Bio-physical closure criteria without reference sites: realistic targets in modified rivers

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Abstract

The use of reference sites for establishing closure criteria in areas disturbed by mining activities is common practice. 'Reference' sites are those considered to be largely unimpacted by anthropogenic activity (retaining desirable natural characteristics), and occurring near disturbed sites. Sites are considered rehabilitated when their biophysical condition approximates that of the reference site. However, this approach often creates impossible or unrealistic targets for miners seeking to close rehabilitated lands. For example, reference sites are often limited in availability (or non-existent) due to impacts by other land uses. Further, any available reference sites might not be realistic matches for the rehabilitated sites – in many rivers (for example) it is questionable whether sites which superficially appear similar are actually ecologically similar.

We propose a more achievable approach to mine closure by comparing the bio-physical characteristics of rehabilitated sites to overall ecosystem variability, rather than specific target reference sites. Using multivariate ordination - a classic data clustering technique in ecology - as an applied management tool allows managers to measure how different their rehabilitated sites are from co-occurring sites, and how the rehabilitated sites are tracking over time. Our approach also identifies the key biological, physical, and chemical parameters that potentially differentiate a rehabilitated site and, therefore, the necessary actions to bring a rehabilitation site within range of normal river variability. Further, this conceptual paper introduces two unique case studies used to develop the model, involving microbes as indicators of rehabilitation progress and mine water impact in Australian rivers. The challenges and benefits associated with implementation of this approach from the practitioners' perspectives are discussed. The outcome of this new approach to closure will allow miners to create realistic and definable targets for relinquishing rehabilitation land in already modified landscapes, potentially simplifying closure and project approvals.

Key words: multivariate ordination, river diversions, mining, rehabilitation, microbe

The problem with reference sites

The fundamental challenge in setting criteria for lease relinquishment or project approval is determining the rehabilitation objective. The use of reference sites for establishing closure criteria in areas disturbed by mining activities (e.g., river diversions, deforestation) is accepted by regulators across Australia (DITR 2006). However, this approach is flawed, often creating impossible or unrealistic targets for miners seeking to close rehabilitated lands.

The concept of an ecological "reference site" is broadly perceived as a location with a suite of desirable conditions, processes, and/or taxa with which to compare sites impacted by (most often) anthropogenic activities. Generally, reference sites co-occur with disturbed sites, yet are unimpacted and retain "naturalness" of the biota (Stoddard et al. 2006). However, many systems are so heavily modified that sites unimpacted by human activities do not exist and, therefore, it can be argued that the use of a reference site is inappropriate (Chessman and Royal 2004). In the instance where reference sites are nominated, a judgement call must be made as to the "desirable" traits of a reference site, which can include: pre-human ecosystem condition, the best of a suite of degraded sites, or an ideal condition that sites might achieve if they were properly managed (Stoddard et al. 2006).

After a site is identified as having reference attributes, comparison with the impacted site must then be made, requiring additional judgement about how similar impacted sites have to be to reference sites in order to meet rehabilitation objectives. Further, any available reference sites might not be realistic matches for the rehabilitated sites – in many rivers (for example) it is questionable whether sites which superficially appear similar are actually ecologically similar (Blanchette et al. 2014). Of particular note is the high level of natural seasonal ecological variability in the landscape, which can confound efforts to define reference sites. For example, Australian dryland rivers exhibit extreme temporal variability, where the drying river naturally contracts into a series of warm, turbid, isolated waterholes, mimicking an ecosystem under anthropogenic stress (Blanchette and Pearson 2013; Blanchette and Pearson 2012). While it is possible to design rehabilitation and monitoring programs in fairly stable ecosystems that account for broad seasonal variability, in the instance of seasonal rivers, their inter- and intra-annual condition changes so dramatically that it would be a challenge to describe, in detail, the characteristics of an ideal reference site. Essentially, reference sites are a human construct, resulting in restoration targets where changing ideals and natural spatial and temporal variability ensure the goalposts are constantly shifting and/or undefined.

River condition assessment programs that provide alternatives to reference sites can more realistically capture the natural variability of a river system, and provide clearer rehabilitation goals. The 'trend approach,' whereby expectations of condition occur along a natural gradient (Sheldon 2005) is one example of a monitoring program that has eliminated the need for reference sites. However, this approach still requires interpretation: where along the condition gradient is sufficient for rehabilitation and, therefore, lease relinquishment? Another approach that operates without reference sites is the 'trait approach,' which involves the characterisation of ecological traits to predict natural suites of taxa (Chessman et al. 2010). This method, which also captures natural variability, still requires judgements about which ecological traits are desirable, as well as significant effort to determine species' traits and the relationship between condition and assemblage characteristics in each river (a program impractical for environmental managers).

From a practitioner's perspective, when governments approve projects that deliver economic benefit, it is acknowledged that there will be some cost to the environment. Consequently, reference sites are only a guide and most likely can't be replicated. In order to increase stakeholder certainty, process transparency and environmental performance in mine closure, we propose moving away from the use of reference sites towards an approach that considers the variability of the entire system under study.

Towards 'system variability' as closure criteria

Evaluating rehabilitation success is based on measuring a combination of physical, chemical and biological criteria ('bio-physical' criteria). Our model compares the biophysical criteria in rehabilitated sites to the overall spatial and temporal bio-physical variability of the local environment (hereafter referred to as 'system variability'), rather than specific reference sites. We used riverine environments to develop and test the model (see below section), but the system variability approach can also be applied to terrestrial ecosystems disturbed by mining.

The system variability approach to developing closure criteria employs multivariate ordination - a data clustering technique traditionally used in ecology - as an applied management tool (see Fig. 1). Ordination (NMDS, non-metric multidimensional scaling for biological data; and PCA, principal components analysis for physico-chemical data) visually portrays similarity among locations based on multiple variables as a physical distance, with similar sites closer together and different sites further apart (Ramette 2007). We suggest that a successfully rehabilitated site would lie within the river's 'normal' variability (Figure 1), which is sustained (and can be tracked) over time, rather than a one-off comparison to an arbitrarily determined reference site. A rehabilitated site would be considered 'within' the variability of the system as determined by (for example) permutational MANOVA (PERMANOVA) in PRIMER (null hypothesis of no significant difference between sites/assemblages with *p* significant at < 0.05) (Clarke and Gorley 2006). Another advantage of the system variability approach is that the temporal trajectory of biological communities and physico-chemical variables of rehabilitated sites can be tracked over time allowing companies to potentially relinquish land that is not yet within the overall variability of the system, but is well on its way.

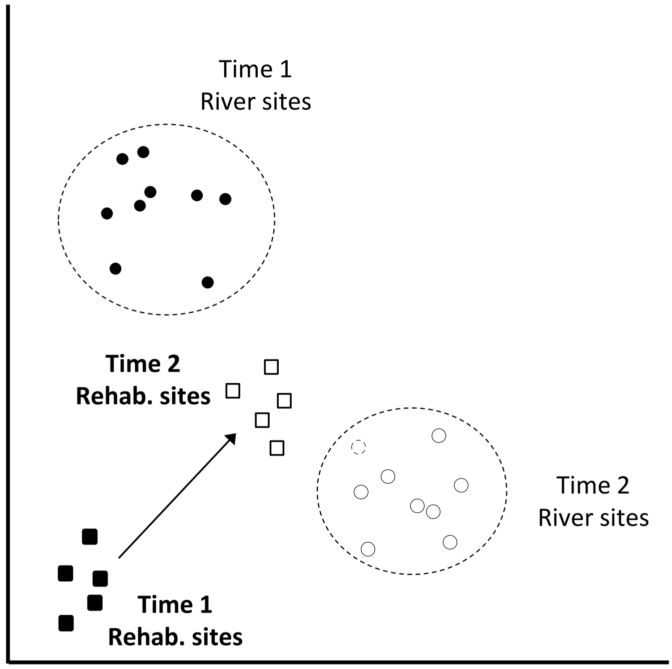

Figure 1 *Hypothetical non-metric multidimensional scaling (NMDS) ordination of biological community data from multiple sites along a river over two time periods (1 and 2). Diagram shows how rehabilitated river sites move from being distinctly different to the rest of the river to being more similar. Relative to closure, the aim is for the rehabilitated site to move within the cluster of river sites during the appropriate period of sampling (i.e, time 2 rehab. sites not significantly different from time 2 river sites, as determined by permutational ANOVA).*

Using BIOENV in PRIMER (Clarke and Gorley 2006), the system variability approach to closure can also identify the key biological, physical, and chemical parameters that potentially differentiate a rehabilitated site from the rest of the environment and, therefore, the actions necessary to bring a rehabilitation site within range of normal river variability (see Figure 2).

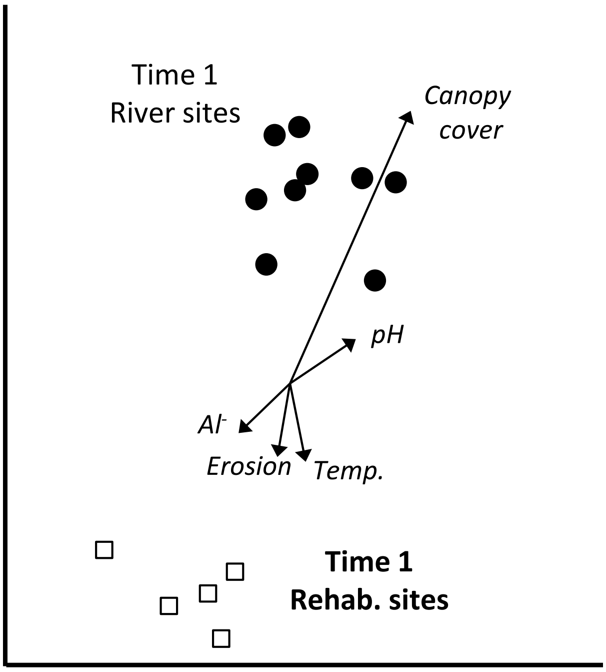

***Figure 2** Hypothetical ordination of biological community data from multiple sites along a river during one monitoring period. Diagram shows community assemblages at rehabilitated river sites (open squares), and at other river sites (black points). Vectors (as generated by BIOENV in PRIMER) indicate which environmental parameters are most influential on the variability in community assemblages (length of vector = importance). In this example, river sites have higher pH levels and more complete canopy cover, whereas the rehabilitated site is acidic with poor canopy cover. Variability in the assemblage at the rehabilitated site also appears to be influenced by higher levels of aluminium, erosion, and temperatures. Therefore, the company would be advised to increase bankside vegetation of canopy trees (decreasing water temperature and erosion), and pay particular attention to sources of acidity and aluminium. Over time, biological assemblages at rehabilitated sites would be expected to become more like those of the rest of the river.*

Developing the approach: river diversions as test beds

As a result of mining activities, rivers may be artificially diverted to allow resource extraction. Current Australian monitoring protocols facilitate comparison of diversion condition to undiverted river sites, but do not allow stakeholders to determine how well the diversion is tracking over time, or the measures necessary to place a diversion on the trajectory to license relinquishment (Alluvium 2014). There is need for a monitoring method that can assess progress towards attainment of a rehabilitation objective, because decades may be required to actually achieve rehabilitation goals. However, the fundamental challenges inherent in designing monitoring protocols (and, therefore, setting criteria for lease relinquishment) is determining the rehabilitation objective.

Case Study 1: Closure of river diversions in the Hunter Valley, New South Wales

Our current project in the Hunter Valley coal mining area of New South Wales aims to test the systems variability approach in regards to closure of two different river diversions. The systems variability approach can both set rehabilitation objectives and assess progress towards attainment of the objectives (e.g., whether diversions are similar or different to the rest of the river). Both these river diversions occur in seasonal tributaries of the Hunter River, which naturally experience little or no flows for much of the year, except during summer rainfall (but see below). In one tributary, the river diversion is a classic trapezoid channel, where no attempt was made to replicate the original river channel that it now replaces. Efforts have been made to stabilise and improve bankside vegetation along part of the channel length. Further complicating the scenario is mine water discharging just below the channel from the active mine, altering this once seasonally-flowing creek into a permanent river system. There is no requirement for this diversion to be modified before closure. The second tributary contains a more recent diversion where every effort has been made to match the characteristics of the river it replaces. Stringent monitoring requirements have been imposed by regulators to ensure diversions match reference sites.

Our sampling methods for this project combine classic ecological techniques with cutting-edge genome technology. Environmental genomics ('metagenomics' or 'community genomics') facilitates rapid identification of microbes by sequencing DNA directly from field samples, free from the selective effects of culturing that hampered previous attempts to understand microbial communities (Whiteley et al. 2012). Essentially, we now have potential bio-endpoints that can inform faster, cheaper, and more sensitive monitoring protocols than current bio-endpoints (e.g., fish, aquatic insects). Using microbial communities as our bio-endpoint, we will sample in, above and below the diversion in each river, measuring microbial communities in the waters and sediments, as well as physico-chemical and riparian parameters quarterly (as per the hydrological cycle) for one year.

Using the system variability approach, if (for example) the 'modern' diversion sites are not significantly different to the rest of the river, it would be considered a strong contender for closure and relinquishment. If the 'modern' diversion sites are significantly different from the rest of the river (and are in worse condition), we could determine what bio-physical parameters were driving this difference and intervene if necessary. Setting the criteria for future closure at this site could be based around the biota if considered important. For example, fish communities may be required to be similar to the rest of the river, even if the water quality remained outside this variability. Ongoing monitoring would demonstrate that the diversion site would remain similar to the other sites, as determined to the satisfaction of stakeholders. The trapezoid channel site will likely be distinct from the rest of the river, and downstream river permanency will likely have an impact on all the parameter groups measured. Further, any impacts of remediation works on the channel will be identifiable. Although closure is already permitted for the diversion, further remediation will be beneficial. The system variability approach can also be applied to closure of ongoing discharge to identify the consequences of permanency and set closure criteria.

Case Study 2: River diversion as a pit lake closure strategy in Collie, Western Australia – effects on the Collie River

Diverting a river through a former pit lake may carry beneficial nutrients, propagules, and pH-neutral water to an acidic hyper-oligotrophic lake, increasing lake water quality and biodiversity, potentially providing a closure strategy for companies. However, as the lake fills, the water will decant and flow downstream, which poses risks to catchments as potentially acidic and metalliferous run-off enters waterways. In Collie, Western Australia, the Collie River was diverted around an operation then subsequently redirected back through a pit lake (Lake Kepwari) as part of three-year trial to determine the effects on the lake and river. We sampled riverine macroinvertebrates, water quality, riparian condition, microbial communities (benthic and pelagic), and fish communities above and below the pit lake for a year (n.b. the lake was also extensively monitored but is not the focus of this case study).

We will compare multiple samples (macroinvertebrates, microbes, physico-chemical data) collected above and below the pit lake over five time points encompassing the Collie River's annual hydrograph. Using PERMANOVA in PRIMER, our null hypothesis is that there is no significant difference ($p < 0.05$) among *a priori* spatial groups (above and below the lake). Using the system variability approach, a result of no significant difference suggests no measurable impact of diverting the river through the pit lake on a particular variable. If groups above and below the lake were significantly different, the cost of the closure strategy may be quantified; further monitoring could be performed to determine if recovery occurred, or stakeholders could make an informed choice about whether the cost of this closure strategy was acceptable in light of the benefits to the pit lake and the original condition of the river. However, in this instance, statistics must be interpreted with care and accompanied by further data exploration, as results may be due to natural/background spatial variability rather than the effects of the lake.

Conclusion

The system variability approach to closure uses established analytical techniques and current monitoring strategies. It has many advantages over the use of reference sites (see Table 1), in that the criteria are likely to be more ecologically relevant by reflecting natural variability and existing land impacts, as well as having a clear endpoint. In essence, the outlined approach to setting completion criteria is simply an extension of commonly used ecological assessment methods, but applies the normal outputs of these methods to facilitate closure. Current ecological assessment techniques focus on using multivariate approaches to highlight differences in communities (i.e., demonstrating the impact of mining); we are simply suggesting that where there is no significant difference between the rehabilitated area and other parts of the ecosystem, closure has been achieved.

Table 1. *Summary of key elements of the reference site and system variability approaches to closure of mined lands. '+' indicates concept is an aspect of the method/approach, '-' indicates concept is not an aspect of the method/approach.*

	Reference site approach	**System variability approach**
Establishing the criteria		
Pre-disturbance/historical baseline data	+	-
Requires ideal sites in nature for comparison.	+	-
Can be used in heavily modified landscapes	-	+
Accounts for natural ecosystem temporal/spatial variability	-/+	++
Stakeholder consensus to design ideal rehabilitation characteristics	+	-
Stakeholder consensus that companies are 'allowed' to rehabilitate to the standard of the rest of the system.	-	+
The assessment		
Requires determination about how many sites represent 'variability' in a system.	-	+
Ongoing monitoring to establish success has been achieved	+	+
Deciding which bio-physical variables are important to measure	+	+
Visually tracks rehabilitated sites over time relative to overall ecosystem.	-	+
Successful closure		
Demonstrates when a site is sufficiently rehabilitated.	-	+

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