

Monitoring outcomes of rehabilitation of large-scale exploration disturbance: what is the role of remote sensing?

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Abstract

Mineral exploration in Australia can extend across vast areas of land, often in remote locations. The nature of disturbance within exploration areas varies but typically includes vegetation clearing along tracks and around drill pads. In Western Australia, the Department of Mines, Industry Regulation and Safety recently announced a strengthening of its approach to rehabilitation compliance monitoring in relation to exploration (Government of Western Australia 2020). Compliance generally focuses on the prompt completion of activities such as plugging drill holes, filling sumps, removing waste, redistributing topsoil and surface scarification. However, less emphasis has been paid to the long-term (beyond six months) environmental outcomes of exploration rehabilitation, compared to rehabilitation of mine sites more broadly.

Approaches to ecological monitoring are evolving in line with increasing access to high quality imagery with a range of spatial, spectral and temporal resolution, and advances in image analysis techniques. In 2020, Rio Tinto engaged Stantec to trial the use of a remote sensing approach for compliance monitoring of 33 exploration areas distributed across the Pilbara bioregion. The areas had been disturbed for exploration in line with conditions associated with exploration approvals and were distributed across an area exceeding 200,000 hectares (ha).

The first step in the development of a remote sensing assessment involves choosing a suitable data capture approach. In this study, given the importance of accurately delineating live vegetation cover, and the large-scale of the area to be assessed, multispectral (4-band) satellite imagery (SkySat, Planet) at 50 cm spatial resolution was selected. An object-based image analysis (OBIA) approach was applied to the captured imagery at each site in order to accurately quantify ground cover. Cover was allocated into separate classes: live vegetation, bare or sparsely vegetated ground, litter, shadow and any remaining 'other' features. Given that the spatial data available prior to the analysis was limited to drill pad points, rather than the entire disturbance boundary, OBIA was also used to delineate a disturbance area. The remaining area was categorised as analogue and its classification data was extracted separately for comparative purposes.

The 33 areas assessed ranged in size from 30 to 39,000 ha. The proportion of each area detected by OBIA as 'disturbance' ranged from 0.1% to 30%. The number of drill pads located within each site ranged from six to nearly 600. At some of the smaller areas, the majority of drill pads were located within the OBIA-delineated disturbance area. However, at other sites, up to 90% of the drill pads were located outside the disturbance area, indicating that they had sufficient vegetation attributes to align more closely with the areas delineated as 'analogue'. A number of sites contained a range of drill pad ages, and at selected sites, a positive correlation between vegetation cover and rehabilitation age was established, an indicator of rehabilitation progress.

Typically, on-ground compliance monitoring of exploration disturbance has involved photo-monitoring and qualitative assessments of soil and vegetation, requiring travel to each disturbed site, often in remote locations. This project demonstrated that remote sensing is an effective alternative for assessment, particularly where exploration extends over a large area, allowing data capture over an entire area as opposed to point source information, while removing safety risks. However, the outcomes of a remote sensing approach may differ considerably from that of a traditional on-ground assessment. The outcomes, limitations, risks and future directions in monitoring rehabilitated exploration disturbance are discussed further in this study.

Keywords: *remote sensing, satellite imagery, vegetation, object-based image analysis, compliance monitoring, Pilbara, Western Australia*

1 Introduction

The Pilbara bioregion in Western Australia (WA) covers an area in excess of 178,000 km² and is characterised by inland mountain ranges with cliffs and deep gorges, as well as vast coastal plains. In broad terms, the vegetation is predominantly mulga low woodlands or snappy gum (*Eucalyptus leucophloia*) over bunch and hummock grasses (*Triodia* spp.) (Australian Government 2021). The bioregion provides the majority of WA's exports in petroleum, natural gas and iron ore.

Rio Tinto owns a network of 17 iron ore mines across the Pilbara that are supported by a resource development program requiring exploration. In 2020, Rio Tinto engaged Stantec to trial the use of a remote sensing approach for compliance monitoring of 33 exploration areas distributed across the Pilbara bioregion. The areas had been disturbed for exploration under environmental conditions associated with Programmes of Work under the *Mining Act 1978*, administered by the WA Department of Mines, Industry Regulation and Safety.

Given the large extent of land requiring assessment, distributed across 33 different areas spread across the Pilbara, the procurement of satellite imagery was deemed the best approach to capture data to assess the extent of vegetation cover, bare ground or other groundcover in disturbed and rehabilitated areas, consisting predominantly of former drill pads and access tracks. In this context, rehabilitation activities on cleared areas generally include the removal of infrastructure or waste, plugging drill holes, infilling of drilling sumps, landform reshaping, redistribution of topsoil and surface ripping or scarification. Regulatory compliance focuses on the detection of unlawful clearing (without a valid permit) and the rehabilitation of cleared areas within six months of completion of ground disturbance or within any approved extension. Traditional on-ground monitoring assessments have been used to demonstrate compliance, which includes photo monitoring at rehabilitated and nearby 'undisturbed' analogue areas with qualitative comparisons of soil and vegetation (extent and type) by a qualified environmental scientist.

This study presents a novel, alternative approach to compliance monitoring of exploration areas using remote sensing. Object-based image analysis (OBIA) was used, which involves segmentation and classification of pixels into 'objects' based on a range of characteristics (Blaschke 2010). The characteristics considered typically involve spectral response patterns, including, but not limited to, visible light (red, green, blue; RGB) and near infrared (NIR; particularly important as it is the primary region in which chlorophyll absorbs energy for photosynthesis). Additional features used in OBIA include size, shape, pattern, texture and context. This approach allows for increasing automation and potentially machine learning within the image processing, making it suitable for quantitative, repeatable assessments of large areas or time series (Whiteside et al. 2020).

The obvious advantage of the remote sensing approach compared to on-ground assessment is the ability to quantitatively classify ground cover over an entire area of interest, as opposed to the selected assessment of limited sampling points on ground, which may or may not be representative of the disturbed area as a whole. On the other hand, limitations of the remote approach were the lack of detailed information on specific native vegetation taxa, presence of weeds, or soil surface characteristics, such as evidence of scarification. However, the outcomes of this remote sensing study provide context for the refinement of regulatory

frameworks to best utilise novel technologies, to find the balance in the prioritisation of spatial coverage versus detail in rehabilitation assessments following vegetation clearing.

2 Methods

2.1 Imagery collection

Stantec procured multispectral imagery on the study sites from the provider Planet (<https://www.planet.com>) utilising the SkySat satellite constellation in September 2020. The imagery comprised red, green, blue and NIR bands and was provided as a raster file at a resolution of 50 cm. The study areas were distributed across the Pilbara with a total area exceeding 200,000 ha or 2,000 km² (Figure 1). Vegetation clearing at the sites had occurred under 33 individual exploration approvals.

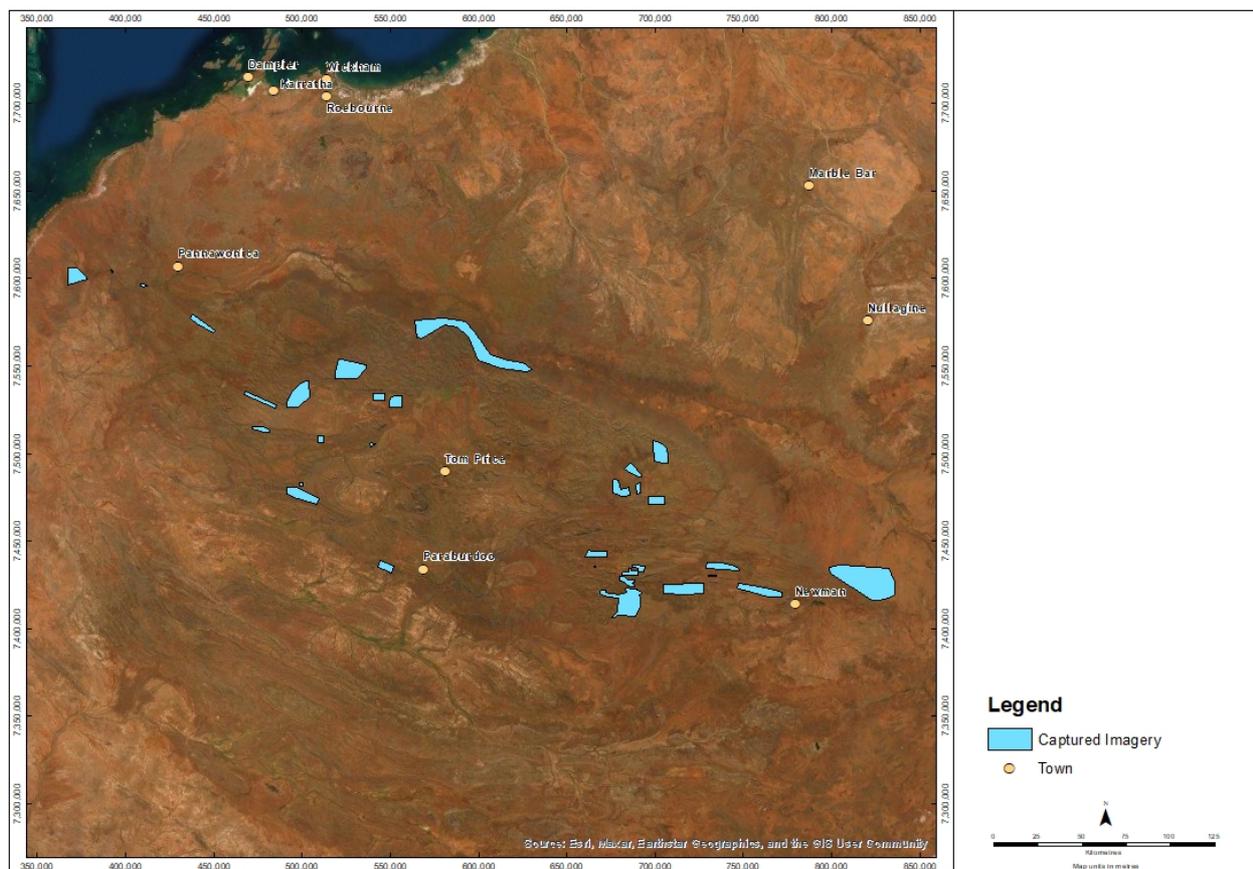


Figure 1 Areas of satellite imagery capture in 2020

2.2 Image analysis

A shapefile containing point data of rehabilitated drill pads was provided by Rio Tinto to assist in identification of rehabilitated areas (example in Figure 2). However, Rio Tinto spatial data that delineated disturbance boundaries (including access tracks and drill pad areas) was not used in this study and not all disturbed areas had been rehabilitated at the time of image capture. Therefore, in order to verify the disturbance footprint within the area of interest, OBIA was used to delineate disturbed versus undisturbed land. ArcGIS Pro with Spatial Analyst extension software was used to segment the image pixels into larger 'objects' based on spectral and spatial similarities. The Modified Soil Adjusted Vegetation Index (MSAVI; Qi et al. 1994) was also calculated and used as one of the OBIA input parameters. Vegetation indices can improve the delineation of live vegetation cover and MSAVI was developed to minimise soil background reflectance influences and has

been used previously to improve vegetation cover assessments in arid or semi-arid environments (Jafari et al. 2007). The index was calculated using the red and NIR bands, using the following equation:

$$MSAVI = \frac{(2 * NIR + 1 - \sqrt{(2 * NIR + 1)^2 - 8 * (NIR - RED)})}{2} \quad (1)$$

The segmentation process delineated a 'disturbance area' that included obvious signs of disturbance, such as tracks/roads and drill pads with low vegetative cover. The remaining area was categorised as the 'analogue'. Both the disturbance and analogue areas were saved as a feature class and analysed separately for comparative purposes.

The software was 'trained' to recognise cover classes in the imagery, using a supervised OBIA classification method. Parameters were adjusted to best suit the target features, to enable creation of the most unique object statistics for each feature, using all spectral reflectance attributes (RGB, NIR, MSAVI), along with size and shape properties. The result was an image classified into the following cover classes:

- Live vegetation.
- Bare ground/sparse vegetation.
- Litter and dry/dead vegetation.
- Shadow.
- Cloud (if present).
- Water (if present).
- Undefined (if present).

Cover class area sizes were extracted and presented separately for the disturbance area and for the analogue area. Any observations from the imagery relevant to the remaining 'undefined' classification were noted.

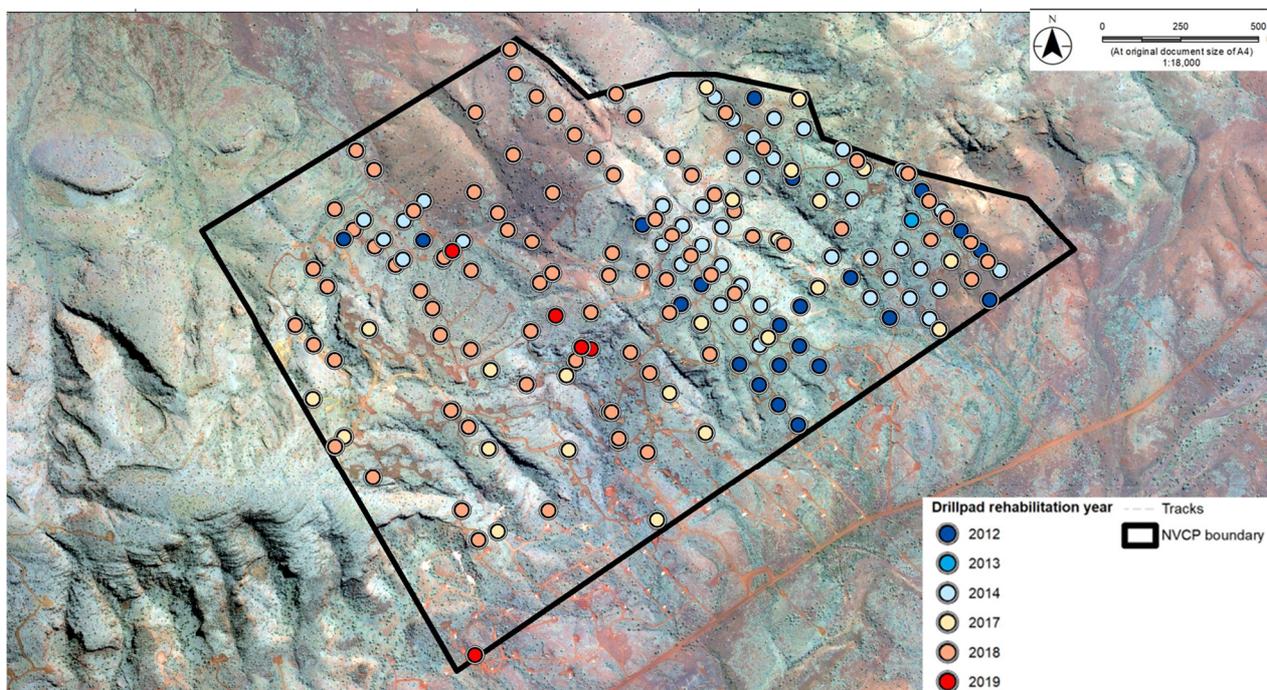


Figure 2 Example of satellite imagery captured within 'site 17' with Rio Tinto drill pad point data

2.3 Drill pad analysis

The provided drill pad point data was used to create a 30 m buffer zone around each drill pad point that fell within the disturbance feature layer to capture the rehabilitated area around each point. A smaller buffer zone of 10 m was created around drill pad points that fell within the analogue feature layer. The smaller buffer zone was used to create an area that best represented the drill pad without including surrounding undisturbed vegetation. The buffered drill pad points were then intersected with the disturbance and analogue features to identify the rehabilitated area. Cover class data was extracted and compared with the year of rehabilitation provided with the drill pad spatial data.

This analysis may have been subject to error, as buffered drill pad points may have captured undisturbed vegetation when the point data was not located in the centre of the rehabilitation. Also, the buffered area may not have captured the full extent of the drill pad due to varying drill pad shapes.

2.4 Limitations

It should be noted that any image classification is limited by the distinctiveness of the target feature's properties compared to its neighbours. The size of the features also makes a difference, in relation to the resolution of the imagery, as well as the number of spectral bands available for use. For example, sections of 'bare ground' may have been sparsely vegetated or vegetated with living but dry plants, such as grasses. In addition, the classification was not tested for accuracy, as on-ground data was not collected as part of this project.

Furthermore, well established rehabilitation that 'blends in' with the surrounding analogue area is likely to share similar spectral reflectance attributes as the analogue area. This could cause established rehabilitation to be classed as part of the surrounding analogue through OBIA. This limitation may impact the accuracy of the OBIA-delineated disturbance area and therefore the cover classes and MSAVI values within it.

It should also be noted that the analogue selection process did not include information on vegetation types or topography, as would typically be employed in a field-based assessment, and therefore the site characteristics between the disturbed and rehabilitated areas may be different to some or all of the analogue area, and the size of area assessed was also not standardised between the disturbance and analogue.

3 Results and discussion

3.1 Climate

The climate of the Pilbara bioregion is arid to tropical. The Pilbara has very hot summers, mild winters and spatially and temporally variable rainfall. Annual rainfall generally declines from the northeast toward the south and west areas, and tropical cyclones cause the most extreme rainfall events and can generate around 20–30% of the total annual rainfall. Rainfall is therefore greatest during summer and autumn and least during winter and spring (Figure 3a; Van Dijk & Summers 2016). Imagery for this study was captured in spring 2020, which followed two relatively dry years in 2018 and 2019 (Figure 3b; Van Dijk & Summers 2016). Average daily temperatures exceed 30°C across the region, during summer and early autumn, and are around 20°C during the winter months. Hot, dry and sunny conditions lead to very high evaporative demand across the Pilbara.

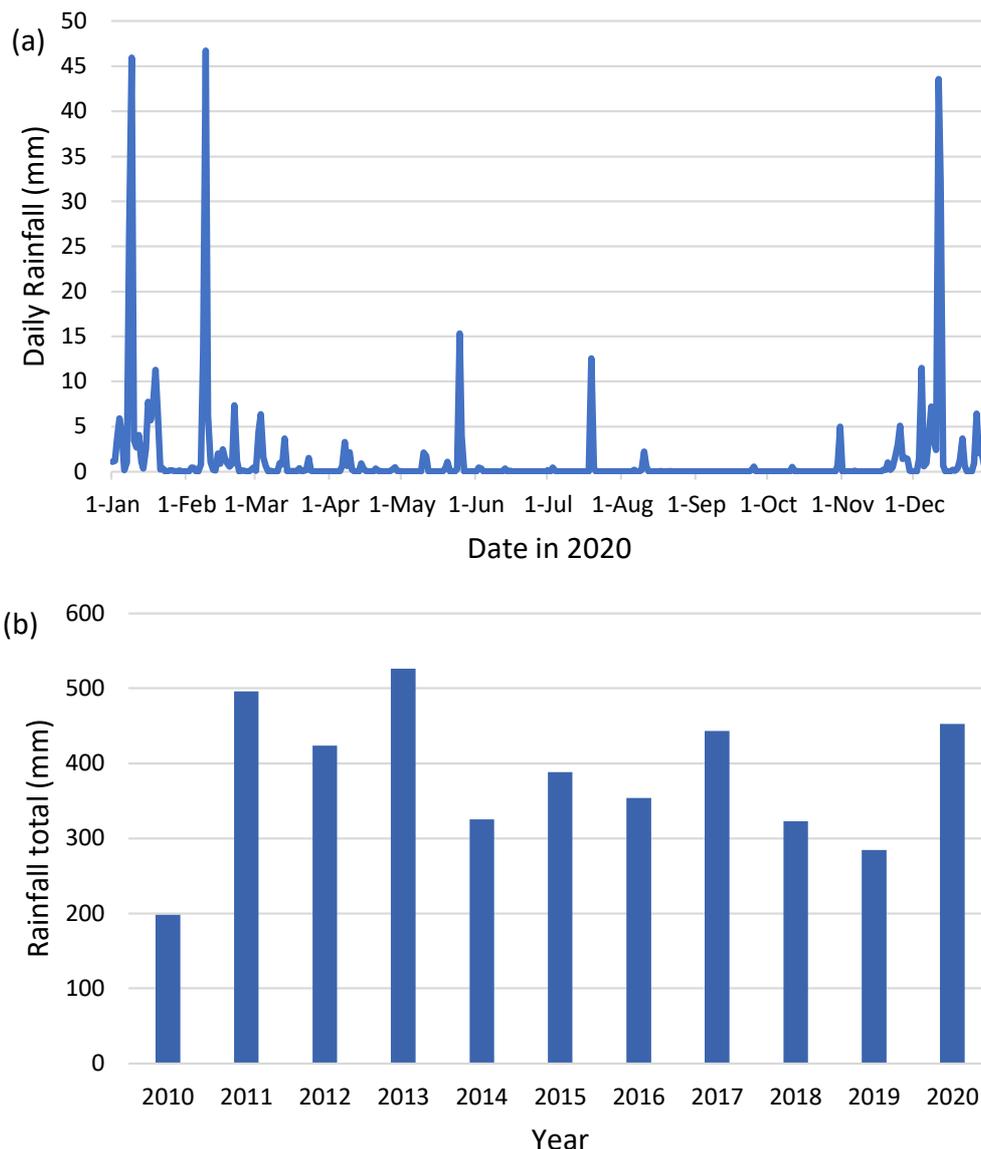


Figure 3 (a) Rainfall data for the Pilbara bioregion derived from Bureau of Meteorology station data and GPM satellite data by the OzWALD model data fusion system (source: Australia’s Environment Explorer) for 2020; (b) Total annual precipitation over 10 years

3.2 Site disturbance overview

In general, the extent of OBIA-defined disturbance varied widely between sites from 2 to 1,200 ha, which corresponded to between 0.1% and 30% of the total area of each site (Figure 4). Disturbance was visually observed to be predominantly drill pads and access tracks, and an example of the spatial data output from OBIA-defined disturbance is provided in Figure 5.

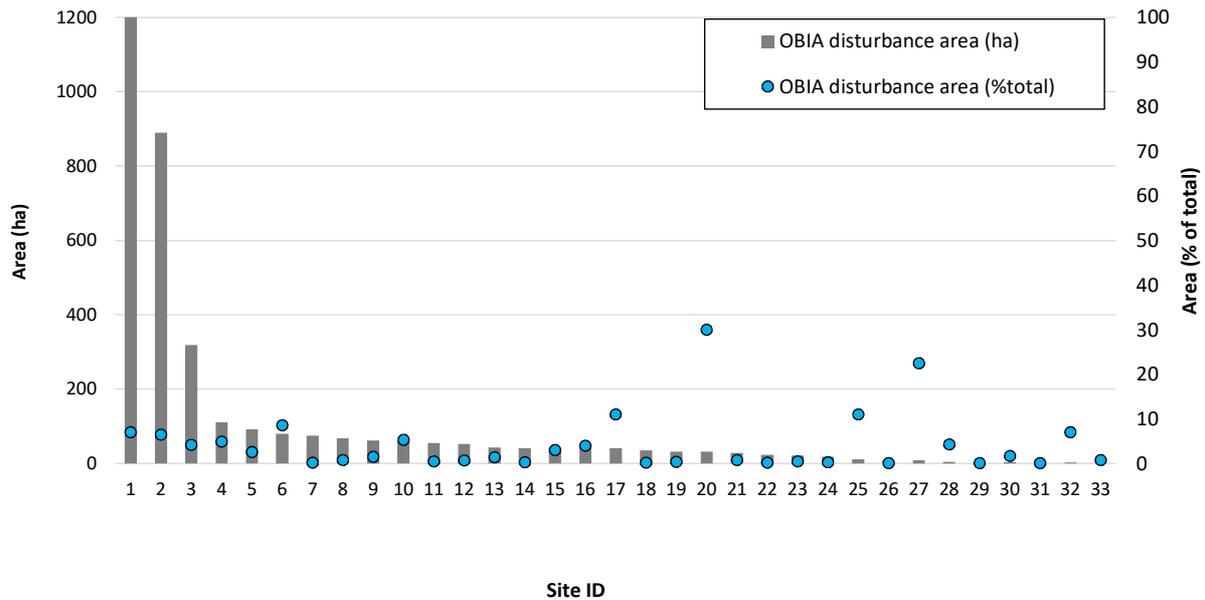


Figure 4 Size of disturbance areas detected by OBIA across 33 sites in 2020 expressed both in hectares and as a proportion of the total area relevant to the specific permit

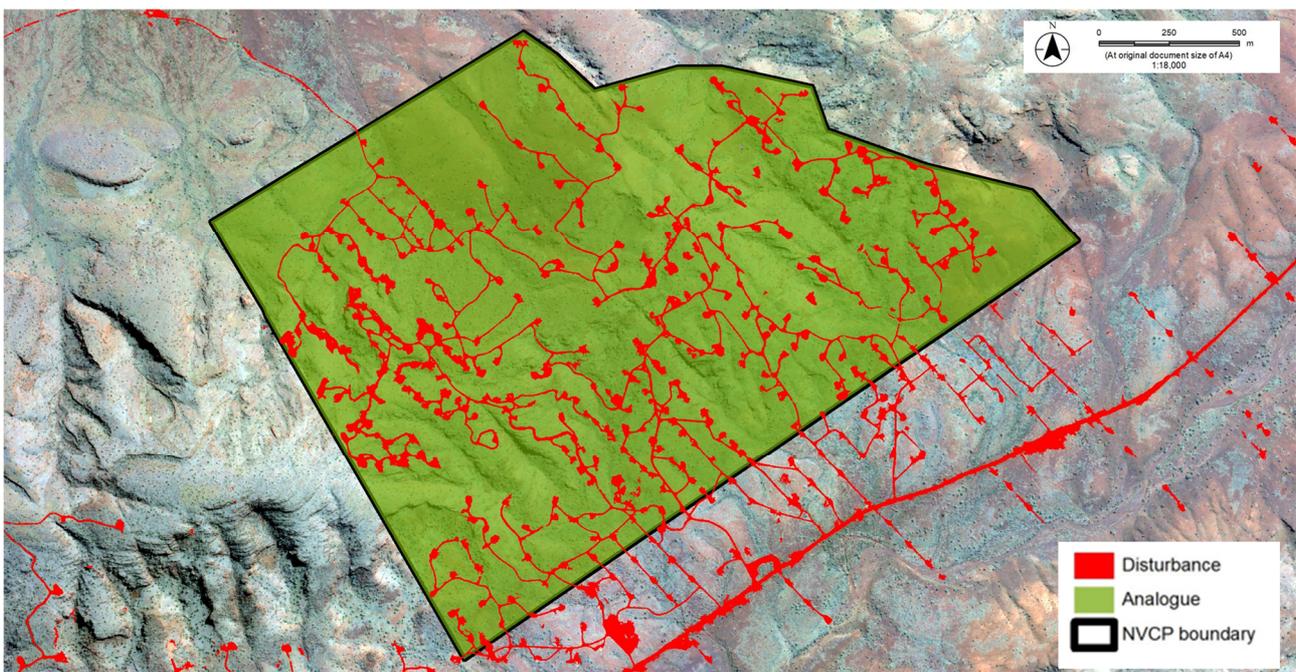


Figure 5 Example spatial output of OBIA-delineated disturbance within 'site 17'

3.3 Cover classifications

Cover classifications provided quantitative information on the extent of live vegetation in the OBIA-defined disturbance, which could be compared with the surrounding area classed as analogue. On average, live vegetation cover was approximately three times higher in the analogue feature than the disturbance feature (Figure 6). An example of the cover classification spatial analysis output is provided in Figure 7.

Cloud cover was present at only one site and was less than 10% of the total area, and mostly fell within the analogue feature class. 'Undefined' areas were present at only seven sites and covered between 0.001% and 0.6% of the total area at each site. Observation suggested these 'undefined' areas were most likely

infrastructure of various types, although at one site appeared to consist of drill spoils, in areas of disturbance not yet rehabilitated.

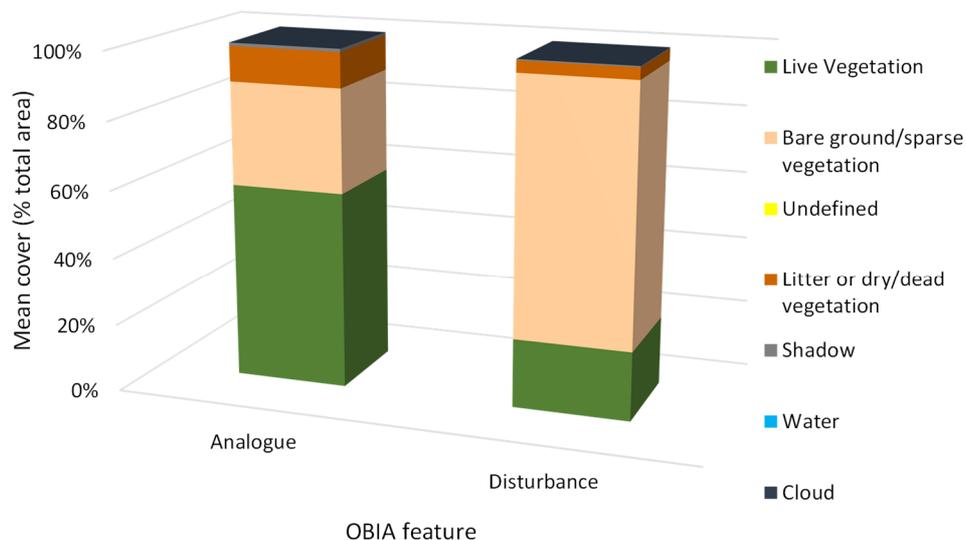


Figure 6 Mean cover classifications for all sites (n = 33) in 2020

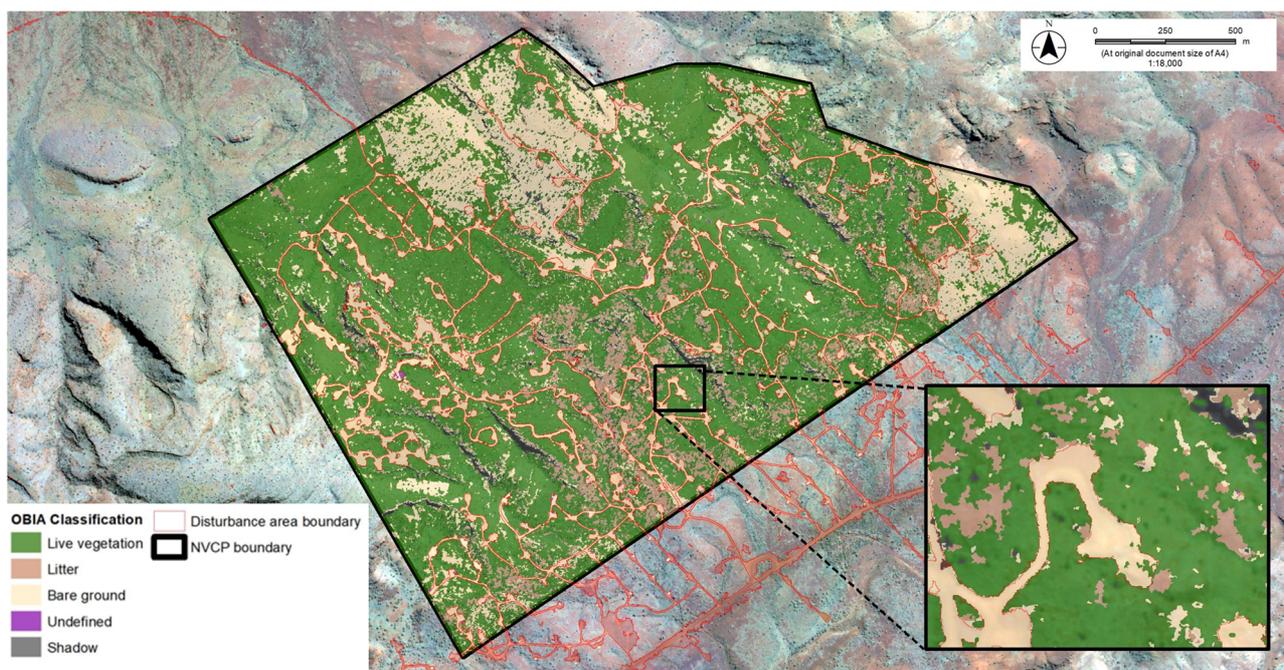


Figure 7 Example spatial output of cover classifications for 'site 17'

3.4 Drill pad analysis

This assessment utilised the drill pad point spatial data, irrespective of whether the drill pad was aligned with disturbance or analogue features, as designated using OBIA. This approach demonstrated that substantial proportions of the drill pads, despite being disturbed land, actually intersected with the designated analogue areas (Figure 8). This finding suggested that either the image analysis process was not sufficiently targeted to pick up historic disturbance or varying proportions of rehabilitated sites had become sufficiently vegetated to not be classed as 'disturbance'. In order to explore this further, cover classifications within individual drill pads were extracted and trends examined where more than one drill pad age was present.

An example site for which the extent of live vegetation broadly increased with drill pad rehabilitation age is provided in Figure 9. For this site, there were 195 drill pad points within the spatial data, of which 158 were found to intersect with the disturbance delineated by OBIA and 37 intersected with the analogue area. Of these 37 drill pads, the majority were either six or eight years old. The high vegetative cover of these drill pads resulted in the spectral signatures of these areas aligning with the analogue area rather than the disturbed area.

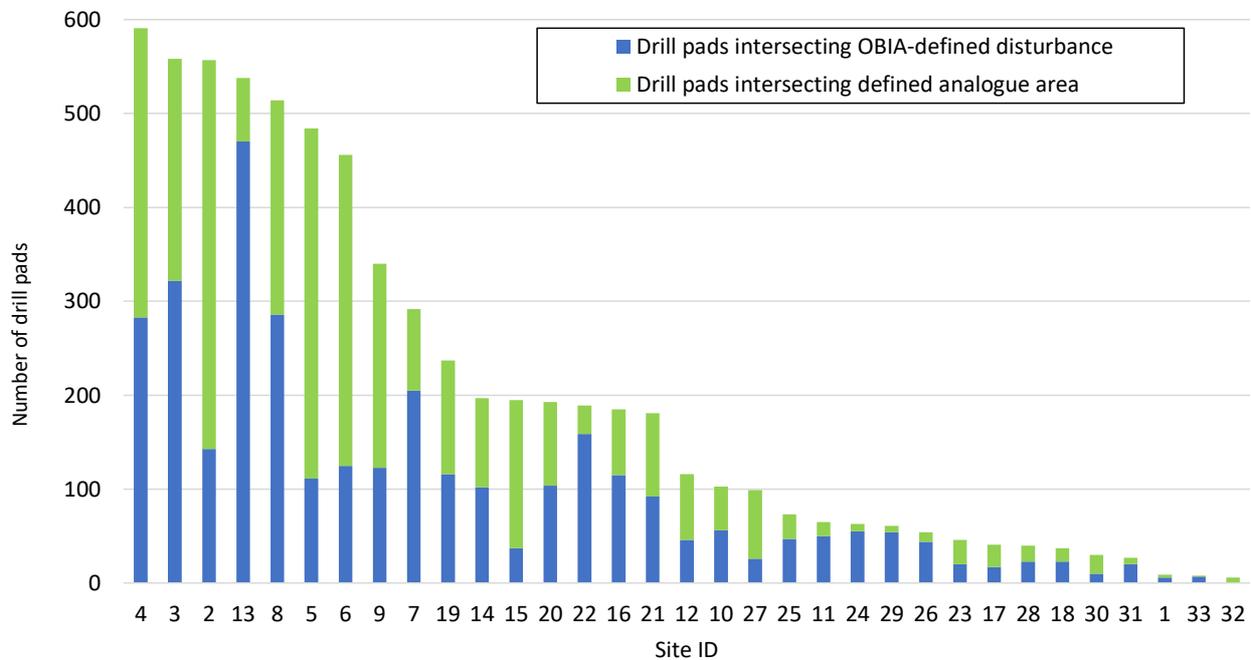


Figure 8 Number of drill pads within each permit area and proportion aligning within or outside the OBIA-detected disturbance

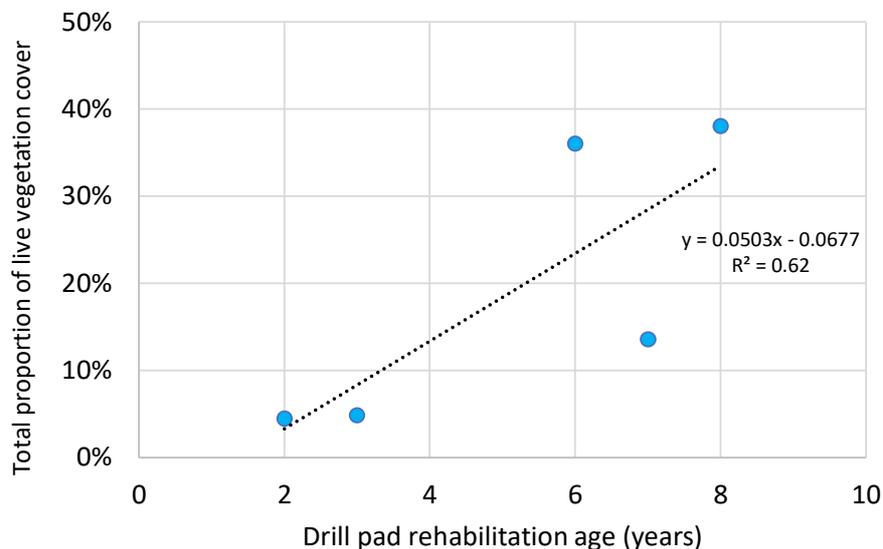


Figure 9 Example site for which vegetation cover increased with age of rehabilitated drill pads

3.5 Future directions

Remote sensing using satellite imagery, as described in this study, has the potential to improve our understanding of long-term environmental outcomes of land disturbed by exploration activity and could be

integrated into regulatory frameworks. A remote sensing approach also provides the potential to assess quantitative changes in vegetation cover at the same site between years. Improvements in the detection of historical disturbance could be developed through use of accurate spatial disturbance data, or improved techniques for detecting disturbance through image analysis.

In future assessments, progress will likely be made in the delineation of vegetation cover into strata or functional groups. Potential further identification of key native vegetation genera or species (e.g. *Triodia* spp.) has been done previously (Jasper et al. 2019) and may be feasible at the sites such as in this study, but generally requires image collection at a higher spatial resolution (10 cm or less) than that provided by satellites (maximum resolution is 30 cm provided by WorldView satellites), which may be cost-prohibitive on such a large scale.

Further studies would benefit from the integration of ground-truthed data for improved accuracy of cover classifications. The remote sensing assessment could also be used as a tool to prioritise where on-ground assessment may be required or where management actions (such as infrastructure or waste removal) is needed. It is recognised that remote sensing assessments remove the safety risks associated with on-ground monitoring in remote areas. However, even though remote sensing may not entirely remove the need for on-ground access, this approach may provide a mechanism for prioritisation of on-ground site assessments, and more targeted and efficient sampling designs.

The method required to adequately undertake compliance-driven monitoring may vary according to the specific conditions outlined in the approvals relevant to each site. Both on-ground and remote sensing monitoring approaches, when undertaken correctly, can meet the intent of typical conditions. However, the choice of methods needs to take into consideration the limitations of each method in the context of what is 'reasonable effort'. Where limitations of on-ground monitoring arise, remote sensing can be used to fill those gaps and vice versa. In addition, it is worth noting that the requirement to accurately track disturbance and rehabilitation footprints remains, regardless of the chosen monitoring approach.

4 Conclusion

This study employed a remote sensing assessment of land disturbed by exploration activity associated with 33 separate sites covering an area of approximately 200,000 ha distributed across the Pilbara bioregion in WA. The extent of disturbance detected by image analysis ranged from 2 to 1,200 ha per site and ranged from less than 1% up to 30% of the total area covered under an exploration approval. The disturbance was predominantly clearing associated with drill pads and access tracks.

An analysis of drill pads, based on Rio Tinto spatial point data (i.e. excluding access track or other disturbance), found that a substantial proportion of drill pads fell outside the disturbance detected through image analysis. While this suggests improvements into the automated detection of historical disturbance could potentially be made, it also suggested that the live vegetation cover at older drill pads at some sites had recovered sufficiently such that the spectral signature of these areas was aligning with the analogue rather than the disturbance area.

In addition, this study provides the mining industry a case study to consider options for the site rehabilitation assessments, including the option to minimise or remove safety risks associated with on-ground access to remote areas, and provide an approach to understand the longer-term environmental outcomes of land rehabilitation following exploration activity.

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