Chapter 7

Discussion

The purpose of this thesis was to develop and critically analyse a series of native vegetation assessment and monitoring techniques appropriate to a postulated range of coarse and fine resolution impacts associated with longwall mine subsidence. Due to the thesis timeframe, and expected longer timeframe for potential longwall impacts to emerge, this thesis was not based on direct observation of consequences of mining: rather the thesis developed methods for high-resolution impact assessment over the longer term. This allows a more generic discussion of the techniques in the wider field of vegetation condition assessment, and this chapter reviews the thesis results in this broader context.

The impact assessment framework comprises the fundamental criterion of vegetation condition, established through a set of indicators, which are then used to monitor for condition changes due some form of impact. In Australia, standard sets of vegetation condition criteria and their indicators have been selected (Oliver et al. 2007) and are being established in the eastern States so the potential contribution of this study can be evaluated in those terms (Table 26). While necessary, this is not a sufficient summary for this study, as it ignores the contributions available via high-resolution remote sensing that are not available to site-based assessments. A more comprehensive evaluation includes the reliability of the indicators as well as their analytical scope. For evaluation, the following questions need to be addressed:

1. What field indicators are replicated, and how well?
2. What indicators are not otherwise available?
3. What field indicators cannot be replicated?
4. What indicators might be developed with extra research?
5. What relevance has the current study to wider research?

A common assumption is that traditional, site-based assessments represent the best readily achievable vegetation indicator measures, with the implication that the criteria assessment is robust within the level of measurement error. This assumption has been challenged by a recent study using multiple observers over a range of sites on the Cumberland Plain, a grassy woodland in the western Sydney metropolitan area (Gorrod & Keith 2009). The range of values recorded by observers was high and even the indicator (metric) native overstorey projective foliage cover (PFC), which had a comparatively low observer

coefficient of variation, typically had inter-quartile ranges of 10-20% for areas with expected PFC of c. 20%. For comparison, the Standard Error for foliage cover from this study ranged from c. 2-8% (Chapter 4), representing a substantial improvement in accuracy. Similarly, ALS measurements of canopy height are often found to be as accurate, or of higher accuracy, than field-based measurement (Wang & Glenn 2008), although adjustment may be required for the effects sub-canopy penetration of the laser pulse. Of equal or greater importance is the high repeatability of ALS-derived indicators (Chapter 4), which compare favourably to site-based observations where the potential for error may be compounded over time by use of different observers (Gorrod & Keith 2009). The answer to Question 1) then is that tree height, canopy cover and foliage cover are all valid substitutes for field measurements, and provide higher levels of accuracy and repeatability. Proxies for site-based indicators may include spectral indices such as NDVI as indicators of foliar health, as well as texture/pattern metrics such as semivariance used to measure canopy – inter-canopy gap size, or variance in canopy height which may serve as a potential indicator for large trees (Chapter 6). The indicators developed in this study can also be independently assessed according to a range of utility criteria such as measurability, sensitivity to impact stress, low variability in response, and impact prediction (Dale & Beyeler 2001). An evaluation of these criteria is given in Table 27.

Table 26 Vegetation condition indicators in eastern Australia

Biodiversity indicators	Published[1,2,3]	This study
Vegetation status	Canopy height	Canopy height
Vegetation status	Over-storey PFC4 or crown cover	Foliage and canopy cover
Vegetation status	Mid-storey PFC	Qualitative
Vegetation status	Under-storey PFC	n. a.
Recovery potential	Tree regeneration	Growth (m-t)[5]
Vegetation health	Weeds, crown senescence	NDVI, gap formation (m-t)
Floristic diversity	Native plant species richness	n. a.
Arboreal habitat	Trees with hollows or large trees	*Potential*[6]
Ground habitat	Fallen timber, litter cover, stumps	*Potential*[7]

[1]Gibbons et al. 2008; [2]Eyre et al 2008; [3]DSE 2004
PFC[4] = projective foliage cover; m-t[5] = multi-temporal
Potential[6] height and canopy-gap variance
Potential[7] surface roughness

Table 27 A qualitative evaluation of indicator utility

Sensitivity and low variability scores are based on ANOVA tests (Chapter 6) as well as general evaluation of statistical validity or repeatability (Chapters 3 and 5). Anticipation scores are based on estimation of when the indicator becomes apparent relative to potential impact. For example, while individual tree gaps are post-fact, gap accumulation may indicate longer-term turnover of vegetation community. In contrast, lack of tree growth (height) is synchronous with, rather than anticipatory of, changing vegetation conditions.

Indicator	Sensitive	Low variance	Anticipate	Score	Comments
Tree height	2	1	1	4	
Canopy cover	2	1	2	5	Proxy by foliage cover
Foliage cover	2	2	3	7	Complementary NDVI
NDVI	3	3	3	9	and foliage cover
Semivariance	2	2	2	6	Additional research
Gap	3	3	2	8	
Boundary	2	3	1	6	Critical baseline
Wet-dry heath	3	2	3	8	
Bare heath	3	3	2	8	Proxy by NDVI?

High resolution remote sensing can provide additional indicators not available to field-based approaches (Question 2). The repeatability of ALS canopy height models allows quantification of canopy gaps, which is virtually impossible by other means. Indicators not addressed by this study include species richness, weeds, tree hollows, regeneration, fallen timber, litter, and shrub or understorey cover (Question 3). Some of these indicators – weeds, species richness – depend heavily on human interpretation and cannot be addressed by current remote sensing technology. The other indicators, however, may potentially be addressed by further research.

1.1 Indicators for further research

While ALS measures features according to height, the fact that the beam is directed from above means that canopy occlusion controls the probability of understorey reflection. Nevertheless, the consistent trend in apparent understorey abundance (1 m – 5 m: Chapter 4) suggests that semi-quantitative assessment of open forest or woodland shrub cover is possible. This may particularly be the case where multiple return ALS technology (e.g. www.optech.ca) allows realistic estimation of vertical foliage distribution (Coops et al. 2007; Popescu & Zhao 2008). Multi-temporal analysis of CHM and height percentiles may also allow estimation of regeneration capacity. Biodiversity components for abiotic cover and site heterogeneity such as rocks, ground litter, logs and bare ground (Oliver et al. 2007) may potentially be encapsulated in a single measure of surface roughness from the ALS DEM by geostatistical methods (Siska et al. 2005; Streutker & Glenn 2006).

Another area of potential research indicated by this study is the fine-grained landscape context for vegetation structural assessment. The utility of DEM-derivable landscape variables – insolation, slope,

aspect, topographic position, temperature, precipitation – for quantifying benchmark vegetation reference conditions has recently been described (Gibbons et al. 2008), but that study used DEM resolution of 250 m, more than two orders of magnitude lower than the landform variables used in this study. That vegetation structural and spectral variation due to insolation and moisture can be quantified at a hillslope scale (Chapter 6) indicates the environmental envelopes used to establish valid reference conditions (Gibbons et al. 2008) need to be developed at much finer grain.

The upland swamp – fringing woodland ecotone was clearly mapped by CHM stratification, as were vegetation communities within the swamps (Chapter 5). But forest ecotone and transitional area mapping was not attempted. Object-oriented classification using high resolution imagery has proven effective in a range of environments (Johansen et al. 2007; Lackner & Conway 2008; Mitri & Gitas 2006) and ALS data have been used for texture-based landform segmentation (Lucieer & Stein 2005). Segmentation or object-based algorithms for ALS data have been mainly directed at mapping individual tree crowns (Falkowski et al. 2006; Lee & Lucas 2007; Popescu et al. 2003) or harvest (Yu et al. 2004) rather than vegetation communities, suggesting potential for mapping-based research using high resolution data. The fusion of ALS and satellite image data for forest mapping is confounded, however, by horizontal layover effects due to off-nadir imagery.

1.2 Relevance to wider research

The initial investigation of criteria and indicators for this study identified a range of ecosystems, process and impacts that occurred at spatial and temporal scales similar to this study (Chapter 1; Table 3 & Table 4). Of particular relevance are shallow groundwater dependent ecosystems (Eamus & Froend 2006) such as coastal heaths (Griffith et al. 2008) and woodlands or wetlands threatened by salinity (Cramer & Hobbs 2002; Lyons et al. 2007). The fine spatial and structural grain of this study also matches that of the mosaic rainforest and fire-prone sclerophyll forest of the Australian Wet Tropics, characterised by sharp ecotones and potential for abrupt ecological transitions (Warman & Moles 2009). Australian forests often exhibit a mosaic pattern due to interaction of landform and fire, and the resultant complexity has been assessed using parameters very similar to those for vegetation condition, described above (Coops & Catling 2000). The current study, therefore, embodies many of both the spatial and structural indicators necessary for forest-fire landscape analysis. And, the timeframes for LWMS monitoring (annual to decadal) are also appropriate for fire succession both for characteristic shrub maturation categories (c. 1-2; 3-4; > 5 years) as well as senescence (< 5; 10-30; 30-50; > 50 years) (Keith et al. 2007). Decadal changes to Woronora Plateau swamp boundaries mapped by aerial photograph interpretation have been interpreted as a climate cycle response, and recognised as an important indicator for anthropogenic climate change (Keith et al. 2006), to which the current study can make a strong contribution. Similarly, the forest sensitivity to insolation and topographic wetness makes these metrics (foliage cover, NDVI) important indicator

response variables for climate change. Other applications may relate more directly to anthropogenic activities, whether covert, such as illegal logging, or overt, such as foot traffic impact in sensitive areas (Whitecotton et al. 2000; Yorks et al. 1997).

Remote sensing and field studies both have a long and credible history for vegetation assessment and monitoring. There has been, however, a disjunction between their application scales. Remote sensing has typically been seen as addressing diversity or habitat change through multi-temporal application at broad scale (Coops et al. 2009), or resource management at fine scales (Hilker et al. 2008). Site-based data, in contrast, is seen as imperative for fine-scale investigations of biodiversity (Gorrod & Keith 2009) with modelling seen as the appropriate means to extend analysis beyond the site (Drielsma & Ferrier 2006; Hill et al. 2005). This study has show that current high resolution remote sensing provides valid and often higher accuracy substitutes to key site-based metrics, and offers further advantages in repeatability, landscape extensibility as well as providing metrics not easily captured by field-based methods. The disjunctive gap between field and remote sensing studies is closing, and with both the increasing demand for accurate monitoring, as well as the increasing availability and affordability of high resolution remote sensing, the latter should become an essential part of assessment and monitoring programs.

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