

USE OF REFERENCE SITES IN THE EVALUATION OF SOME REHABILITATED NATIVE FORESTS ON SURFACE MINES IN AUSTRALIA¹

R.N.Humphries²

Abstract: The rehabilitation of forest and other woody vegetation ecosystems on mineral extraction sites is common place and a major post-mining land use throughout Australia. Owing to the need for government certification (under Australian and State legislation specified completion criteria which are indicative of rehabilitation goals are or have been achieved) there is often referral to and comparison with reference native vegetation sites.

Examples of the ways in which reference sites have been selected and their limitations are considered in relation to some published examples for the rehabilitation of mineral sand, coal and bauxite surface mines in Queensland and Western Australia. Reference sites have been used for mainly setting mine closure land uses and vegetation types and the evaluation of the success of schemes.

The identification and selection of reference sites requires rigour and justification according to the purpose and context of the comparisons being made. Importantly, the selection and sampling protocols need to be clearly set out and justified rather than, for example, simply stating number and sizes of plots used. This is particularly importance with respect to the bias introduced as the methodology used determines both the outcome and interpretation of the comparison being made. Greater consideration of the above might result in reference sites being more 'fit for purpose' than apparently might be the case.

Another issue relating to the identification and selection of reference sites and their attributes as metrics for evaluation purposes is the matter of their state and condition. The use of mature reference stands rather than similar states to the immature rehabilitated stands needs to be factored in when selecting sites and interpreting the outcomes. In this context the recently suggested CARGIE model might be applied and developed further.

Additional Key words: completion criteria, mineral sands, coal, bauxite

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² R. Neil Humphries, Visiting Academic, Centre for Mind Land Rehabilitation, Sustainable Minerals Institute, University of Queensland, Brisbane, Queensland 4072, Australia. Current address, Blakemere Consultants Ltd, 1 Lower Blakemere Road, Dorchester DT1 3RZ, UK. Journal American Society of Mining and Reclamation, 2015 Volume 4, Issue 2 pp 36-54 DOI: <http://doi.org/10.21000/JASMR15020036>

Introduction

The use of designated ‘reference sites’ (sometimes referred to as analogue sites) is an established practice deployed in the evaluation of the status of biodiversity and land assets, and assessment of restored degraded and rehabilitated disturbed native vegetation in Australia and elsewhere (e.g., White and Walker, 1997; Tongway and Hindley, 2003; Society for Ecological Restoration, 2004; Ruiz-Jaén and Aide, 2005a; Herath et al., 2009; Eyre et al., 2011; Gravina et al., 2011), besides being a useful tool used for research purposes (e.g., Norman et al., 2006; Tibbett, 2010).

The purpose of a reference site is to provide a target or bench-mark, using attributes of the site to set criteria and metrics relevant to the objectives and aims of the comparison. For example, Eyre et al. (2011) in assessing the in situ condition of biodiversity (vegetation) assets used eight site-based attributes comprising native plant species richness, tree canopy cover, tree canopy height, shrub layer cover, native perennial grass cover, number of large trees, coarse woody debris, and litter cover. Whereas, for the assessment of mine rehabilitation achievement, four different generic vegetation attributes of vegetation type and density, foliage cover, and leaf litter are suggested (Department of Environment and Heritage Protection, 2014). Other examples of the use of reference sites, such as Ruiz-Jaen and Aide (2005a), have adopted a wider scope of attributes such as fauna and soil properties, as well as those of vegetation in a broader approach to ecosystem restoration.

In the case of mine land rehabilitation, the attainment of selected attributes is an option for setting rehabilitation completion criteria for certificating mine closure (e.g., Department of Mines and Petroleum and the Environmental Protection Agency, 2011; Department of Environment and Heritage Protection, 2014). Hence, the choice of reference sites and the measured attributes can be of significance in determining whether a rehabilitation scheme is considered to have met the objectives and aims or is predicted to do so. In some circumstances, there could be significant consequences in the choice of reference sites and their attributes for the outcome of mine rehabilitation assessments. This is particularly the case where mining has drastically altered the landscape and substrate creating tailings dams, rock dumps and strip-mine overburden mounds and for which there may be no locally occurring equivalent reference sites (Doley et al., 2012; Humphries, 2015). Here, the default adoption of undisturbed local reference sites is seemingly rarely debated and likely to be inappropriate, whereas for less drastic forms of mining (such as

mineral sand, bauxite and shovel-and-truck coal surface mines) the landform and soils are more capable of reinstatement and so such undisturbed reference sites are likely to be more relevant and realistic.

The aim of this short paper is to share some thoughts on the use of reference sites that occurred whilst considering the lessons learnt from examples of long term monitoring of forest rehabilitation using reference sites in Australia (Humphries, Unpublished). Seven examples are considered, encompassing a range of mineral types (gold, mineral sands, bauxite, and surface coal mining) and a range of conditions from tropical, sub-tropical, and Mediterranean climates. All the reference sites reviewed were a Eucalypt type of forest or woodland (Table 1).

Table 1: Types of Eucalyptus Forest / Woodland Reviewed as Example Reference Sites

Vegetation Community Type	Mineral	Information Sources
<i>Eucalyptus microneura</i> – <i>E. creba</i> Low open woodland	gold	Mulligan et al., 2006
<i>Eucalyptus marginata</i> – <i>Corymbia calophylla</i> Open forest	bauxite	Grant, 2006; Norman et al., 2006; Koch, 2007
<i>Eucalyptus pilularis</i> Woodland/Open forest; <i>E. racemosa</i> Woodland; <i>Corymbia intermedia</i> Open forest; <i>E. planchoniana</i> Open forest	mineral sand	Herath et al., 2009; Gravina et al., 2011; Smith and Nichols, 2011
<i>Eucalyptus populnea</i> Woodland	coal	Erskine and Fletcher, 2013

Types of Reference Sites

The rationale behind the use of the reference site approach of Eyre et al. (2011) to assess ecosystem condition is fundamentally different to that of those using reference sites for mine rehabilitation assessment and compliance. In the former, a direct comparison is possible (i.e., neither being in developing nor decaying states) and the selection and interpretation of attributes is simple and straight forward. Whereas, the latter invariably involves comparing selected attributes from a mature reference site with those occurring in an immature rehabilitated one. To overcome the difference in developmental stage, between the reference and rehabilitated sites, the attributes selected from the reference site would have to be of a predictive nature and an

indicator of similar mature stands in the future, and likely to be representative of the building phases of forest stands (Grant, 2006; Smith and Nichols, 2011; Gravina et al., 2011).

Reference sites can differ in their contexts and hence later interpretation:

- Pre-mining features and condition of the area being mined
- Features and condition of a paired local unmined area
- Published accounts of areas with similar features and condition

Each of the above approaches relies on assessing and determining the degree of similarity and the significance of any differences between the reference and the area disturbed and rehabilitated.

The pre-disturbance composition and condition approach has often been adopted in the USA, following the enactment of the Surface Mining Control and Reclamation Act 1997 (Plass, 2000). Inherently, pre-disturbance reference sites will be historical in their context and restricted to relating the achievement of rehabilitation attributes to biotic and abiotic conditions which were a product of past events, such as climate, management, and other events. The approach also does not address the inherent variation owing to the dynamic nature of vegetation composition and structure as illustrated by Král et al. (2014). Such matters and their influence need to be considered carefully in the selection of the attributes and criteria to be used, and importantly for creating the realistic expectations of the rehabilitated outcome. The latter is particularly important for long-lived ecosystems such as those characterised by woody species which may be a product of influences of previous decades which may not be capable of replication nor necessarily relevant to future conditions (Harris et al., 2006). This approach also has the disadvantage that later referral is not possible should other attributes be considered necessary for evaluation.

The adoption of paired reference contemporary sites has been favoured in Australia and potentially overcomes the loss of access to the pre-disturbance condition. It is suggested in government guidance that such undisturbed reference sites might be adopted for evaluation purposes (e.g., Department of Environment and Heritage Protection, 2014). However, paired undisturbed types also have inherent limitations as the pre-disturbance approach. In particular, similarity and difference in biotic and abiotic composition, as well as historical events, influences and climate should be considered. The availability of strictly paired sites can be problematic and challengeable as to the undisturbed site's representativeness of the pre-mined condition and rehabilitation context. Referral to this type has included both initial and later comparisons where

there are examples of comparisons of rehabilitation made with past pre-mining paired undisturbed sites and examples of contemporary comparisons. This confers a particular advantage over the pre-disturbance type, given that the reference site may continue to develop and change in its features and attributes over the life of the mine project. Such changes were illustrated by the study of Král et al. (2014) of the dynamic nature of forests over a period of only 33 years.

A third approach is the use of unpublished or published descriptions (White and Walker, 1997; Neldner and Ngugi, 2014) rather than actual sites. This approach is often used in the UK where there is a longer tradition of using published vegetation descriptors for evaluating environmental and rehabilitation schemes (Humphries, 2014). This approach has similar limitations to the other two and is dependent on appropriate and authentic descriptions being available, along with the representativeness to the site being disturbed. On the other hand, the published descriptors are readily understood and overcome the problem of finding paired sites, particularly in the UK where local undisturbed and comparative examples may not be available locally and in the same setting.

Form of Reference Sites

Hobbs and Norton (1996) have argued against the use of local reference sites in restoration schemes whilst accepting and advocating the use of reference criteria for setting targets. Despite this view, in practice, referral in some manner to a type of reference site (as described above) is unavoidable.

Reference Sites

Reference sites, in the context referred to above, typically comprise plots and/or transects in which vegetation attributes are measured and from which comparative metrics are derived. Hnatiuk et al. (2009) set out a formalised format for monitoring vegetation by plots and transects that is applicable to monitoring natural and naturally degraded vegetation cover types found in Australia, and presumably rehabilitated mine sites too. Similar formats (Table 2) are widely used elsewhere, for example in assessing comparative ecosystem condition of vegetation in Queensland (Eyre et al., 2011) and in describing vegetation types in the U.K. (Rodwell, 1991). Tongway and Hindley (2003) formulated a transect methodology for assessing and comparing the condition of Australian vegetation, soils and landscapes, including those of rehabilitated mine sites.

Table 2: Examples of Formalised Methodologies for Plot and Transect Monitoring Formats

Vegetation Field Handbook (Hnatiuk et al., 2009)	BioCondition (Eyre et al., 2011)	Ecosystem Function Analysis (Tongway and Hindley, 2003)	Nation Vegetation Classification (Rodwell, 1991)
Nested Plot Design	Nested Plot Design	Nested Transect Design	Nested Plot Design
30 m x 30 m (900 m ²) – Trees >20 m height; 20 m x 20 m Trees and Shrubs 1 m-20 m height	100 m x 50 m (5,000 m ²) - Large trees, tree richness, canopy cover		50 m x 50 m (2,500 m ²) – Tree canopy and upper understory
50 m transect – Tree crown and canopy gap	100 m transect - Tree and shrub canopy cover	5 m intervals 50 m wide sub-transects along 100 m transect – Vegetation attributes	
	50 m x 20 m - Coarse woody debris		
5 m x 5 m – Understorey and ground layer <1 m height	50 m x 10 m - Shrub, grass and forb richness		10 m x 10 m / 4 m x 4 m – Lower understory and ground layer
50 x (1 m x 1 m) - Grass cover, litter cover; 50 x (0.02 m x 0.02 m) - Moss cover	1 m x 1 m - Grass cover, litter cover		
1 m x 20 m transect - understory canopy			

Each of the above methodologies has a set of protocols to be applied in the locating of plots and transects. For example, Hnatiuk et al. (2009) refer to the plots comprising homogenous areas, whilst being a) characteristic of the vegetation it is meant to represent, b) comprising single vegetation unit and not transcending boundaries, and c) free from bias (i.e., making conscious adjustments to location and boundaries). Eyre et al. (2011) apply strict criteria for the adoption and rejection of locations. They should be within vegetation >5ha in extent and of a mature state, but are to be located >50 m away from highways, >6 km from large artificial water bodies, and

not subject to recent change or disturbance (e.g., erosion, fire, flood, timber harvesting, grazing, weed infestation). It is implicit in both cases that degrees of conscious selection will be involved, rather than using a completely randomised process.

Table 3 sets out some published examples where plots and transects have been used. The distance from the rehabilitated areas to the reference used at the Gordon mineral sand mine was cited to be 2 k m (Gravina et al., 2011). For the Kidston gold mine tailings, one of the reference sites was adjacent to the rehabilitated site and the other was 20 k m to the south (Mulligan et al., 2006). For the others, either the location was less specific, such as being ‘nearby’ to the mined area (Herath et al., 2009) or simply no information was given as to their location (Koch, 2007; Erskine and Fletcher, 2013).

Table 3: Examples of Plot and Transect Monitoring Formats Used

Format and Specification	Mineral	Source
Nested Transects – 3 x (100 m transects) + 1 m x 4 m sub-plots at 10 m intervals + 1 m x 1m sub-plots at 10m intervals	Gold	Mulligan et al., 2006
Random Plots 20 x (2 m x 2 m quadrats)	Bauxite	Norman et al., 2006
Nested Plots - 12/15 x (20 m x 20 m plots) + 5 x (20 m x 4 m sub-plots)	Bauxite	Grant, 2006 & Koch, 2007
Nested Plots – 40 m x 40 m plots + 5 m x 5 m sub-plots	Mineral sand	Herath et al., 2009
Nested Plots – 50 m x 20 m + 50 m transect + 10 x (2 m x 2 m sub-plots)	Mineral sand	Gravina et al., 2011
No details given	Mineral sand	Smith and Nichols, 2011
Varied between 100 m x 10 m / 200 m x 20 m / 50 m x 20 m / 50 m x 3 m plots	Coal	Erskine and Fletcher, 2013

Grant (2006), Koch (2007) and Herath et al., (2009) explain that the location of reference sites in their studies were selected to represent each of the vegetation and topographical types relevant to the rehabilitation of the mines in question. In contrast, George et al., (2010) do not detail their sampling protocol with respect to vegetation types being represented.

The occurrence of spatial and temporal variation in native forest attributes, even within the same vegetation type, is well known and illustrated by the range of tree density in the jarrah forest

of Western Australia (Koch and Samsa, 2007) and the Regional Ecosystems accounts of Queensland (Department of Science, Information Technology, Innovation and the Arts, 2012). Despite this, there is seemingly little consideration given to the selection of reference sites for mine rehabilitation in relation to the inherent variability of the target vegetation and ecosystem.

Knowing the sampling protocol within or across the types of vegetation selected is of particular importance, because as Tongway and Hindley (2003) point out, the range of associated attributes and metrics influence in the outcome of rehabilitation assessments. For example, some forested areas may contain few trees due to die-back because of disease, reaching the end of their life-span, or other reasons. This raises the point whether particular types and poor conditions should be excluded or the entire range should be represented in the setting of rehabilitation targets?

Often, it can only be assumed that the locating of the reference plots in most cases was a ‘conscious’ restrictive selection process excluding, often unspecified, various forest features and conditions. The sampling may or may not have involved randomisation, stratification or other forms of systematic sampling. In Table 3, only Norman et al. (2006) confirm the randomised selection of their plots. Other than for the examples provided by Erskine and Fletcher (2013), no explanation or consequence for representativeness is given as to the inclusion or exclusion of features where a selection approach was deployed. For the five Queensland coal sites in the Bowen Basin, only the most diverse plant communities within the local area were selected (Erskine and Fletcher, 2013), thereby biasing the reference sites and the attributes selected to supposedly the most biodiverse condition or to a particular structural or developmental state. For the other examples in Table 2 no insight is given as to whether the plots represent the entire range of variation or some state within the range of variation exhibited within the target vegetation type.

It is understood that the selection of homogeneous areas is often used as a means of controlling within-plot variation in order to enhance statistical detection of differences or similarities, and to reduce sampling effort. This approach may be a legacy of the predominant use of experimental-design based approaches as opposed to mapping and census geographical based techniques that usually embody the full range of variation. The limitations of the former could serve to mask the characteristics and the inherent heterogeneity which determines the ecosystem’s composition, structure and function dynamics, and prediction of the developmental trajectory. For instance, the occurrence and scale of spatial and temporal heterogeneity in native stands might be expected to

influence species persistence, development and recruitment according to canopy, age, density and structural formation. If appropriate types and scales of heterogeneity were not occurring in rehabilitated stands, then stalled developmental trajectories are likely to result (as evident from the rehabilitation reports of Grant (2006) and Gravina et al. (2011)). An alternative approach might be to sample the distribution of variation within the target forest stand (i.e., inclusion of regenerating and decaying parts) with the aim of setting limits for the attributes to be measured and criteria to be set.

If it is assumed the examples in Table 3 are representative of general practice, it appears there is a range of plot and transect sizes and configurations used. Notably, the reference and monitoring plot sizes used (Table 3) were smaller than those recommended (Table 2) for mature forests and which is a requisite in the recommended methodologies. The choice of the main-plot size used in the reference sites is not explained in any of the cited examples in Table 2 nor is the consequence for representativeness and bias in using the smaller plots in mature stands. One explanation might be that the choice of plot size used in the reference sites has been determined by that needed for immature rehabilitation vegetation owing to the absence of large trees and their spatial effects. The implied assumption being the scale of recording can be reduced to the next recommended tier as appropriate for smaller structural formations such as grassland or shrub (see Table 2). However, for reference sites, this overlooks the fact that the distribution of the selected attributes in the reference site may not only be influenced by the developmental stage of the forest, but also the skewed spatial by the distribution of mature trees and their canopies (Choy, Undated), and consequently there was an irregular distribution of the understory vegetation. In addition, the understory vegetation is also unlikely to be uniform in its distribution. The deployment of sub-plots in the nested formats provides the means whereby variation at the understorey levels can be defined. There may have been a conscious selection of the understory-like tier for sample sizes in both the reference and the rehabilitation sites in recognition of the immature nature of the latter. Hence, the use of substantially smaller plots than recommended in mature forests needs to be justified.

From the above, it is striking how non-standardised the selection and monitoring of reference and rehabilitated sites has been in the examples cited. Consequently, as Erskine and Fletcher (2013) point out that the outcome of using non-standard approach in the selection of reference sites makes it difficult to generalise in the findings between and within sites and these schemes.

Whilst the examples in Table 3 predate the current guidance (Table 2), other similar or earlier versions of guidance were undoubtedly available at the time. Whilst the size of plots used were smaller than the recommended for mature stands, they were more consistent with the smaller sized plots recommended for the lower and smaller shrub and ground flora growth forms, which would have been reflected in the early growth of the rehabilitated areas. However, the reason for the choice of monitoring formats and sizes is unknown, but may have arisen for reasons of historical precedent, personal preference or practicality when dealing with large numbers of young plants.

Reference Criteria

Hobbs and Norton (1996), and others have suggested using a range of generic ecosystem attributes as criteria for assessing restoration success as a better system for assessment than reference to local sites features per se. Such criteria have been or are to be derived from specific reference site attributes or broader attributes associated with ecosystems. Ruiz-Jaén and Aide (2005b) and Wortley et al. (2013) give examples of the use of the generic ecosystem attributes used for assessing restored native ecosystems. Examples of criteria derived directly from local reference sites include Tongway and Hindley (2003) and Ruiz-Jaén and Aide (2005a). In the examples of mine rehabilitation referred to in Table 3, the choice is limited to vegetation attributes rather than the wider spectrum suggested by others above (see Table 4). Gravina et al. (2011) and Smith and Nichols (2011) go further and report on the use of derived vegetation attributes where the thresholds have been ‘discounted’ following agreement with the regulators. It is unclear whether the basis for this is recognition that forest composition and development is variable and therefore variance from the target is acceptable or that targets based on an ideal state is not realistically achievable.

Table 4: Examples of Vegetation Attributes Recorded in Plots and Transects

Forest – Woodland Community Type	Vegetation Attributes Used	Source
<i>E. microneura</i> – <i>E. creba</i> Low open woodland	Number of species (inc. richness); number of woody and shrub species; number of life-forms; foliage cover of ground layer; height and basal diameter of Eucalypts and Corymbia species; plant litter cover	Mulligan et al., 2006

<i>E. marginata</i> – <i>Corymbia calophylla</i> Open forest	Number of species; species density; species foliage cover; number of Eucalypts >2 m height	Norman et al., 2006
<i>E. marginata</i> – <i>Corymbia calophylla</i> Open forest	Number of species (inc. richness); stem density of Eucalypts and legumes; stem sizes of Eucalypts and legumes; litter cover	Grant, 2006
<i>E. marginata</i> – <i>Corymbia calophylla</i> Open forest	Number of species (inc. richness); number of recalcitrant species; density of recalcitrant species	Koch, 2007
<i>E. marginata</i> – <i>Corymbia calophylla</i> Open forest	Number of species (inc. richness); species density; number of life-forms; crown canopy cover; seed bank-species foliage cover; resprouter foliage cover	Herath et al., 2009
<i>E. pilularis</i> Woodland/Open forest; <i>E. racemosa</i> Woodland; <i>Corymbia intermedia</i> Open forest; <i>E. planchoniana</i> Open forest	Number of species (inc. richness); canopy cover; number of trees >2 m height	Gravina et al., 2011
<i>E. pilularis</i> Woodland/Open forest; <i>E. racemosa</i> Woodland; <i>Corymbia intermedia</i> Open forest	Number of species; density of tree species >2 m height; canopy cover of trees, understorey and ground layer	Smith and Nichols, 2011
<i>E. populnea</i> Woodland	Number of species; density of graminoid and forb species	Erskine and Fletcher, 2013

In the context of mine rehabilitation in Australia, derived local reference site criteria seem to be preferred by the regulators in the assessment of rehabilitation performance (e.g., Department of Mines and Petroleum and the Environmental Protection Agency, 2011; Department of Environment and Heritage Protection, 2014) and realistically this might be all that may be possible when comparing establishing immature vegetation on a rehabilitated site with that of established mature vegetation.

The Use of Local Reference Sites

Hobbs and Norton (1996) suggest that a compositional-structural-functional set of inter-related attributes could be used to assess ecosystem recovery. Intrinsically, reference sites are capable of providing all three. Species composition and structural formation criteria are self-evident and can be readily gleaned from the reference and rehabilitated site surveys.

Consensus as to which functional attributes are to be used seems to be more elusive with no universal opinion and practice yet arrived at, although the thinking is moving towards ecosystem functional traits. Preference is seemingly determined by which specialist group is involved. Currently, a plethora of suggestions are found in the literature ranging from soil ecosystem characteristics and measurements particularly focused on nutrient cycling (e.g., Tongway and Hindley, 2003; Grant et al., 2007; Tibbett, 2010; George et al., 2011) to assemblages of flora and fauna (e.g. Ruiz-Jaén and Aide, 2005b).

However, it is implicit in the adoption of vegetation based criteria (e.g., Grant 2006; Koch, 2007; Gravina et al., 2011; Smith and Nichols, 2011) by the regulators (e.g., Department of Environment and Heritage Protection, 2014) that they are a sufficient expression and integration of both soil and aerial ecosystem functions for mine rehabilitation purposes.

Taking the use of vegetation attributes further, Humphries (2013) proposed an approach that integrates composition, structure and function (Table 5). The proposed CARGIE Model comprised six vegetation based criteria that represent the ecosystem function attributes of canopy cover, age class, regeneration potential, genetic pool, local indicators, and exotics/aliens that are applicable to forest and other terrestrial ecosystems as a universal model. All of these functional attributes can be readily gleaned from the reference and rehabilitated site surveys.

Table 5: Vegetation Attributes, Criteria and Metrics Used in CARGIE Model as Indicators of Forest Ecosystem Function (Humphries, 2013)

Vegetation Attribute	Attribute Criteria	Metrics
Tree canopy cover	Tree layer; understorey layer; ground cover layer	Percentage cover; thresholds/ranges
Age class	Seedlings; saplings; young (pole stage) trees; mature trees; decaying trees; dead trees	Number of classes; thresholds/ranges
Regeneration potential	Seed production/sprouting shoots-rhizomes etc	Yield; numbers; thresholds/ranges
Genetic pool	Local provenance	Number/density; thresholds/ranges
Indicators	Notable species	Number/density; thresholds/ranges
Exotic/Alien species	Non-native / notifiable	Presence; thresholds/ranges

Candidly, Gravina et al. (2011) in reviewing the rehabilitation achievement on a mineral sand site in Queensland stated that there is an inherent short-coming in the use of reference sites when comparing mature reference sites with immature rehabilitated stands. This is of some particular concern when, for example, a published standard methodology requires bona fide reference sites to be “mature” stands (Eyre et al., 2011). Implicitly, this involves a ‘leap of faith’ that the young stands are on a trajectory towards the target forest or woodland (Powter, 2014).

Simple logic must demand that structurally immature rehabilitation sites should be compared with structurally immature reference sites (given that the maturation of rehabilitated stands are decades away), and conversely, that structurally mature rehabilitation sites being compared with structurally mature reference sites. Importantly, in the former, the immature condition should not comprise of only early successional species, but also, at some stage, those of the later climatic and edaphic determined forest ecosystem. Examples using this secondary succession-like form of development with structurally immature forest stands seem not to exist, and therefore this methodology seems to be little used.

Vegetation is dynamic with building, maturation, and decay cycles occurring in native ecosystems (Humphries, 2013). Král et al. (2014) illustrate this well in their study of developmental stages in native fir-beech forests in Central Europe. Here, the forests comprised a

mosaic of stages on a scale which would provide for immature, mature, and decay reference sites. Similar, but modified cycles occur due to cropping/management in anthropogenic systems.

Immature forest stands may be manifest in forest gaps following death and decay of major canopy trees, as regrowth/planting following forest clearance and also possibly as successional stages from pioneer/secondary stands. In practice, suitable immature sites on a local basis and of sufficient scale might be difficult to locate. One example is where a forest is predominantly even aged following recent timber harvesting, as is the case for much of the jarrah forest in Western Australia that has been heavily cut-over and logged during the 20th Century.

As stated above, the deliberate selection of derived vegetation attributes such as species, density, and canopy cover that are considered to predict progression (trajectory) to mature forest (e.g., Grant, 2006; Koch, 2007; and Smith and Nichols, 2011) may be the only practical way to overcome the short-comings of mature reference sites and the limited availability of local immature forest examples. Application of the vegetation composition-structure-function based CARGIE Model (Humphries, 2013), rather than the timber production forestry-base metrics that have been traditionally used, could advance beyond these approaches as it can address both immature and developing, as well as mature and decaying stands, all of which are indicative of a functioning ecosystem.

Finally, much of the focus of the literature and this paper has been concerned with using local reference sites in assessing rehabilitation achievements. In terms of species composition, local reference sites have played an invaluable role in the evolution of rehabilitation practices in Australia where the objective was to re-establish pre-mining or other native vegetation and ecosystems. The restoration of native forests on mineral sand and bauxite mines is an example of this approach (Koch, 2007; Herath et al., 2009; Smith and Nichols, 2011). Importantly, local sites have also served to define the associated site variation and factors to be recreated according to both abiotic (e.g. topography, soil, wetness), biotic (e.g., structural formation, disease, alien species), and anthropogenic (e.g. harvesting, grazing) influences. An example of the selection of species for the rehabilitation of a surface coal mine according to topography, soil acidity, wetness, and availability of plant material is described by Humphries (2014).

Conclusions

Whilst the reference sites were predominantly used for the assessment of rehabilitation in the examples used, in some instances, they had also been used to guide the setting of rehabilitation aims and aiding the specification of schemes and their management.

In both roles, the identification and selection of reference sites requires rigour and justification according to the purpose and context of the comparisons being made. Importantly, the selection and sampling protocols need to be clearly set out and justified rather than, for example, simply stating number and sizes of plots used. This is of particular importance with respect to the bias introduced where selection criteria are introduced rather than full randomization as the methodology used determines both the outcome and interpretation of the comparison being made. For example, the outcomes derived from the selection of only the best examples for reference sites will be different from those which encompass the full range of the states and conditions exhibited. The consequence of adopting only the best examples is likely to raise expectations beyond the reality. Hence, it should be questioned why a particular state and condition is being used. For assessment purposes, the consideration of the above might result in reference sites being more ‘fit for purpose’ than apparently has been the case in the examples considered.

The other issue relating to the identification and selection of reference sites and their suitability for evaluation purposes is the matter of their state and condition. The use of mature reference stands rather than states similar to the immature rehabilitated stands needs to be considered when selecting sites and interpreting the outcomes. It may be that attributes and metrics derived from mature stands may differ from those of regenerating stands. This is an area where further debate and research may be usefully focused. In this context the CARGIE model might be usefully applied.

Importantly, there is a need for greater standardization in the sampling methodology used to enable comparison between and within sites and schemes.

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