Mine Closure 2006 — Andy Fourie and Mark Tibbett (eds)
© 2006 Australian Centre for Geomechanics, Perth, ISBN 0-9756756-6-4
https://papers.acg.uwa.edu.au/p/605_69_Suhartoyo/

Evaluating Rehabilitation of Sand Mined Sites at Tomago, NSW — Measuring Success and its Criteria

H. Suhartoyo *Centre for Mined Land Rehabilitation, The University of Queensland, Australia*

D.R. Mulligan *Centre for Mined Land Rehabilitation, The University of Queensland, Australia*

D. Doley *Centre for Mined Land Rehabilitation, The University of Queensland, Australia*

1 INTRODUCTION

As an increasing number of mining operations approach closure, criteria by which to measure the success of rehabilitation efforts have become increasingly important and several workers have developed ecosystem success indicators (Tongway et al., 1998; Ludwig et al., 2003; Nichols et al., 2005; Grant, 2006). Mined land rehabilitation as ongoing process designed to restore the physical, chemical and biological qualities or potentials of air, land and water systems for post-mining land users (ANZMEC, 2000). Operators, regulators and communities need quantitative data on ecosystem development in order to support decision on mining relinquishment. Both regulators and mining operators are now addressing these issues throughout Australia, despite the relatively few examples of mine closure that have been reviewed publicly and approved (Nichols, et al., 2005).

Mining for heavy mineral sands in the Tomago Sandbeds, north of Newcastle, NSW, by RZM Pty Ltd (RZM) has disturbed substantial areas of coastal vegetation. However, a continuous rehabilitation program, initiated by RZM soon after mining commenced in 1972, aimed to return to the mined area plant communities which would have , as far as practicable, similar species compositions and structures to those existing before mining (RZM, 1981; RZM, 2000). The ultimate long-term objective of RZM's rehabilitation program is dune forests that are similar to undisturbed dune forests in the region. What is yet to be clarified is whether the rehabilitated ecosystems have reached the desired condition or whether the pattern of development indicates that the ultimate goal will be achieved.

In judging rehabilitation success, numerous authors have used Odum's (1969) succession traits as primary attributes (e.g. Ewel, 1987; Aronson et al., 1993; Aronson and Le Floc'h, 1996; Hobbs and Norton, 1996; and see review by Ruiz-Jaen and Aide, 2005), emphasising ecosystem or landscape approach for developing criteria of rehabilitation success (e.g. Tongway et al., 1998). However, in a changing environment, a quantitative, site-specific and process/dynamic approach is increasingly demanded (Parker, 1997; Cumming, 2003; Choi, 2004).

In case of RZM, multiple disturbances have contributed greatly to the patterns of development of native forest vegetation on rehabilitated sites not only through the re-mining of a number of rehabilitated areas, but also through the occurrence of fires across the sites. These events raise further questions regarding the feasibility of re-establishing native ecosystems. The ability to judge the success or otherwise of rehabilitation is further complicated by a lack of knowledge on the basic ecosystem processes and the rate of ecosystem dynamics in many areas (Court et al., 1996; Ormerod, 2003; Maestre et al., 2006). To date, few studies have considered the effects of multiple disturbances during succession, especially on mine rehabilitation sites (Brennan, 2003; Ross et al., 2004). Therefore studies of ecosystem development on a rehabilitated mine site is of critical importance, especially when the complexity of rehabilitation progression is compounded by multiple disturbances.

In this paper, the development of structural and functional attributes within rehabilitated sand mined sites with multiple disturbances was examined. Characteristics of ecosystem structure and function were accessed against the following criteria: first, the overall trend of condition on the rehabilitated sites should be towards that of a reference site, and second, age-related trends on chronosequence of rehabilitated sites should be repeatable over time.

2 METHODOLOGY

2.1 Study Areas

The study was conducted within rehabilitated sand mined sites of the Tomago Sandbeds, (32°52'S, 151°45'E), located on the inner barrier dunes 4 km inland of the Newcastle Bight embayment, 13 km north of Newcastle, New South Wales (Figure 1). The Tomago sandbeds landscape is geologically young, having resulted from sand deposition associated with sea level fluctuations during the last (late Pleistocene) interglacial period between 120000 years and 10000 years ago (Thom et al., 1992). The region has a humid temperate climate. Mean annual rainfall is 1127 (± 37) mm at Williamtown (53-year mean), distributed uniformly throughout the year but with a slightly wetter autumn period.

Mining in the Crown Water Reserves was commenced in late 1972. The operation was carried out under stringent environmental conditions to protect water quality and supply (RZM, 2000). The mining process was mainly conducted by means of dredging, using either cutter suction or bucket-wheel dredges. Concentrators were either traditional floating plants in the mining pond with the dredge or modular land based plants. Some dry mining was carried out, usually in shallow, supplementary orebodies in the vicinity of the main orebodies, using earthmoving equipment to transport ore to the dredge path. From about half-way through the mine life, in April 1986, remining operations commenced in the Tomago Main Lead, encouraged by changes in mining technology, operating conditions and market demand. Remining operations continued to the end of the mine life in the Sandbeds.

Figure 1 Tomago study site (www.earthgoogle.com)

2.2 Rehabilitation Process

The rehabilitation process was an integral part of the mining operation and management of rehabilitation areas extends beyond the end of the mining process. The first step in the rehabilitation process was landform reconstruction. Mine tailings were deposited by mining plants to create the bulk features of the reconstructed landforms. Earthmoving machinery was then employed to shape the final post-mining landform according to the design prior to topsoil respreading. Management of topsoil resources was achieved using a front-end loader to bucket soil to appropriate locations for subsequent spreading using a bulldozer. From 1987 onwards, in the areas where timber and brush material was stockpiled after clearing operation, this material was distributed over the respread topsoil prior to commencement of revegetation works.

The establishment of native overstorey species is central to rehabilitation objectives in the Tomago Sandbeds (RZM, 2000). Techniques for native species establishment on mined areas continued to evolve over the life of the mining operation. Species were established by various means (planting of advance stock, tube stock, direct seeding or brush spreading) and for different purposes. Most rehabilitation species were established from nursery propagation programs.

2.3 Vegetation Monitoring

The various combinations of disturbance, including the passage of fire across mined areas and into the adjacent unmined forest, were sampled in this study. Following a preliminary reconnaissance survey, study sites were selected that incorporated the monitoring transects established by RZM (Table 1). The ages of rehabilitation from single mining operations ranged from 11 to 27 years, and from double mining operations from 6 to 17 years. Sites in unmined forest were used to compare the effects of multiple disturbances and to provide a "reference or benchmark" condition as an indicative rehabilitation goal of a sustainable ecosystem.

Table 1 Sites and conditions selected on the RZM Tomago study sites
(*re-measure in the following year)

Disturbance	Rehabilitation State		Rehabilitation Age (yrs)	Transect	Code
Single Mining	Intermediate	Unburned	11*	T 136, T 137	11UB
		Burned 2003	13*	T 122, T 124	13UB
		Unburned	16	T 86, T 87	16UB
		Unburned	18	T 10, T 11	18UB
	Mature	Unburned	23	T 24, T 26	23UB
		Unburned	25*	T 17, T 18	25UB
		Burned 2003	27*	T 3, T 4	27B
Double Mining	Young	Unburned	6*	R 54, R 56	6UB
		Burned 2003	8*	R 48, R 50	8B
		Unburned	10*	R 37, R 38	10UB
		Burned 2003	11*	R 34, R 35	11B
	Intermediate	Burned 2003	12	R 25, R 28	12B
		Burned 2003	14	R 09, R 10	14B
		Burned 2003	17	R 18, R 19	17B
Native Forest	Unburned-Unmined				Native

Ecosystem properties assessed at each site (Table 2) included functional attributes (soil properties) and structural attributes (canopy cover, basal area, litter cover, and species richness). Vegetation sampling was conducted in May 2005, along 100 m x 20 m transects (five 20 m x 20 m plots). Within each 20 m x 20 m plot, five soil samples (0-5 cm), were taken and bulked for chemical analysis, including pH, total phosphorus, total organic carbon, total nitrogen and cation exchange capacity (CEC). Some sites were re-assessed in May 2006.

2.4 Data Analysis

The data are presented in two ways: first, as comparisons of mean values of attributes across sites, and second a summary of statistical analysis of each attributes against success criteria. For each variable, the benchmark was the value in the native unburnt forest and ordinary least squares were used to determine trends for rehabilitated areas against site age. The requirement of development towards the benchmark was met if the trend was significantly different from zero and was proceeding towards the benchmark value.

Table 2 Functional and structural variables used for monitoring

Factor	Variable	Description
a. Ecosystem function		
Soil nutrients	Organic Carbon (%) Nitrogen (mg/kg) Phosphorus (mg/kg) CEC (cmol$^{(+)}$/kg)	The percentage of the soil that consist of carbon and carbon compounds. Total nitrogen concentration. Total phosphorus concentration. The sum total of exchangeable cations that soil can absorb.
b. Ecosystem Structure		
Biomass components	Basal area (m^2/ha) Canopy cover (%) Leaf litter cover (%)	Measurement of all trees and sapling above 1cm DBH. Visual estimation of projective cover of vegetation 2m above the ground using FPC. The percent cover of leaf litter and small branches.
Composition	Species richness (n/ha)	Number of species within measured plots

3 RESULTS

3.1 Functional Attributes

Soil variables are considered as surrogates of ecosystem functions. Total organic carbon (TOC) is an essential part of any site characterization since its quantity can markedly influence how other chemicals will react in the soil. Within single mined sites at Tomago (Figure 2a), rehabilitated areas are generally progressing towards the reference (native site) condition, except in the burnt site (13B) which has a greater than expected TOC value. In contrast, the TOCs of all rehabilitated double-mined sites (Figure 2b) were still below the reference site.

Cation Exchange capacity (CEC) is the capacity of a soil colloid to retain cations by electrostatic forces. CEC is important because first, exchangeable cations such as calcium, magnesium and potassium are readily available for plant uptake, and second, cations adsorbed to exchange site are more resistant to leaching. CEC of rehabilitated sites was highly variable, but the rate of increase is greater in the single-mined site. The variability may due to many factors affecting CEC, such as the number of colloidal particles present (soil texture), type of colloid present (soil consistency), and organic matter content (Sopher and Baird, 1978; Walker and del Moral, 2003).

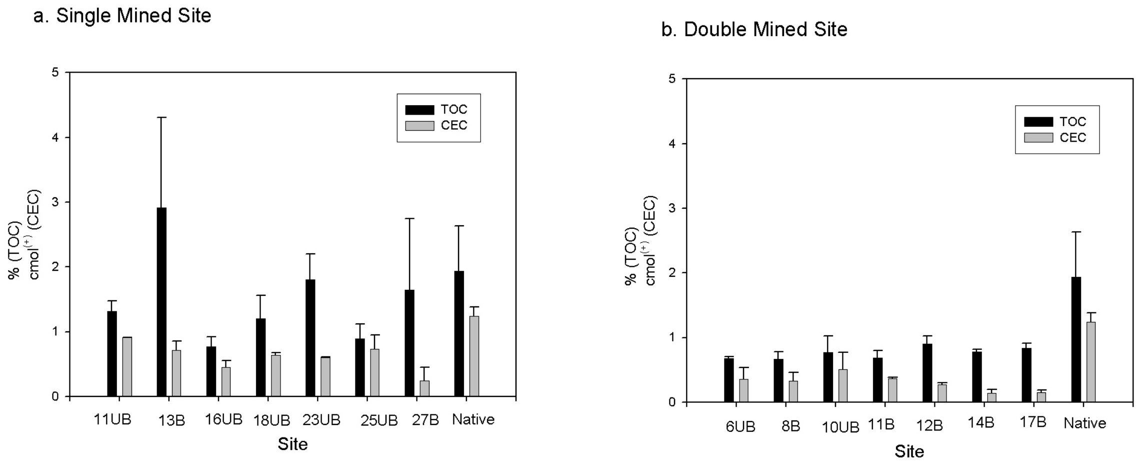

Figure 2 **Total Organic Carbon (TOC) and Cation Exchange Capacity (CEC) Single mined (a), Double mined (b), UB=Unburnt, B=Burnt**

Total phosphorus and total nitrogen varied between rehabilitated sites. Total nitrogen within single-mined and burnt sites (13B and 27B) exceeded the native reference site (Figure 3a), whereas with increased age of rehabilitation, most sites approached the reference site. Within double-mined sites (Figure 3b), total nitrogen was below native the reference site. On the other hand, total phosphorus on rehabilitated sites mostly exceeded that on the native site.

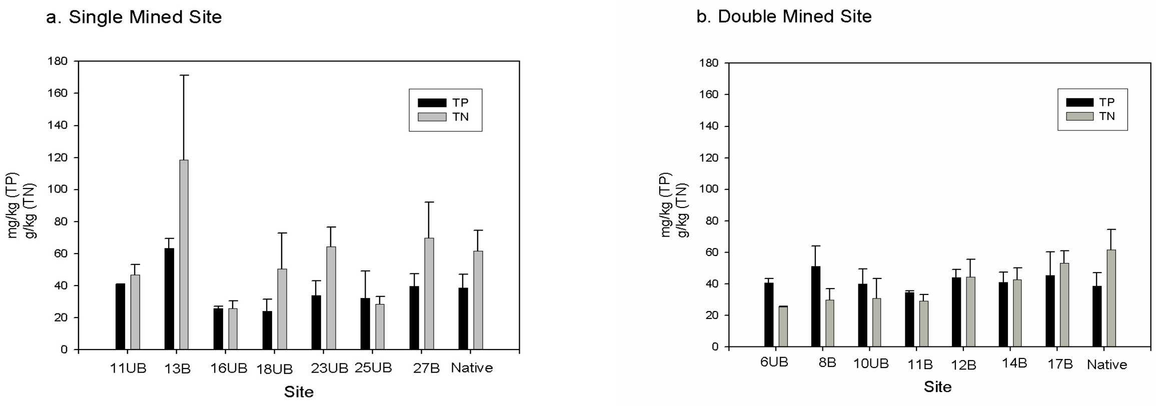

Figure 3 **Total Phosphorus (TP) and Total Nitrogen (TN) Single mined (a), Double mined (b), UB=Unburnt, B=Burnt**

3.2 Structural Attributes

In general, the basal area of woody stems increased with the density of planted stems and the age of rehabilitation on single-mined sites and the limited evidence indicated a non-significant effect of burning (Figure 4a). Double mining substantially reduced stem basal area and there was a consistent, often significant further reduction following burning (Figure 4b). Medium and large diameter trees were well represented in intermediate aged and mature rehabilitation on single-mined sites, and the basal areas were progressing towards that of the unmined native forest. In contrast, all of the trees on the double-mined sites were small, particularly after burning.

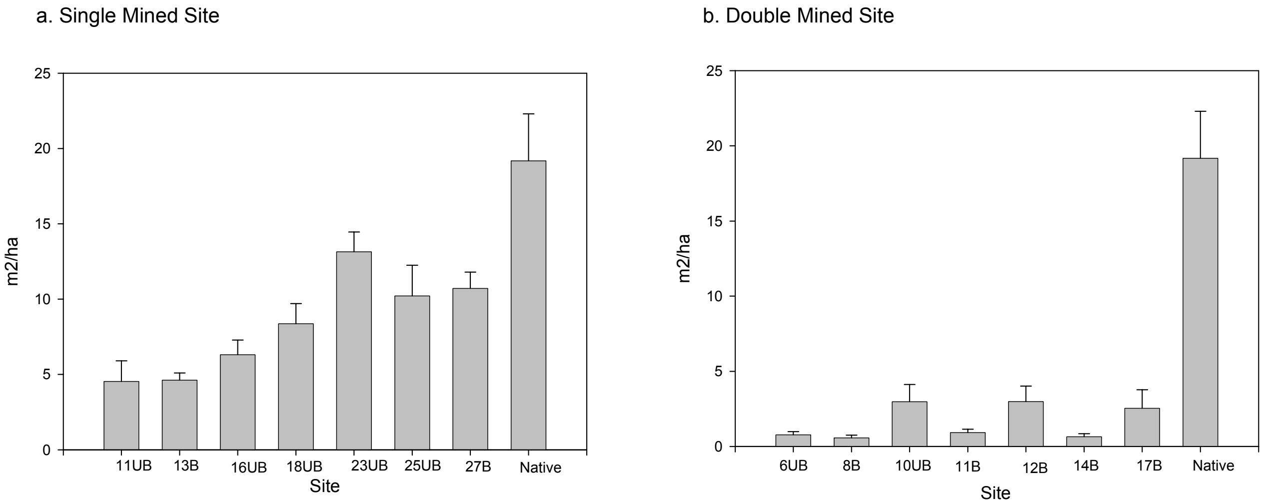

Figure 4 **Basal areas of rehabilitated stands Single mined (a), Double mined (b), UB=Unburnt, B=Burnt**

The average canopy cover of unmined forest was 82%. Unburned rehabilitated single-mined sites approached this value but burning resulted in significant reductions (Figure 5a). On double-mined sites, canopy cover of 11 to 17 year-old burned rehabilitation varied from 9 to 14%, whereas 6 to 10 year-old rehabilitation reached 23 to 26% cover (Figure 5b).

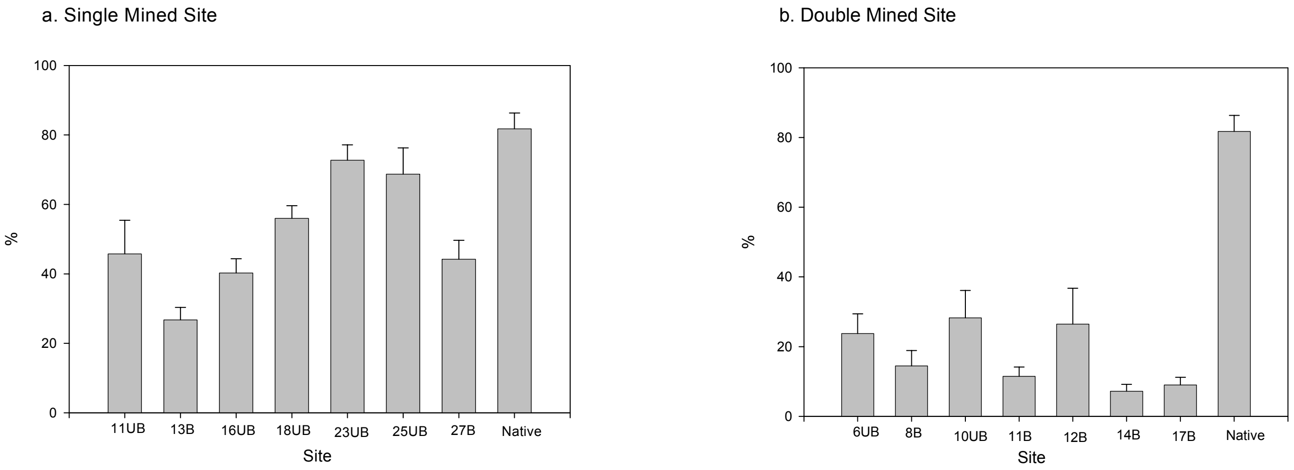

Figure 5 **Canopy cover of rehabilitated stands Single mined (a), Double mined (b), UB=Unburnt, B=Burnt**

3.3 Assessment Criteria

The goal of mined land rehabilitation in Australia has increasingly progressed from simple revegetation towards more comprehensive ecosystem rehabilitation (Hobbs, 2003; Nichols et al., 2005). Post-disturbance rehabilitation should enable the dynamic return of ecosystem structure and function (Ormerod, 2003; Maestre et al., 2006). Structural and functional attributes have been the principal tools of many researchers (e.g. Ruiz-Jaen and Aide, 2005) in assessing rehabilitation or restoration success. In the present work, two questions were asked concerning the recovery process: first, were rehabilitated sites similar to the benchmark site, and second, is it the rehabilitated site progressing towards benchmark site?

3.3.1 Ecosystem function

Some attributes of ecosystem function, in terms of soil properties, were no different between rehabilitated and benchmark sites. Total organic carbon, total nitrogen and total phosphorus within single-mined sites were not significantly different between rehabilitated and benchmark site (Table 3). In contrast within double-mined sites, most functional attributes, except for total phosphorus, revealed significant differences, between rehabilitated and benchmark sites.

Table 3 Summary statistics of trends in rehabilitated sites and soil variables
(*transect 13B was omitted due to high value of TOC and TN)

Attributes	**Criteria**	
	1. Rehabilitated site = benchmark (native site)?	**2.** Overall developmental trend towards benchmark (native site)?
Ecosystem function		
Total Organic Carbon		
a. Single Mined Site	Yes (t_{14}=0.62, P>0.05)	Yes (y=0.87+0.021x, P>0.05, R^2=0.93)*
b. Double Mined Site	No (t_{14}=5.19, P=0.0001)	Yes (y=0.55+0.011x, P=0.001, R^2=0.92)
Cation Exchange Capacity (CEC)		
a. Single Mined Site	No (t_{14}=2.74, P=0.015)	No (y=1.01-0.021x, P>0.05, R^2 =0.94)
b. Double Mined Site	No (t_{14}=6.61, P=0.0001)	No (y=0.61-0.016x, P=0.04, R^2=0.94)
Total Nitrogen		
a. Single Mined Site	Yes (t_{14}=0.13, P>0.05)	Yes (y=76.6+1.001x, P>0.05, R^2=0.80)*
b. Double Mined Site	No (t_{14}=2.46, P=0.027)	Yes (y=6.57+1.572x, P=0.001, R^2=0.98)
Total Phosphorus		
a. Single Mined Site	Yes (t_{14}=0.41, P>0.05)	Yes (y=50.8+0.722x, P>0.05, R^2 =0.91)
b. Double Mined Site	Yes (t_{14}=0.21, P>0.05)	Yes (y=42.5+0.008x, P>0.05, R^2 =0.98)
Ecosystem structure		
Basal area		
a. Single Mined Site	No (t_{37}=4.81, P=0.0000)	Yes (y=0.83+0.479x, P=0.006, R^2=0.80)
b. Double Mined Site	No (t_{37}=13.12, P=0.0001)	Yes (y=0.26+0.123x, P>0.05, R^2=0.25)
Canopy Cover		
a. Single Mined Site	No (t_{37}=2.86, P=0.0001)	Yes (y=20.86+1.567x, P>0.05, R^2 =0.35)
b. Double Mined Site	No (t_{37}=8.36, P=0.006)	No (y=31.78-1.304x, P>0.05, R^2=0.31)
Litter Cover		
a. Single Mined Site	No (t_{37}=4.684, P=0.0001)	Yes (y=20.86+1.567x, P=0.005,R^2 =0.22)
b. Double Mined Site	No (t_{37}=11.14, P=0.0000)	Yes (y=16.42+0.519x, P>0.05, R^2 =0.18)
Species Richness		
a. Single Mined Site	Yes (t_{14}=1.41, P>0.05)	Yes (y=38.97+0.576x, P=0.006, R^2=0.21)
b. Double Mined Site	No (t_{14}=19.25, P=0.0001)	No (y=21.08-0.164x, P>0.05, R^2=0.10)

The overall development of functional attributes showed that only total organic carbon has a positive trend towards the reference benchmark site, both within single-mined and double-mined sites. On the other hand, CEC showed negative trends towards their reference benchmarks.

3.3.2 Ecosystem structure

Almost all ecosystem structural attributes show significant differences between rehabilitated sites and reference benchmark sites. It means that even after 27 years of rehabilitation, structural attributes are still different from an unmined site. The structure of a complex forest cannot be restored in a short time-frame after mining (Suhartoyo et al., 2006). However, trends towards reference site conditions were apparent for basal area, canopy cover and litter cover in both single and double-mined site. Species richness within single-mined sites was no different from the reference site, but it was significantly different in double-mined sites. The trend of species richness is also shown negatively towards reference site.

4 DISCUSSION

Assessing rehabilitation success after mining is not an easy task. It has often been judged by a superficial resemblance to a local vegetation type in the form of pasture, forest, woodland or wetland (Bellairs, 1988; Bell, 2001). Furthermore, the success of rehabilitation is determined by social and political considerations and in turn acceptability judgments or completion criteria are derived jointly by regulators and the company. Therefore quantitative measures of ecosystem development should enable the best decisions to be reached (Palmer et al., 1997).

Ruiz-Jaen and Aide (2005) emphasized the need to use more than one ecosystem attribute to measure the success of a rehabilitation program. Our results confirm that simple measurements of ecosystems structure and function may be useful indicators. Based on the assessment of ecosystem attributes against two criteria, namely, how similar the rehabilitated site was to the reference site, and is it moving towards the reference condition, every attribute had a different response. In brief, the majority of functional attributes may have reached the condition of the reference site, but the trends in most were negative. Functional attributes are the resultant of many components of the ecosystem, as shown in soil properties. It was intended to use multivariate analysis to depict the relationship between each attribute with the vegetation data (Suhartoyo et al., 2006), but no clear results could be obtained. As suggested by Grant (2006), univariate analysis may give a better understanding of how an ecosystem is progressing. On the other hand, structural attributes showed significant differences between rehabilitated and reference sites, but the trends were positive, indicating progress towards the reference site. Measurement of ecosystem productivity, through stand basal area, is the traditional means of assessing condition in forest ecosystems, and this indicator proved to be the most effective means to evaluate ecosystem progression (Ludwig et al., 2003; Ruiz-Jaen and Aide, 2005).

The present work suggests that functional attributes may have been restored after 25 years within single-mined site. These functions will be disrupted if there is subsequent disturbance e.g. fire. Within double-mined sites, restoring functional attributes appears to be much more difficult, especially if there is subsequent fire disturbance.

Ecosystem structural attributes indicate that the rehabilitated site is still far from the reference site condition, but it may be restored if there is no further disturbance. The trends of most structural attributes were progressing towards the reference site. The next question is how long it may take to reach the reference site condition. Species richness appeared to be different from the reference and it may difficult to restore within double-mined sites, but within single-mined sites the species richness was similar to that in the reference site.

High annual rainfall (~ 1130 mm) in the Tomago area means that the rehabilitation of a sand mined site has important biological advantages in comparison to dry sites. However, multiple disturbances, particularly double-mining, but also burning, may impair the chances for success.

5 CONCLUSION

Developing criteria of rehabilitation success can be achieved by exploring ecosystem properties in the form of functional and structural attributes. Assessing the rehabilitated sites against a known reference benchmark site gives a clearer indication of whether a sustainable ecosystem can be achieved in a rehabilitation program. The rehabilitated sand mined site at Tomago may progress towards the reference site condition provided no further disturbance occurs. However, within double-mined sites the progress may need more time. These results indicate that when all rehabilitation procedures are carried out according to the rehabilitation prescription, ecosystem developing on rehabilitated sand mined site is likely to be sustainable in the long-term.

ACKNOWLEDGEMENTS

This study was funded through the Sustainable Mineral Institute (SMI) UQ. A special thank to Ken Meadley (RZM) and John Simpson (formerly RZM) for support and guidance throughout the project. Thanks also to Melina Gillespe, Craig Lockhart and Hendry Baiquni (Centre for Mined Land Rehabilitation - UQ) for assistance with fieldwork, and to David Appleton for analysing the soil samples. Senior author (HS) is an AusAid scholarship recipient.

REFERENCES

ANZMEC (2000) Strategic framework for mine closure. Ausinfo, Canberra (http://www.minerals.nsw.gov.au) Accessed in October 2005.

Aronson, J., Floret, C., Le Floc'h, E., Ovalle, C. and Pontanier, R. (1993) Restoration and rehabilitation of degraded ecosystems in arid and semi-arid lands. II. Case studies in Southern Tunisia, Central Chile and Northern Cameroon. Restoration Ecology. 3, pp. 168-187.

Aronson, J. and Le Floc'h, E. (1996) Vital attributes: missing tools for restoration ecology. Restoration Ecology 4, pp. 377-387.

Bellairs, S.M. (1988) Determining ecological indicators for native vegetation and wildlife habitat rehabilitation success at the Blair Athol and Tarong mines. Workshop proceedings on Indicators of Ecosystem Rehabilitation Success, Melbourne October 1988, pp. 105-118.

Bell, L.C. (2001) Establishment of native ecosystems after mining –Australian experience across diverse biogeographic zones. Ecological Engineering 17, pp. 179-186.

Brennan, K.E.C. (2003) The successional response of spider communities following the multiple disturbances of mining and burning in Western Australian Jarrah forest. Australian Journal of Entomology. 42, pp. 379-381.

Choi, Y.D. (2004) Theories for ecological restoration in changing environment: Toward 'futuristic' restoration, Ecological Research 19, pp. 75-81.

Court, J., Wright, C. and Guthrie, A. (1996) Environmental assessment and sustainability: Are we ready for the challenge? Australian Journal of Environmental Management. 3, pp. 42-57.

Cumming, J. (2003) Using process-orientated parameters to assess degradation. Ecological Management and Restoration. 4, pp. S79-82.

Ewel, J.J. (1987) Restoration is the ultimate test of ecological theory. In: Restoration Ecology, a synthetic approach to ecological research, Jordan, W.R., Gilpin, M.E., and Aber, J.D. (eds), pp. 331-333. Cambridge University Press, Cambridge.

Grant, C.D. (2006) State and transition successional model for bauxite mining rehabilitation in the Jarrah forest of western Australia. Restoration Ecology 14, pp. 28-37.

Hobbs, R.J. (2003) Ecological management and restoration: Assessment, setting goals and measuring success. Ecological Management and Restoration 4, pp. S2-3.

Hobbs, R.J. and Harriss, J.A. (2001) Restoration ecology: repairing the earth's ecosystem in the new millennium. Restoration Ecology 4, pp. 239-246.

Hobbs, R.J. and Norton, D.A. (1996) Towards a conceptual framework for restoration ecology. Restoration Ecology 4, pp. 93-110.

Ludwig, J.A., Hindley, N. and Barnett, G. (2003) Indicators for monitoring minesite rehabilitation: trends on waste-rock dumps, northern Australia. Ecological Indicators 3, pp. 143-153.

Maestre, F.T, Cortina, J. and Vallejo, R. (2006) Are ecosystem composition, structure, and functional status related to restoration success? A test from semiarid Mediterranean steppes. Restoration Ecology 14, pp. 258-266.

Nichols, O.G., Grant, C. and Bell, L.C. (2005) Developing ecological completion criteria to measure the success of forest and woodland establishment on rehabilitated mines in Australia. The 2005 National Meeting af the American Society of Mining and Reclamation, June 2005. Lexington.

Odum, E.P. (1969) The strategy of ecosystem development. Science 64, pp. 262-270.

Ormerod, S.J. (2003) Restoration in applied ecology: editor's introduction. J. Applied Ecology 40, pp. 44-50.

Palmer, M.A., Ambrose, R.F., and Poff, N.L. (1997) Ecological theory and community restoration ecology. Restoration Ecology 5, pp. 291-300.

Parker, V.T. (1997) The scale of successional models and restoration objectives. Restoration Ecology. 5, pp. 301-306.

Ross, K.A., Taylor, J.E., Fox, M.D. and Fox, B.J. (2004) Interaction of multiple disturbances: importance of disturbance interval in the effect of fire on rehabilitating mined areas. Austral Ecology 29, pp. 508-529.

Ruiz-Jaen, M.C. and Aide, T.M. (2005) Restoration success: how is it being measured? Restoration Ecology 13, pp. 569-577.

RZM (1981) Tomago Mineral Sands Mining Revegetation Assessment. Unpublished Report by The Hunter District Water Board, ERCON Australia and RZM.

RZM (2000) RZM Tomago Sandbeds Operation Post-Mining Vegetation Assessment Program. Unpublished Report by URS Australia.

SER (Society for Ecological Restoration International Science & Policy Working Group) (2004) The SER International Primer on Ecological Restoration (http//www.ser.org) accessed in October 2005.

Sopher, C.D. and Baird, J.V. (1978) Soils and soil management. Reston Publishing Company Inc. Virginia, 238 p.

Suhartoyo, H., Mulligan, D.R. and Doley, D. (2006) Trajectory of native forest restoration on sand mined site at Tomago, NSW: structural development affected by multiple disturbances. Proceedings JKMRC-ISS II, the University of Queensland, Brisbane, March 2006.

Thom, B.G., Bowman, G.M. and Roy, P.S. (1981) Late quaternary evolution of coastal sand barriers, Port Stephens-Myall Lakes are, New South Wales. Australia Quaternary Research. 15, pp. 345-364.

Tongway, D., Barnett, G., Kearns, A. and Hindley, N. (1998) Developing success indicators for minesite rehabilitation. The Australian Coal Review. April edition, pp. 56-59.

Walker, L.R. and del Moral, R. (2003) Primary succession and ecosystem rehabilitation. Cambridge University Press, Cambridge, UK, 427 p.