Part 4: Nabarlek

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[1] List of papers grouped by Key Knowledge Need.

Quantitative use of remotely sensed data for minesite revegetation assessment

K Pfitzner & P Bayliss

Introduction

An important component of minesite monitoring and rehabilitation assessment includes an analysis of revegetation success. The disadvantage of traditional ecological-based assessments are that they are very labour intensive at broad scale and so can only sample a small proportion of the area affected by mining (eg at field point locations, along transects or within quadrants). The qualitative nature of many methods may also cause problems with consistency when used by different assessors (Corbett 1999).

The challenge in monitoring minesite environments using remotely sensed data is to differentiate cover types with wide spectral variation across an inherently variable land surface, and over different capture times. Differentiation between introduced weeds, native ground and tree canopy cover and exposed soil is required as these index local environmental conditions in addition to rehabilitation success. Remotely sensed data that combines small pixel size and/or high spectral resolution with the capability to capture new images soon after disturbances provides such continuous coverage and, in contrast to intensive ground-based methods over much smaller sample areas, may be more cost-effective.

The rehabilitated Nabarlek minesite is being used as a test site. Very high resolution (VHR) satellite data are being utilised for revegetation assessment at the Nabarlek minesite. The major aims of the study are to help assess whether or not vegetation communities on the Nabarlek minesite blend with the undisturbed surrounding landscape and to contribute to a quantitative description of the plant communities in the region. Further, the data are being used to assess the impact of threats such as fire and to develop methods applicable to the future rehabilitation assessment of the Ranger mine.

Method – Nabarlek

A ground-based monitoring program was initiated by SSD in the late dry season of 2003 and repeated in the late wet season of 2004 to quantitatively assess revegetation performance and to develop survey methodologies applicable to the future rehabilitation of the Ranger uranium mine. Details of the ground-based method and results of sampling can be found in Bayliss et al (2004a & b). Because only 0.51% of the total rehabilitated area was able to sampled across the variable minesite VHR satellite (Quickbird) captures were commissioned to coincide with the ground-based sampling to facilitate scale up from the transect-based data. In addition to the transect-based fieldwork, hundreds of point data and regional data of ground covers were sampled using a GPS across the minesite. The 4-band (B G R IR) Quickbird data were pan-sharpened (PS) to 60 cm pixel size using the University of New Brunswick (UNB) algorithm and data were orthorectified.

During June 2004 and November 2005, the Northern Land Council reported that fires occurred on the minesite. Quickbird image captures were tasked and data obtained in August 2004 and November 2005 to map the extent of fire impact. Another image capture was tasked in December 2005 to assess the impact of vegetation recovery as a result of onset of wet season rains. In April 2006, Cyclone Monica crossed Nabarlek. A flyover the following week showed that the site had been severely impacted, with 90% of trees defoliated and/or fallen. Unfortunately a fire occurred on the minesite prior to acquisition of the post cyclone Quickbird data in July 2006.

Native four band data and transformations, including ratios (B4/B3, B3/B2, B4/B1) and Principal Components Analysis (PCA) were assessed for their suitability in extracting land cover features. Regions characterized by the field surveys were used to obtain spectral regions of interest from the remotely sensed data, including introduced ground covers (such as *Urochloa mutica*, *Pennisetum* spp*, Hyptis sauveolens, Passiflora foetida, Cynodon dactylon, Chloris* spp*),* native ground covers (*Heteropogan* spp *Sorghum stipodeum, Schizachyrium fragile)* and bare surfaces (exposed soils and rocks and infrastructure). Spectral separability of these regions were assessed using the Transformed Divergence separability statistic (Research Systems 2005).

A contextual classification approach using image objects rather than pixels was required to identify and map meaningful objects from within a highly variable data set (Pfitzner 2005). However, a contextual approach is limited by the number of image objects that can be used, and therefore prevented an analysis of the entire image scene. For this reason a buffer of 300 m was created from the minesite perimeter to create a tractable subset of the image data.

The surrounding country (vegetation, landform and soils) are well described by detailed Land Units mapping (Day and Czachorowski 1982). For the minesite subset, different data layers (bands 1–4, ratios and PCA bands) were assessed for their usefulness in creating image objects. Bands 1–4 were input for image segmentation using an object-orientated method (www.definiens-imaging.com). The segmentation was a bottom-up region merging approach starting with single pixel objects. In an optimisation pair-wise clustering process, smaller objects were merged into larger objects based on heterogeneity criteria of colour (spectral response) and shape. The pair of adjacent objects with the smallest growth (deviation) from the defined heterogeneity criteria were merged with each iteration. The process stopped when the smallest growth for merging of adjacent objects exceeded a predefined scale parameter. The heterogeneity criteria weighted gave a higher weighting of colour over shape. Spectrally similar objects were merged based on a scale parameter analysis.

Results

Figure 1 shows selected false colour composites of Quickbird subsets covering the minesite (May 2004, November 2005, December 2005 and July 2006).

In May 2004, much of the minesite was covered by introduced ground cover species. Tree cover is dominated by *Melaleuca* spp on Evaporation Ponds 1 and 2 and *Acacia* spp on the pit. The November 2005 image shows the effect of a fire on the minesite, with much of the minesite characterised by a fire scar (burnt canopies are indicated by a yellowy-brown colour). One month later (December 2005) introduced species were regenerating with the onset of wet season rains. The July 2006 image illustrates the loss of vegetation cover as a result of both cyclone Monica and an intense dry season fire. In May 2004, 71% of the minesite was covered by vegetation, compared to just 15% of the minesite in July 2006.

Separability statistics showed high separability (>1.9) for like pairs of ground covers, including *Urochloa mutica*, *Heteropogan* spp, *Cynodon dactylon* and schist rocks (ie two regions representing the same cover type had a separability score of > 1.9 with the 4 band Quickbird data). These results confirmed the high spectral variability for surface cover, even for like species, and showed that there was limited ability to discriminate species using a spectral-based approach. A contextual method was then assessed and implemented (Pfitzner and Bayliss 2006) to enable spectrally similar but contextually different ground covers to be extracted.

The buffered mine region from the Quickbird scene and Land Unit data are illustrated in Figure 2. Image objects were created from the pixel level, and spectrally like neighbours merged at increasing scale factors (levels). The scale parameter modal statistic provided an appropriate scale factor for increasing levels. The segmentation parameters were not transferable across temporal images, but the methodology was. The contextual approach maintained individual tree canopies, while the high variability within like surface covers was simplified (averaged), making a four band spectral analysis appropriate at the Quickbird mapping scale (Figure 3).

A binary classification to broadly separate vegetated surfaces from non-vegetated surfaces was possible with the transformed Normalised Difference Vegetation Index (NDVI) data. The membership function used for discriminating vegetated land cover was a NDVI threshold based on larger than values. Tree canopy was further classified by shape (compactness) and also indicated by non-vegetated cover, such as shadow. Non-vegetated cover was separated using an inverted similarity to green vegetation.

Membership functions to distinguish different non-vegetated surfaces included: mean band 1 (painted surfaces such as concrete and tanks and airstrip guidelines), mean band 3 (sediments) and pca2 (fire scar). The PCA transformed data applied to image segments was required to separate the fire scar from the bitumen of road surfaces and the airstrip.

The approach described above is being implemented for assessing revegetation progress on the Nabarlek minesite over time and shows promise as a monitoring and assessment tool for rehabilitated minesites in general (Pfitzner & Bayliss 2005).

Summary

Revegetation success at Nabarlek is under pressure from threats such as weeds and fire. While ground-based measurements provide necessary information on species abundance, broad scale use of this method is limited due to small sample sizes and the effort required for monitoring changes in abundance due to disturbance. Remotely sensed data provides the potential to monitor broad landscape changes. Due to the short range variation in surface cover types at the Nabarlek minesite, VHR data are required to resolve the land cover features required for revegetation assessment. Four-band data are of limited use for spectral separation of land cover features. Pending further developments (substantially increased numbers of spectral bands) of remote sensing technologies, a contextual approach for separating cover components shows considerable promise as a monitoring tool for rehabilitated sites in general. This involves indexing local environmental condition using VHR satellite data.

Steps for completion

The analysis of the multitemporal data (including detailed ground and canopy cover maps) and accuracy assessment using ground-based data need to be finalised. The results are to be written up and published. Vegetation recovery from the effects of the cyclone and fire in 2006 will be assessed with a late wet season Quickbird capture in 2007. To separate the effects of the cyclone and the fire, three captures of Landsat 5 data were acquired, including data pre-cyclone, post-cyclone (pre-fire) and post-cyclone post-fire. These data will be analysed and published.

Acknowledgments

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Future work – Ranger/Jabiluka

Ranger/Jabiluka – satellite data

Cyclone Monica passed through Jabiru during April 2006, causing changes in vegetation cover, fire impact, soil exposure and implications for sediment transport. To research the extent and intensity of change due to the storm effects, VHR Quickbird data, covering 14 km x 45 km was acquired in July 2006. Figure 4 illustrates the extent of data capture. Because fire disturbed the landscape prior to the capture of Quickbird data, multi-temporal Landsat data were acquired to separate the cyclone effects from fire. Landsat data were acquired pre-fire and cyclone, post cyclone (pre-fire) and post cyclone/fire. It is envisaged that Landsat data will also be acquired in the late wet season of 2007 to assess revegetation recovery.

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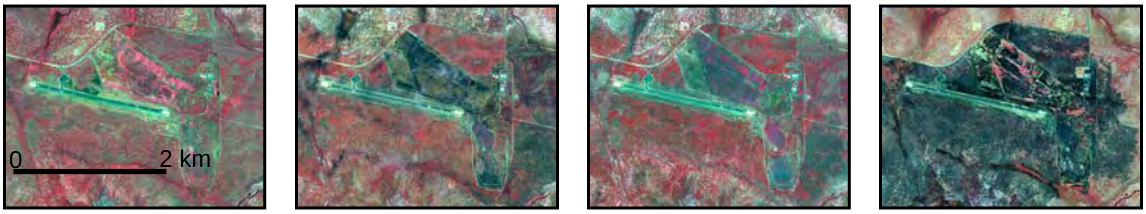


May 2004 | November 2005 | December 2005 | July 2006

Figure 1 Multitemporal Quickbird subsets of the Nabarlek minesite. IR R G (R G B). Vegetation is reflective in the IR (shown as red colours for native vegetation and pink colours for grassy weeds). Fire impacts are shown in shades of blue-grey.

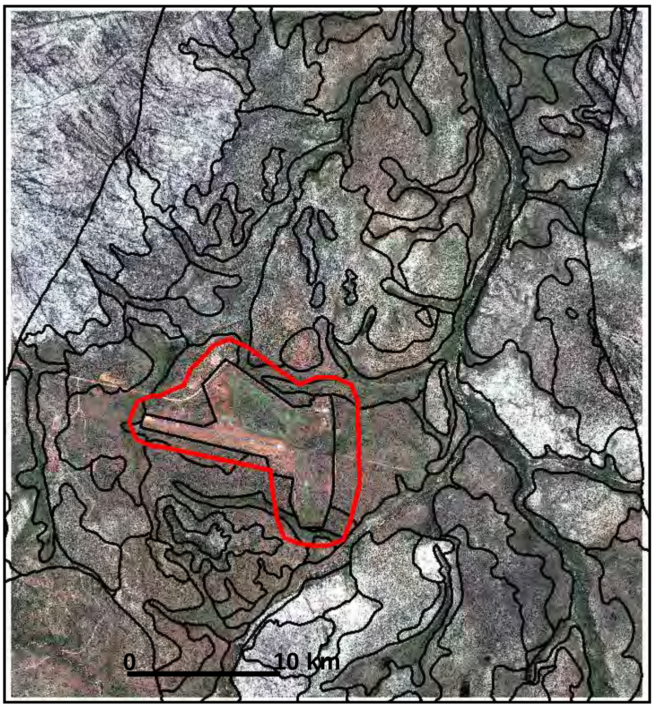
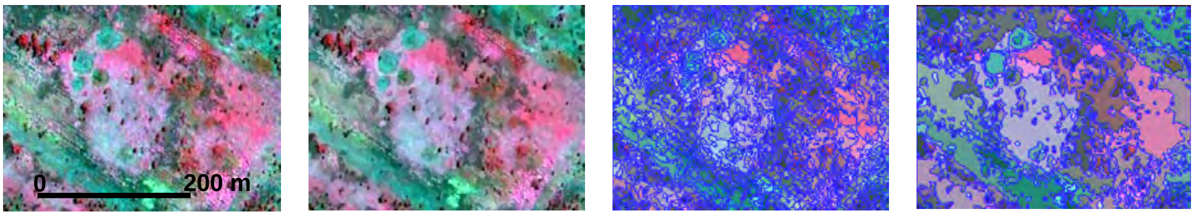


Figure 2 (left) Quickbird data capture May 2006 – full extent (65 km^2) (R G B). Land units overlaid (black lines) and buffer subset (red polygon).



Pixel based | Level 2 | Level 4 | Level 7

Figure 3 (above) Small sub-samples of Quickbird data (May 2004), IR R G (R G B) using the multi-level segmentation approach. Image objects boundaries are depicted in blue for levels 4 and 7.

Figure 4 (right) Extent of June 2006 Quickbird data. Ranger – Jabiluka surrounds.

Radiological impact assessment of the rehabilitated Nabarlek site

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Introduction

There is no permanent habitation close to the rehabilitated Nabarlek uranium mine site at present, but future occupancy of the site (on a part or full time basis) cannot be ruled out. Radiological risk assessment, including all exposure pathways, is needed to assist planning for any future changes to land use.. Such an assessment requires integration of data from: 1) gamma dose rate surveys; 2) radon flux densities and airborne radon concentration surveys; 3) radionuclide concentration in surface soils and erosion/stability assessment; 4) bore water uranium isotope and radium concentration measurement; and 5) measurement of radionuclide uptake into edible plants growing on and off site.

Fieldwork, data analysis and interpretation for tasks 1, 2 and 3 above are mostly complete. In 2005–06 the spatial variability of the airborne radon concentration at the site was determined using track etch detectors. Particular emphasis was given to evaluating groundwater radionuclide activity and metal concentration data, and assessing the potential impact on off-site groundwater quality.

Reference should also be made to the paper under KKN 2.1.6 ('Radio- and lead isotopes in sediments of the Alligator Rivers Region') that describes the potential for use of radionuclides and Pb isotopes as tracers of mine impact. A substantial component of this paper describes results from the Nabarlek site.

Methods and results

Radon concentrations in air

78 passive radon monitors (PRM) were distributed across the site, at a height of 1 m above ground, at 37 individual sites. Two detectors were deployed at each site, covering various areas on the mine. These areas included the evaporation ponds (EP1 and 2), the plant run-off pond (PROP), the stockpile run-off pond (SPROP), the pit including a radiological anomalous area (unit-7), the waste rock dump (WRD), the waste rock dump run-off pond (WRDRP) and an environmental control site (ENV).

Radon concentrations measured at individual sites ranged from a minmum of 25±9 Bq·m^{-3} at the environmental control site close to the Myra camp turn-off up to a maximum of 500±100 Bq·m^{-3} at evaporation pond 2. Radon concentration were also high at unit-7 (maximum 380±50 Bq·m^{-3}), a relatively bare area, which has previously been identified as an area of high soil radium activity concentration (Hancock et al 2006) and radon flux densities (Bollhöfer et al 2005). Table 1 summarises the results of the radon concentration survey.

Area-averaged concentrations of radon in air at Nabarlek were compared with average gamma dose rates determined from groundtruthing of an airborne gamma survey (Martin et al 2006), from a detailed survey of unit-7 in 2005, and with radon flux densities determined across the site (Bollhöfer et al 2005). As expected from first principles, higher soil radium concentrations lead to elevated average radon concentrations. This was observed at the pit, WRD, WRDRP, unit-7, EP1 and PROP.

Table 1 Average airborne radon concentrations measured at Nabarlek and a comparison with dose rates (Martin et al 2006) and radon flux densities (Bollhöfer et al 2005) at Nabarlek

	Radon concentration [Bq·m^{-3}]	Gamma dose rate [uGy·hr^{-1}]	Radon exhalation [mBq·m^{-2}·s^{-1}]
EP-2	361 ± 162	0.37	105 ± 102
Unit 7	296 ± 83	0.98	6508 ± 6831
PROP	66 ± 18	0.36	278 ± 203
SPROP	249 ± 78	0.36	137 ± 120
EP-1	152 ± 88	0.48	169 ± 86
PIT	137 ± 76	0.51	971 ± 739
WRD	113 ± 18	0.46	335 ± 318
WRDROP	138 ± 92	0.47	335 ± 318
ENV	41 ± 15	0.09	31 ± 15

However, both EP2 and SPROP stand out in this comparison with the highest and third highest radon concentrations, respectively. Compared to the other sites these locations had a significantly denser vegetation cover at the time of deployment. Track etch detectors were deployed amongst dense stands of weeds (red natal grass, and para and mission grasses). This condition may have inhibited air flow and hence promoted a build up of radon and its progeny during the night and in the early morning hours, and inhibited an effective convective air exchange during the day.

This accumulation of radon in 'dead zones' has potentially important implications for assessing human exposure routes on rehabilitated mines landforms. In particular, measurements made in well flushed open environments may underestimate exposure that would occur in an area with denser mid-story or canopy development. Moreover, humans are typically much closer to the ground (sleeping) during the night and early morning hours when the potential for radon accumulation will be the greatest. Addditional work was planned to investigate near ground surface concentration of radon in vegetated areas at Nabarlek during the 2006 dry season. However, the occurrence of Cyclone Monica and subsequent fires meant that this followup work could not be done.

Groundwater

Radionuclide activity and dissolved metal concentrations in borewaters from the decommissioned and rehabilitated Nabarlek uranium mine have been analysed by ***eriss*** in samples collected from 1996 to 2005. The standing water levels for all bores for the collection dates were acquired from Northern Territory Department of Business, Industry and Resource Development. Bore logs were obtained to aid in the interpretation of the data.

The standing water levels (SWL) at Nabarlek from the deep aquifer tend to reflect the local topography. Groundwater flow directions are generally eastwards towards Cooper Creek in agreement with the regional groundwater flow patterns calculated by Salama (1986).

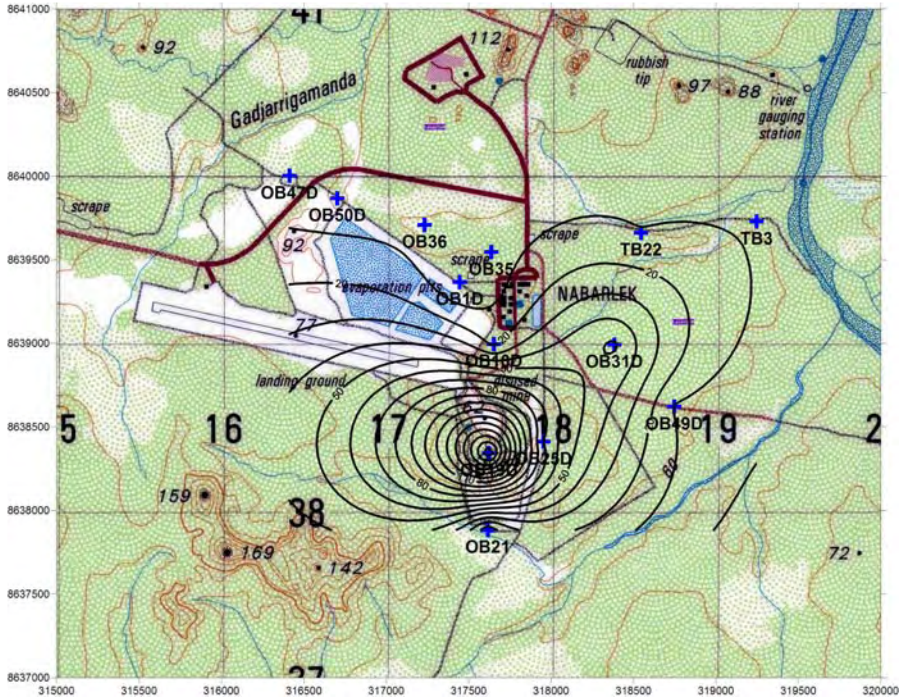

Figure 1 ^{238}U activity concentration [mBq·l^{-1}]contours for Nabarlek groundwater 2004

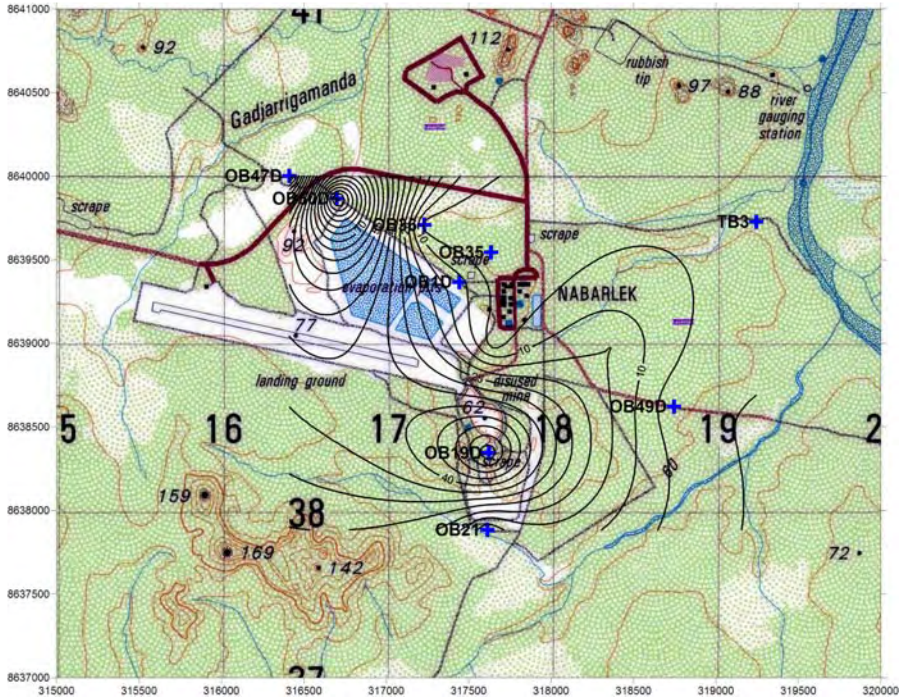

Figure2 ^{226}Ra activity concentration [mBq·l^{-1}] contours for Nabarlek groundwater 2004

Uranium activity concentration data collected from 1996 to 2005 range from < 1 mBq·l^{-1} in OB1D to the north-east of the mine to 179 mBq·l^{-1} in OB19D, which is situated down gradient from, and closest to, the former pit where the tailings were deposited. Borewaters from OB25D and OB31D also exhibit significant uranium activity concentrations of 124 mBq·l^{-1} and 94.9 mBq·l^{-1}, respectively. All the other bores analysed since 2003 have uranium levels of ≤ 20 mBq·l^{-1}. OB25 is closest to the eastern edge of the former pit and uranium activity concentrations have decreased over the past 10 years, whereas levels have increased in OB19. Uranium levels in OB31 did initially increase but have displayed a decrease in the past two years.

Uranium and radium contour lines shown in Figures 1 and 2 suggest a plume moving from the pit and waste rock dump areas to the northeast of the Nabarlek area towards Cooper Creek. Bores OB25, OB31 and TB22 exhibit endmember $^{234}U/^{238}U$ activity ratios of ~ 1. A ratio close to 1 can indicate a mining-related source of uranium in groundwater as shown previously by Iles et al (2002).

The remnants of spray irrigation may be the reason for the higher ^{226}Ra activity concentration measured in bores situated at the northern end of the mine (Figure 2). OB1D, SP29, OB47D and OB50D have relatively high ^{226}Ra activity concentrations and $^{238}U/^{226}Ra$ ratios well below 1, which may suggest that ^{226}Ra, which was deposited by spray irrigation between 1984-87, is being leached and mobilised into the groundwater from the soil profile in the vicinity of the bores. This has also been observed by Martin and Murray (1991).

Steps for completion

Further statistical analysis of all Nabarlek groundwater data, including metal and trace metal concentrations, needs to be conducted. Future work at Nabarlek will focus on bushtucker collection and analysis, and the determination of plant radionuclide uptake factors for the site. This will enable a comprehensive dose model to be developed for Nabarlek that will include all relevant exposure pathways.

Acknowledgments

All bore samples collected between 1996 and 2005 and associated field data were supplied by the Minerals and Energy Group of the Department of Primary Industry and Fisheries and Mines.

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