pinnacles and depressions.

References cited

Bednarik, R.G. 2002. The survival of the Murujuga (Burrup) petroglyphs. *Rock Art Research* 19:29-40.

Bednarik, R.G. 2007. The science of Dampier rock art - Part 1. *Rock Art Research* 24:209–246.

Black, J.L., MacLeod, I.D. and Smith, B.W. (2017). Theoretical effects of industrial emissions on colour change at rock art sites on Burrup Peninsula, Western Australia. *Journal of Archaeological Science: Reports* (In Press).

Dorn, R.I. (1998). "Rock Coatings". Volume 6 of Developments in Earth Surface Processes, 1st Edition. Elsevier Science, Amsterdam. 429 pp.

Dragovich, D. 1986. Weathering of desert varnish by lichens. In: *Readings in Australian geography : proceedings of the 21st Institute of Australian Geographers' Conference, Perth, 10-18 May 1986* , Edited by Arthur Conacher. Published by Institute of Australian Geographers (WA Branch) and Dept. of Geography, University of W.A Perth [W.A.]

Engel, C.G. & Sharp, R.S. 1958. Chemical data on desert varnish. *Geological Society of America Bulletin* 69:487-518.

Environmental Protection Authority 2004 Cumulative impacts of oxides of nitrogen emissions from existing and proposed industries, Burrup Peninsula, Environmental Protection Authority, Perth, Western Australia<edit.epa.wa.gov.au/EPADocLib/Burrups16e-archived-280115.pdf>

Gillett, R. (2008). Burrup Peninsula Air Pollution Study: Report for 2004/2005 and 2007/2008. 168 pages.

MacLeod, I. D. 2005. Effects of moisture, micronutrient supplies and microbiological activity on the surface pH of rocks in the Burrup Peninsula. *In 14th Triennial Meeting, The Hague, 12-16 September 2005*: Preprints (ICOM Committee for Conservation), Isabelle Verger, ed. pp. 385-393, Earthscan Ltd.

Nilsson J. and P. Grennfelt 1988 Critical loads for sulphur and nitrogen: Report from a workshop held at Skokloster, Sweden *Critical loads for sulphur and nitrogen*, vol. Miljørapport 1988 : 15, eds J. Nilsson & P. Grennfelt, UN-ECE, Nordic Council of Ministers, Skokloster, Sweden.

Woodside 2016. http://www.woodside.com.au/Working-Sustainably/Documents/2014%20Sustainable%20Development%20Report%20-%20Interactive.pdf.

Yara Pilbara Nitrates (2014). Annual Environmental report February 2013/February 2014. http://www.yara.com.au/images/2-250-329-REPTRE-8055%20TAN%20Plant%20EPBC%20CAR%202014_tcm583-240486.pdf

Yara Pilbara Nitrates (2016). Annual Compliance Report EPBC 2008/4546 February 2015 – February 2016 Technical Ammonium Nitrate Plant. http://www.yara.com.au/images/2-250-329-REPTRE-8055%20TAN%20Plant%20EPBC%20CAR%202014_tcm583-240486.pdf