Gnangara Sustainability Strategy

An across-government initiative

Groundwater – Biodiversity – Land use

MONITORING VEGETATION CONDITION IN THE *BANKSIA* WOODLAND OF THE GNANGARA MOUND: THE ROLE OF REMOTE SENSING TOOLS

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Report to the Department of Environment and Conservation and Gnangara Sustainbility Strategy

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Executive summary

Remote sensing tools have the potential to provide valuable information for the monitoring of vegetation. The multi-spectral Landsat data is particularly suited to monitoring vegetation at the regional-landscape scale as:

1. Indices can be derived to assess vegetation cover over large areas
2. Changes in vegetation cover through time can be assessed using an archival database of imagery
3. Imagery is acquired at a high frequency (every 16 days).

The key to successfully using remote sensing tools to monitor vegetation is being able to identifying vegetation indices or measures that can act as surrogate measures of vegetation condition.

This project sought to gain a greater understanding of how remote sensing tools can be used in the monitoring of *Banksia* woodland vegetation, at the landscape-regional scale, across the Gnangara Mound. This was done by exploring vegetation cover dynamics, as assessed by the projected foliage cover (PFC) vegetation cover index derived from Landsat data, on a number of small scale study sites across three *Banksia* woodland vegetation types. These study sites were across a range of ages since last fire and were either un-disturbed or in variable or poor condition. It also investigated how, and at what scale the Land Monitor Vegetation Cover Linear Trend products could be used as part of a monitoring system for *Banksia* woodlands.

At the small scale study sites the greatest change in vegetation cover was related to fire, irrespective of vegetation condition class. Generally, on undisturbed sites there was a rapid increase in vegetation cover 7 years post fire. Thereafter vegetation cover stabilised to PFC cover index values between 17 and 25, with small fluctuations related to variable seasonal conditions between years. On poor and variable condition sites the recovery of vegetation

cover after fire was more haphazard and vegetation cover, after a long period with no fire, was not as high (PFC cover index values between 12 and 22 for variable condition sites and between 10 and 16 for poor condition sites). Vegetation cover was determined to be more variable within the site on poor condition sites compared to un-disturbed sites (higher standard deviation of PFC cover index values on poor condition sites). This result indicates that vegetation cover becomes increasingly patchy once a disturbing process has altered the vegetation structure.

From this work two possible surrogate measures, of vegetation condition, have been identified for the three vegetation types studied. The proposed surrogate measures are:

1. PFC cover index condition thresholds
2. Variability of PFC cover index.

Because of the limited understanding of vegetation cover dynamics on the Gnangara Mound, no vegetation condition rating should be applied to an area based on only information from the two proposed surrogates. Rather these surrogates can be used to identify priority areas for on-ground assessment or to monitor areas once an on-ground assessment has been completed. Further development and refinement of the proposed surrogates is also required.

Examination of the Vegetation Cover Linear Trends at the small scale study sites revealed this tool has limited ability to discriminate between poor and un-disturbed sites. Comparison of the Vegetation Linear Trends, across the whole of the Gnangara Mound, over three time periods has revealed that this tool can provide a general picture of the broad levels of vegetation cover gain and loss at the regional scale. However, several drawbacks were identified when using Vegetation Linear Trends at the regional scale including:

1. The outcomes of Trend Analysis is very dependent on the level of vegetation cover at the first image date
2. It is not possible to identify a single date, to start the Trend Analysis sequence, when vegetation cover will be high across the whole region
3. The difficulty in attributing change in vegetation cover to a single threatening process when multiple threatening processes are impacting on the vegetation.

Therefore it is suggested that Landsat Vegetation Linear Trends is not suitable for a regional level assessment of vegetation cover. Rather this type of analysis should be undertaken at a smaller scale such as within the boundaries of a Conservation or National Park. The benefits of working at a smaller scale include:

1. It will be easier to identify a single appropriate date to start the Trend Analysis sequence
2. Dates to run the Trend Analysis over can be related to management interventions
3. Outcomes of the Trend Analysis can be related to information, either spatial or anecdotal, on known impact areas or management interventions
4. Scope to tie Trend Analysis to outcomes of periodic on-ground monitoring of vegetation condition.

Introduction

Remote sensing is widely accepted as a useful assessment tool which can play a role in vegetation monitoring systems in conjunction with conventional field based methods of assessing vegetation condition (Canci *et al.* 2006; Scarth *et al.* 2006; Bleby *et al.* 2008). A number of different sensors, such as airborne and satellite based multi-spectral and hyper-spectral sensors and airborne laser scanners, are now available that can be utilised to determine vegetation cover and other characteristics of vegetation relevant to the assessment of vegetation structure.

Remote sensing tools have the potential to provide valuable information for vegetation monitoring at the Regional-Landscape, Community-Ecosystem and Population scales (Bleby *et al*. 2009; Caccetta *et al*. 2000; Pfitzner and Bayliss 2006). The multi-spectral Landsat data is particularly suited to monitoring vegetation changes at the regional-landscape scale as it can assess vegetation cover over large areas, and has an archival database of imagery going back 35 years, thus enabling changes through time to be assessed. Landsat imagery has a high frequency of image acquisition with repeat overpasses every 16 days (USGS 2005). The use of Landsat data in regional-landscape scale monitoring is well established (Kuhnell *et al.* 1998; Caccetta *et al*. 2007; Pickup *et al*. 1994).

Airborne high resolution multi-spectral and hyper-spectral sensors and airborne laser scanners have increasingly been used to assess vegetation attributes at the community-ecosystem and population scales. Lau *et al*. (2006) investigated the use of hyperspectral imagery to map diatomaceous earth, and vegetation vigour and condition in relation to acid sulphate soil impacts on the Gnangara Mound. The study found that vegetation communities could be differentiated and the variations in vegetation condition states could be related to irrigation, hydrography or acid sulphate soil levels. The attribution of the cause of the vegetation condition states, however, requires validation. Lee and Lucas (2007) have applied small footprint LiDAR data (Light Detection And Ranging) to determine individual trees heights in the top and sub canopy, crown cover and foliage and branch projective cover. This approach provides important measures to assess a multi-layered forest environment. It is anticipated that the value of these types of sensors in vegetation monitoring programs will increase once robust vegetation measures have been developed and on-going programs are established to capture data on a regular basis. In the Perth metropolitan region high resolution photogrammetric multispectral airborne data has been captured on an annual basis since 2007 (see CSIRO 2009 for more details). Once this dataset has achieved production standards the applications in vegetation monitoring can be applied.

The key to successfully using remote sensing tools in vegetation monitoring centres on developing vegetation indices or measures that can act as surrogate measures of vegetation condition. A number of vegetation change measures and monitoring frameworks have been developed in Australia and are currently in use over varying land uses and contexts; for example, the Land Monitor Perennial Vegetation Trends (Furby *et al*. 2008) and the Department of Climate Change 'National Carbon Accounting System Land Cover Change Project' (NCAS-LCCP; Caccetta *et al*. 2007). It has only been in recent times that conservation agencies have started investigating how well these can act as surrogate measures of vegetation condition in a biodiversity conservation context.

Wallace *et al.* (2006) contains examples of how vegetation condition has been assessed using a multi-temporal imagery approach in environments ranging from north east Kimberley grasslands to remnant vegetation in the south west agricultural zone and former pastoral leases in Shark Bay. Knowledge of how the different environments functioned was important when interpreting the changes in vegetation and what they meant for the condition assessment. For example, in Shark Bay an area of a large increase in vegetation cover was attributed to an invasion of the weed Buffel Grass. Gaining a greater understanding of vegetation cover dynamics will be important to these investigations as any surrogate measure will need to be able to discriminate between 'natural' or 'background' variability in vegetation cover and changes in vegetation cover due to threatening processes.

Until recently remote sensing tools have not been widely used to assess vegetation on the Gnangara Mound. Since 1995 the Land Monitor program (Caccetta *et al*. 2000) has been making available a suite of vegetation change products, derived from Landsat data, for the South West Agricultural Region of Western Australia, of which the Gnangara Mound is part. These products include perennial vegetation extent, vegetation history and vegetation trend, which summarises the change in reflectance of perennial vegetation areas over time (Furby *et al*. 2008) and are targeted to monitoring at the landscape and regional scales. In recent years the Water Corporation has been using high spatial resolution airborne Digital Multi-Spectral Imagery (DMSI) to monitor native vegetation around bore fields and has been developing methods to identify individual tree deaths and their spatial patterns (Canci *et al*. 2006). This work is part of the monitoring that Water Corporation is required to carry out to identify any environmental impacts of water extraction from the Gnangara Mound. The approaches and surrogate measures developed in this study would provide valuable native vegetation monitoring information, in a biodiversity context, at the community-ecosystem/population-species scale. The Department of Water and CSIRO have also been investigating the use of Hyperspectral imagery to map diatomaceous earths and environmental conditions related to acid sulphate soils in several wetland areas (Lau *et al*. 2006).

The project presented in this report sought to gain a greater understanding of how remote sensing tools can be used in the monitoring of *Banksia* woodland vegetation, at the landscape – regional scale across the Gnangara Mound. *Banksia* woodlands account for 50% of the current extent of native vegetation on the Gnangara Mound and their regional conservation significance is high. Clearing for urban and rural development across the Swan Coastal Plain has been to such an extent that very few large un-fragmented areas of remnant vegetation now exist with the largest occurring on the Gnangara Mound (68 541 ha). Additionally some of the vegetation complexes occurring in this area do not have adequate levels of retention and protection and some are only found within the Gnangara Mound (Kinloch *et al*. 2009). A number of threatening processes impact on these woodlands such as *Phytophthora cinnamomi*, fragmentation, weeds, decreasing rainfall due to climate change, ground water extraction and changed fire regimes. The close proximity of these woodlands to the expanding urban area of Perth will mean that the risk of impact from these threatening processes will only increase in the future. Therefore there is an urgent need to develop methods to adequately monitor native vegetation condition so this information can inform the management of these woodlands.

This project firstly explored the vegetation cover dynamics, as assessed by vegetation indices derived from Landsat data, of un-disturbed and poor condition areas across a range of ages since the last fire. This analysis aims to improve our understanding of how remote sensing tools could be used for monitoring *Banksia* woodlands. The project also investigated how and at what scale the Land Monitor Vegetation Cover Trend products could be used as part of a monitoring system for *Banksia* woodlands.

Specific objectives addressed:

1. Across a number of small scale undisturbed, variable condition and poor condition vegetation sites on three *Banksia* woodland vegetation types:
    a. Use Landsat data to assess and characterise vegetation cover changes over a 35 year time period
    b. Evaluate Landsat Vegetation Cover Linear Trends Products between 1973 and 2008
    c. Use Landsat vegetation index values and time since last fire data to determine characteristics of recovery of vegetation after fire.
2. Determine Trends in vegetation cover between 1973 and 2008 across the Gnangara Mound.

Study area and climate

The Gnangara groundwater system is located on the Swan Coastal Plain just north of Perth and covers an area of approximately 2200 square kilometres. It extends from the Swan River in the south, Moore River and Gingin Brook in the North and from Ellen Brook and Swan Valley in the east to the Indian Ocean to the West. The area has undergone intensive urban, rural and pine plantation development though extensive areas of *Banksia* woodlands remain, as do permanent and seasonal wetlands. The groundwater system comprises several different hydrological units or aquifers and provides approximately 60% of Perth's drinking water (Government of Western Australia 2009). Declining ground water levels since 1960 due to climate change, increased abstraction and interception loss has brought into question the sustainability of the Gnangara groundwater system and its associated values (Government of Western Australia 2009).

The vegetation of the Gnangara groundwater system is dominated by heath and/or tuart woodlands on limestone, *Banksia* and jarrah – *Banksia* woodlands on dune systems of various ages, marri on colluvial and alluvial soils, and paperbarks in swampy areas

(Mitchell *et al*. 2003). Mattiske (2003) identified 32 vegetation types on the Gnangara groundwater system based on available floristic plot data and the system developed by Havel (1968). This study focused on two of the more widespread *Banksia* woodlands vegetation types mapped by Mattiske (2003): H1 and I1 (Figure 1; Table 1). Areas located on G2 *Banksia* woodland vegetation type (Mattiske 2003) were also investigated (Figure 1; Table 1). The G2 vegetation type is the dominant vegetation type over CSIRO's GSS recharge trial site (Caraban UCL, Figure 1). For all three vegetation types the dominant species is *Banksia attenuata* (see Table 1 for a full description of each vegetation type).

Table 1: Description and extent of Vegetation Types studied. Taken from Mattiske (2003).

Vegetation Type Code	**Description**	**Total area* (hectares)**	**Proportion* (%)**
I1	Low Open Woodland of *Banksia attenuata - Banksia menziesii* over *Verticordia nitens, Dasypogon bromeliifolius, Melaleuca seriata* and *Patersonia occidentalis.*	19932	12.8
H1	Low Woodland to Low Open Woodland of *Banksia attenuata - Banksia menziesii - Banksia ilicifolia - Nuytsia floribunda* over *Beaufortia elegans, Leucopogon polymorphus, Melaleuca systena, Calytrix angulata, Calytrix flavescens, Stirlingia latifolia, Dasypogon bromeliifolius, Leucopogon conostephioides, Lyginia barbata, Macrozamia riedlei* and *Xanthorrhoea preissii.*	13478	8.7
G2	Low Open Woodland of *Banksia attenuata - Banksia menziesii - Allocasuarina fraseriana - Eucalyptus todtiana* over *Xanthorrhoea preissii, Lysinema ciliatum, Verticordia nitens, Hibbertia hypericoides, Philotheca spicata, Eremaea pauciflora* var. *pauciflora, Bossiaea eriocarpa, Daviesia nudiflora, Mesomelaena pseudostygia* and *Stirlingia latifolia.*	1200	0.8

* Of portion of the Gnangara Mound mapped by Mattiske (2003)

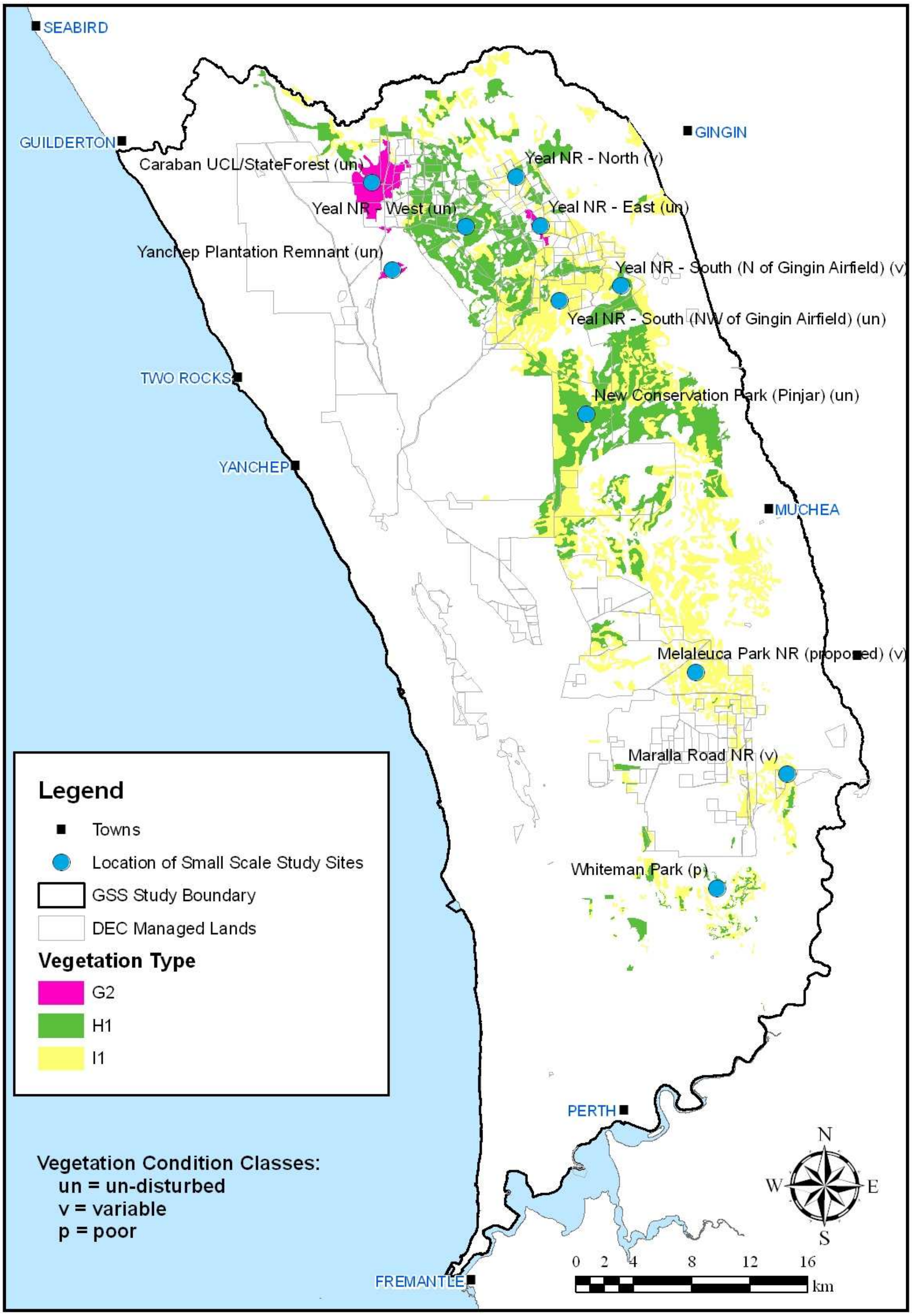


Figure 1: Location Map showing the extent of I1, H1 and G2 vegetation types on the Gnangara Mound and the location of the small scale study sites.

Fire plays an important role in the ecosystems of the Gnangara groundwater system with many of the plant species showing adaptations to fire (Bleby *et al.* 2009). Inappropriate fire regimes have the potential to considerably impact on native species and communities (Bleby *et al.* 2009). The Department of Environment and Conservation conducts prescribed burning across 45 120 ha of native woodlands on the Gnangara Mound to protect biodiversity assets, infrastructure and the life and property of neighbours (Bleby *et al.* 2009). Native woodlands are burnt during spring and autumn on an 8 to 12 year rotation (Bleby *et al.* 2009).

The Gnangara Mound experiences long dry summers and mild wet winters. The long term average annual rainfall of the region is 752 mm (1907 – 2007) but since the 1970's the wider south-west region has been experiencing a decline in rainfall (Government of Western Australia 2009) with the short term annual average rainfall declining to 664 mm (Figure 2). Not only has the total amount of rainfall over a year declined, but so has the frequency of wet months (Government of Western Australia 2009). At the Perth Airport the number of months, per decade, with total rainfall greater than 100mm, 150 mm or 200mm has declined especially since the 1970's (Figure 3).

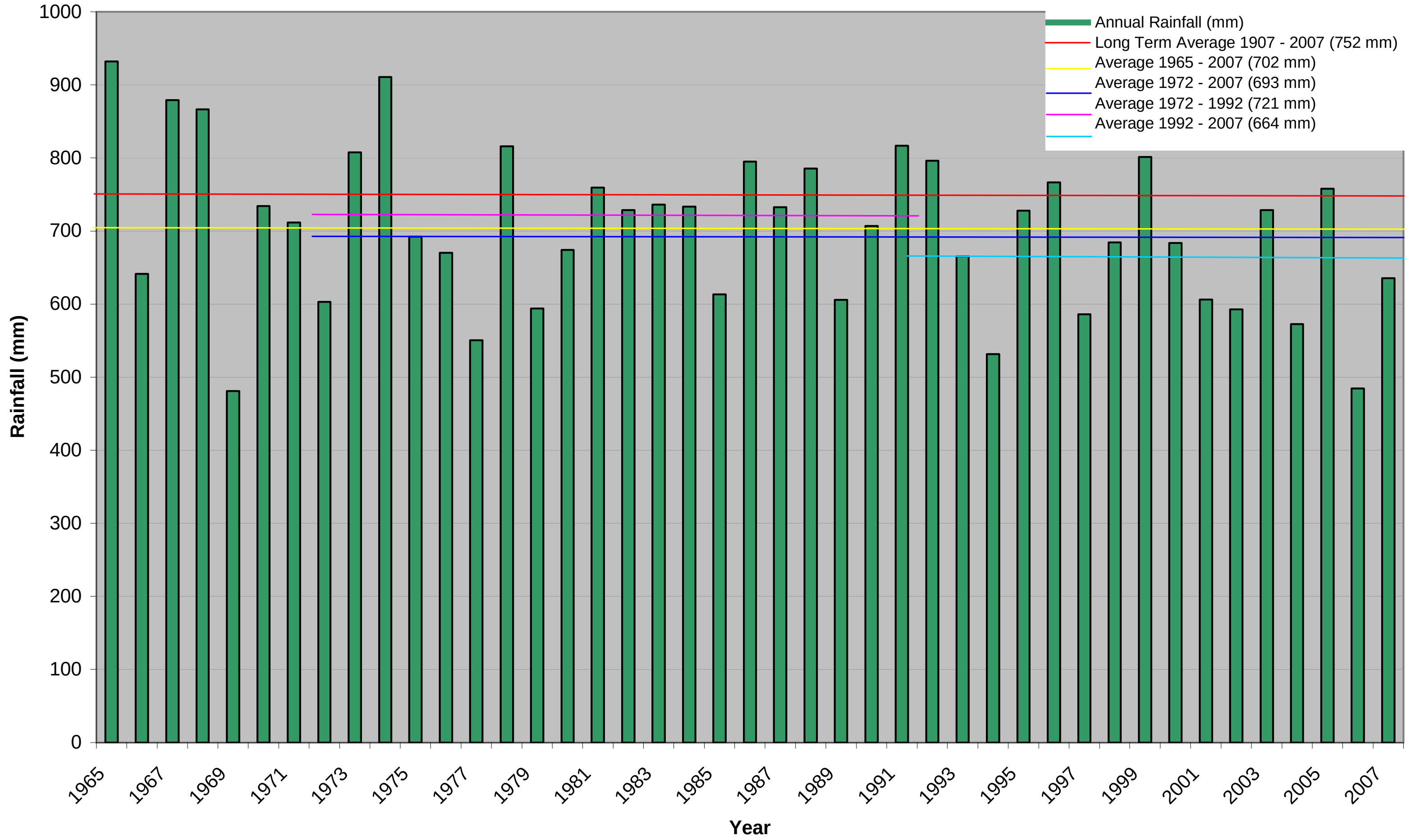


Figure 2: Mean annual rainfall for four meteorological stations across the Gnangara Mound (Allambie, Perth Airport, Muchea Tree Farm, Yanchep) for the period of 1907 – 2007. Rainfall data for each station is a combination of observations and interpolated data to fill any gaps ('patch') in the record. Data source: Patched Point Dataset http://www.nrw.qld.gov.au/silo/.

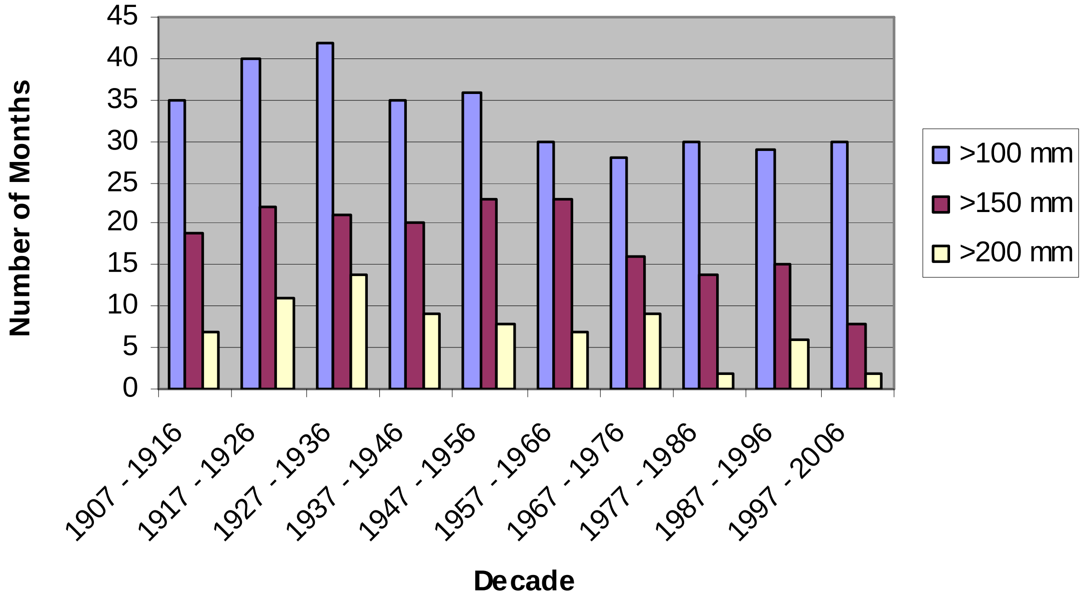


Figure 3: Frequency of wet months for the last ten decades at the Perth Airport. Rainfall data is a combination of observations and interpolated data to fill any gaps ('patch') in the record. Data source: Patched Point Dataset http://www.nrw.qld.gov.au/silo/.

Methods

Development of vegetation index

Mathematical combinations of the spectral bands of Landsat imagery can be used to derive vegetation indices which can differentiate vegetation from other cover classes and can discriminate between vegetation of different densities. An archive of data is available of Landsat satellite (MSS, TM and ETM+) imagery for 16 dates between the period of 1973 and 2008, to which geometric and radiometric corrections have been applied (Caccetta *et al*. 2007). The methods used to calculate the vegetation index are described in Behn *et al*. (2009) and are summarised below. To estimate the variation in crown cover across the landscape, a spectral image index, which discriminates vegetation from other cover types, was calculated using the visible red waveband (Band 3 from Landsat TM and Band 2 from Landsat MSS) for each image date. Other combinations of spectral bands are more effective at discriminating vegetation (e.g. TM band 3 plus TM band 5) but the visible red waveband was used in this instance as it can be applied across both the MSS and TM

Landsat platforms thus enabling the archival database to be fully utilised. The spectral image index was then calibrated with field measurements of projected foliage cover (PFC) to produce a calibrated PFC index for each image date. The calibrated PFC index ranges from 0 to 33 with low values relating to low vegetation cover and high values to high vegetation cover.

Vegetation cover dynamics

A series of study areas were identified within the H1, I1 and G2 *Banksia* woodland vegetation types. For the H1 and I1 vegetation types, study areas were located on remnant vegetation that is classed as either un-disturbed or in variable or poor condition. All G2 study sites were classed as un-disturbed. No broad-scale mapping of vegetation condition is available for the area so we relied on our own knowledge of the area, and that of colleagues, to identify study areas that were representative of the un-disturbed, variable and poor condition classes. Areas which are subject to multiple threatening processes (e.g. *Phytophthora cinnamomi* impact, fragmentation or past grazing by livestock) were classed as in poor condition. The *Phytophthora* dieback status of the study areas was determined using Project Dieback Interpretation mapping (Strelein *et al*. 2008). Those study areas classed as having high or medium confidence *Phytophthora cinnamomi,* in the aforementioned dataset, and *Phytophthora* dieback was the only known threatening processes were classed as being in variable condition. At each study area, data on the year since last burn (DEC 2008), satellite imagery from 1972 – 2008 and the most up-to-date ortho-photos available were used to select a series of small scale (approx 2.25 ha) study sites, of different years since last burn, for each of the three vegetation types. All three vegetation types were not present at all study areas. Sites were located so that they fitted within the boundaries of the last fire and preferably within the boundaries of any fires between the years 1973 – 2008. See Appendix A for information on the condition, vegetation type and *Phytophthora* dieback status of all small scale study sites and Appendix D for location information.

Calibrated PFC cover index (hereafter referred to as PFC cover index) values were extracted for 6 x 6 25 m pixels (2.25 ha) at each site for each year date. Means and standard deviations were calculated for each site and graphed to show the PFC cover index values over the 35 years. The fire history of the site, from 1973 – 2008, was then reconstructed using the cover index information on the graphs. When a decline in vegetation cover was evident, the satellite imagery for that date was inspected to determine if the decline was due to a fire or seasonal rainfall variability. From the fire history reconstruction the following attributes, at each site, were determined to characterise its fire history:

1. Year since last burn (YSLB) for each Landsat image date. This included verifying the YSLB information from DEC corporate records (DEC 2008). Where there was uncertainty to the exact year of a fire event YSLB was not recorded.
2. Number of fires from 1977 to 2008. This assessment did not extend back to 1973 as for a number of sites it was not possible to be confident on how recent the fires for 1973 were (see below);
3. 1973 burn status class:
   a) just burnt
   b) recent burn but recovery evident (or less intensely burnt if very recent)
   c) recent burn but recovery evident
   d) fire scar evident - hard to determine how recent
   e) fire scar present but not recently burnt
   f) no recent fire - high cover
4. Maximum length of time over the 35 year period with no burn.

The fire history reconstruction also enabled the YSLB to be determined for each image date for all of the sites. This was graphed against the cover index values so the rate of recovery of vegetation cover after fire could be characterised for un-disturbed, variable and poor condition sites on each vegetation type.

Vegetation Cover Linear Trends

The Vegetation Cover Linear Trends procedure summarises the temporal change in vegetation cover for each pixel over time (Wallace *et al.* 2006). The calculation of the Trends follows the methodology of Wallace *et al*. (2006) and Furby *et al*. (2008), is described in detail in Behn *et al*. (2009) and is summarised below:

1. A calibrated PFC index was calculated for each time period (image date).
2. Scaled temporal summaries of the calibrated PFC index for the 1973 – 2008; 1973 – 1992 and 1992 – 2008 time periods were calculated. The 1973 – 2008 time period

represents the full range of image dates available in the Landsat archive whilst the years of 1973 – 1992 were comparatively more wet than 1992 – 2008 (Figure 2).

3. Areas that were classified as never having perennial vegetation cover were masked out.
4. Linear ‘Trendclass’ images were produced, for each time period.

The Linear Vegetation Cover Trend class images for each time period were clipped to the 2005 Remnant Vegetation Extent (DAFWA 2006) the most current mapping available of remnant vegetation. By clipping the data to the 2005 vegetation extent, only clearing between the years of 2005 and 2008 would be detected as negative trends. The total area of remnant vegetation, across the GSS study area, in each trend class was then calculated for the aforementioned time periods. At the small scale study sites a visual assessment of the proportion of the study site in each linear trend class was undertaken.

Results

Small scale study sites

Vegetation cover dynamics for a range of vegetation condition classes

The mean vegetation cover index values over the 35 years for un-disturbed sites, on all three vegetation types, were characterised by a large fall immediately after fire, then followed by an increase in cover index values associated with the period of vegetation recovery (Figure 4a and b; Figure 5a and b; Figure 6a and c). An exception to this type of response was evident in the Yanchep Plantation remnant (Figure 6b) where all three sites did not show a substantial decline in cover after fires in 1979 – 1980 and 1998 - 1999. The 1979 – 1980 fire is likely to have been just prior to the Landsat pass (image date 01/12/1979). Litter cover just after a burn can be quite high and this may well be affecting the PFC cover index values. It also appears that the sites were not burnt intensively in the 1979 – 1980 fire. The 1998 – 1999 fire also appears to have been not intense. This has meant that there has been little reduction in the vegetation canopy. This fire was also a full year prior to the Landsat pass (image date 20/02/2000) so some recovery in the vegetation may also have occurred. If an area remained un-burnt for a long period of time the vegetation cover values stabilised between 17 and 25 with the small fluctuations in cover index values most likely related to differing amounts of rainfall between years. A good example of this type of response is evident at site ID 36 at Yeal West (Figure 4a), which had been burnt prior to the 1973 image date and remained un-burnt for the entire 35 years. Mean vegetation cover index values were similar over all three vegetation types and on these un-disturbed sites the standard deviation was usually low (Figure 4a and b; Figure 5a and b; Figure 6a - c).

The poor condition sites were similar to the un-disturbed sites in that the greatest falls in mean vegetation cover index values over the 35 years were related to fire (Figure 4d; Figure 5f). Recovery after fire was evident but when a disturbed area remained un-burnt for a long period the mean vegetation cover index values were more variable, compared to long unburnt un-disturbed sites, and PFC cover index values stabilised between ~10 to 16. The consistently high standard deviations reveal that the vegetation cover is also more variable within these sites compared to un-disturbed sites.

Not surprisingly fire had the greatest impact on vegetation cover index values on the variable condition sites (Figure 4c; Figure 5c - e). Some of these sites were similar to un-disturbed sites in that they show a degree of stability both between years and within the site (low standard deviation; site ID's 3, 5, 43, 45, 46). Whereas others were similar to poor condition sites with a greater degree of variability in vegetation cover within the site even after they have recovered from a fire (higher standard deviations; site ID's 40, 41). Vegetation cover was not as high as un-disturbed sites (vegetation index values stabilise to between 12 and 22).

Many sites across all three vegetation types showed a decline in vegetation cover in 1992 despite average rainfall conditions prevailing in the three months prior to the Landsat pass (image date 7/1/1993). It is likely that this decline is related to variability in rainfall between years. Often there is a considerable lag period between a 'wet' or 'dry' year and the response in the tree canopy. Therefore it is likely that in 1992 the decline in vegetation cover is related to the below average rainfall in 1989 and 1990. Nearly all sites that showed a decline in vegetation cover in 1992 showed an increase in vegetation cover in the 1995 which is likely related to the above average rainfall in 1991 and 1992.

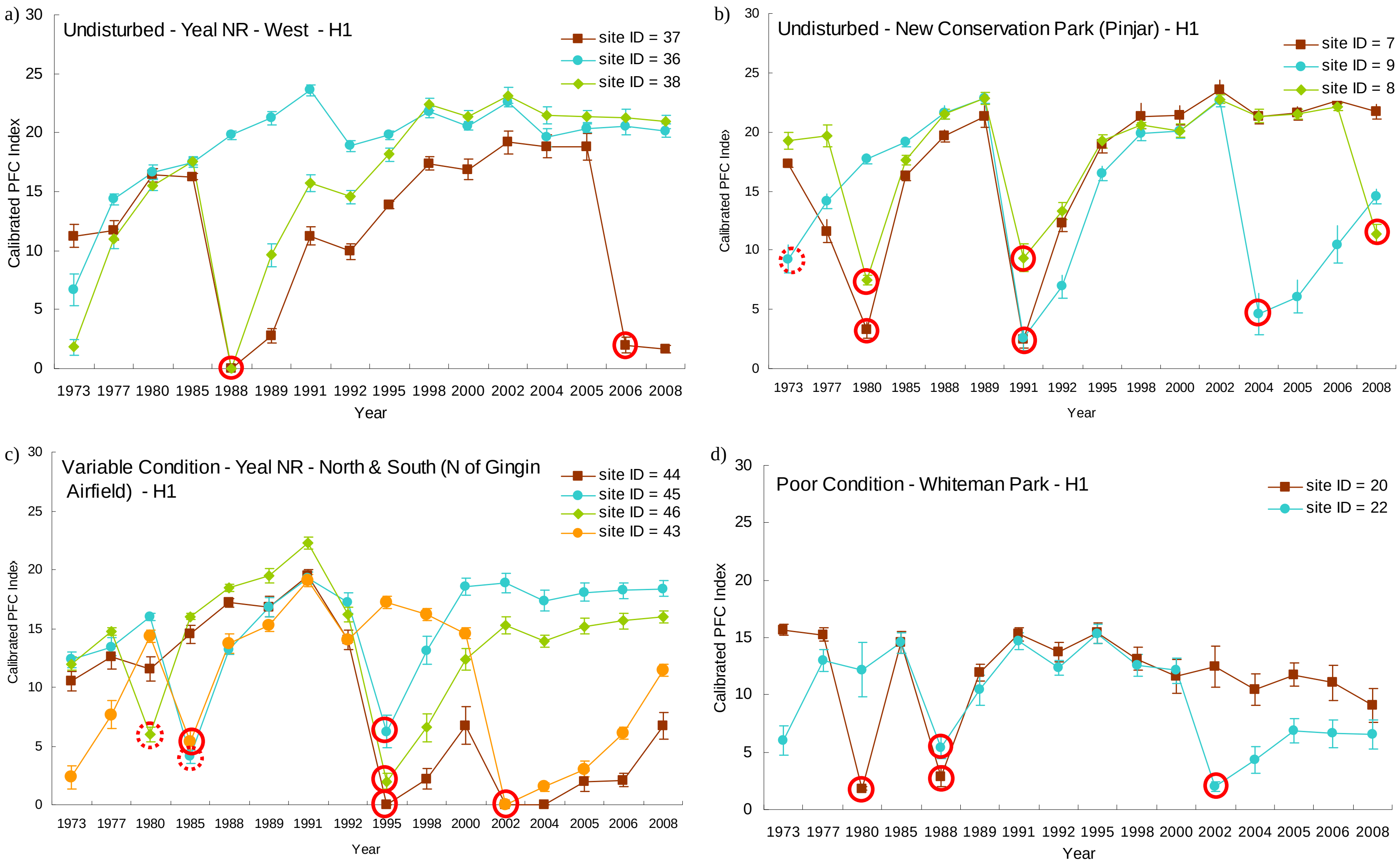
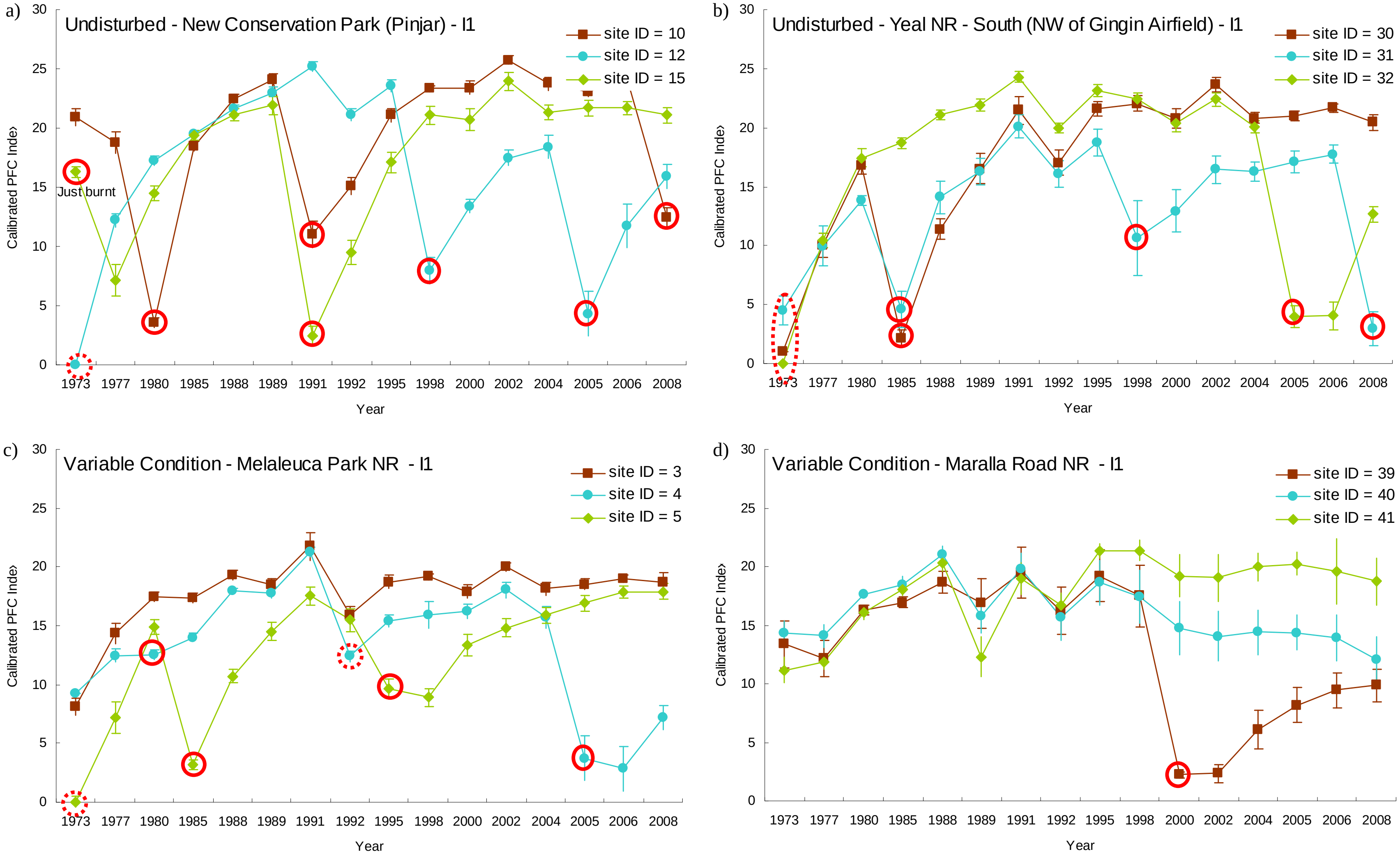


Figure 4: Mean and standard deviation of calibrated PFC Vegetation Cover Index values, over 35 years, on (a) and (b) un-disturbed, (c) variable condition and (d) poor condition small scale sites on Vegetation Type H1. Years when the site was burnt are indicated with a red circle. Dashed circles indicate uncertainty of year of fire event due to the time between image dates.


a)
Undisturbed - New Conservation Park (Pinjar) - I1
site ID = 10
site ID = 12
site ID = 15
Just burnt
Calibrated PFC Index
Year
1973 1977 1980 1985 1988 1989 1991 1992 1995 1998 2000 2002 2004 2005 2006 2008
b)
Undisturbed - Yeal NR - South (NW of Gingin Airfield) - I1
site ID = 30
site ID = 31
site ID = 32
Calibrated PFC Index
Year
c)
Variable Condition - Melaleuca Park NR - I1
site ID = 3
site ID = 4
site ID = 5
Calibrated PFC Index
Year
d)
Variable Condition - Maralla Road NR - I1
site ID = 39
site ID = 40
site ID = 41
Calibrated PFC Index
Year

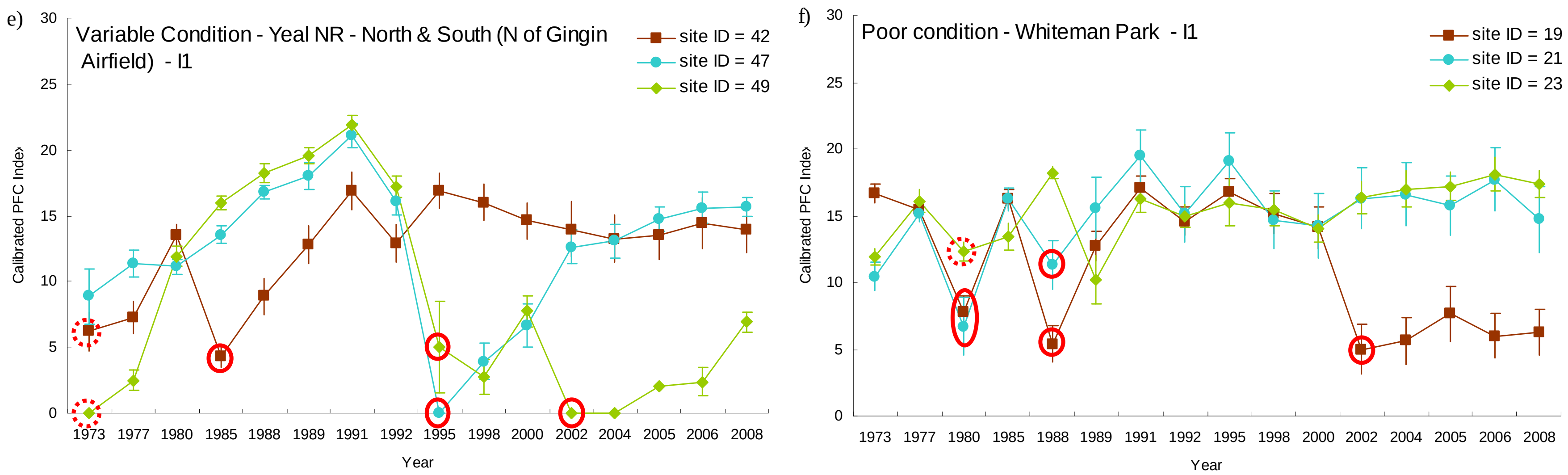


Figure 5: Mean and standard deviation of PFC Vegetation Cover Index values, over 35 years, on (a) and (b) un-disturbed, (c), (d) and (e) variable condition, and (f) poor condition small scale sites on Vegetation Type I1. Years when the site was burnt are indicated with a red circle. Dashed circles indicate uncertainty of year of fire event due to the time between image dates.

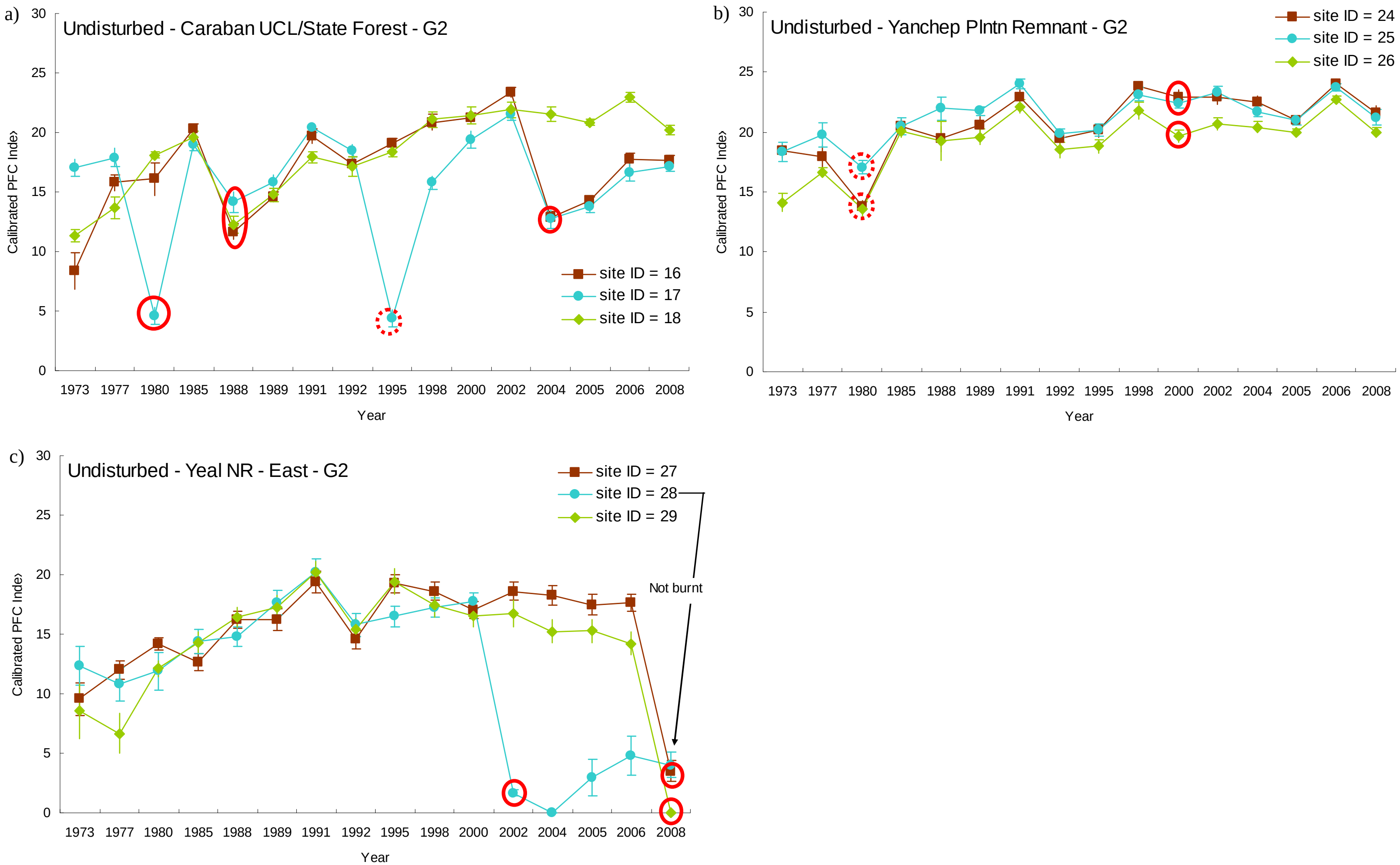


Figure 6: Mean and standard deviation of PFC Vegetation Cover Index values, over 35 years, on (a), (b) and (c) un-disturbed small scale sites on Vegetation Type G2. Years when the site was burnt are indicated with a red circle. Dashed circles indicate uncertainty of year of fire event due to the time between image dates.

Vegetation Cover Linear Trends

For the Linear Trends the majority of small scale study sites had a trend class, or a dominant trend class, of ‘no major change’ in vegetation cover or increasing trend in vegetation cover (‘positive’) for the period 1973 – 2008 (Table 2). No sites showed a large increasing or decreasing trend in vegetation cover (dominant trend class of either ‘major positive’ or ‘major negative’; Appendix A). The dominant trend in vegetation cover in poor condition sites was either ‘no major change’ or ‘negative’. For variable condition sites, the majority of sites had ‘positive’ trends but a significant number were also in the ‘no major change’ and ‘negative’ trend classes. Un-disturbed sites either had a dominant trend of ‘no major change’ or ‘positive’ with nearly all sites in the ‘positive’ trend class having an YSLB of nine years or greater and fewer than three fires between 1977 and 1980 (Appendix A). No long unburnt un-disturbed sites had a trend class of ‘no major change’ or ‘negative’ (Appendix A). Generally ‘negative’ trends in vegetation cover were only a minor proportion of un-disturbed sites (Table 2; Appendix A).

Table 2: Number of small scale study sites, across three vegetation types and three condition classes, which had a dominant Landsat vegetation linear trend class of no major change in vegetation cover, increasing trend in vegetation cover (positive) or decreasing trend in vegetation cover (negative). The Landsat vegetation linear trend classes relate to the 1972 – 2008 time period.

Vegetation Type	Linear Trend Class	Condition Class			Total
		Un-disturbed	**Variable**	**Poor**	
I1	No Major Change	4	3	2	9
	Positive	4	6	0	10
	Negative	0	2	1	3
	Total	**8**	**11***	**3**	**22***
H1	No Major Change	6	2	2	10
	Positive	5	1	0	6
	Negative	0	1	0	1
	Total	**11**	**4**	**2**	**17**
G2	No Major Change	5	N/A	N/A	5
	Positive	3	N/A	N/A	3
	Negative	1	N/A	N/A	1
	Total	**9**	**0**	**0**	**9**
Total	No Major Change	15	5	4	24
	Positive	12	7	0	19
	Negative	1	3	1	5
	Total	**28**	**15***	**5**	**48***

*Landsat Linear Trend class information not available for site ID 48 (I1 variable condition) so was not included in this analysis.

Recovery of vegetation cover after fire

PFC Vegetation Cover Index values generally showed a rapid/exponential increase in the first 7 years after fire on un-disturbed sites (Figure 7a and b; Figure 8a and b; Figure 9a and b). Thereafter any increase in vegetation was not as rapid and in the majority of sites cover values stabilised between PFC Cover Index values of 19 and 23. Vegetation Cover Index values within 7 years of a fire were quite variable at some sites and is likely to be related to the differing severity of the fires (Figure 8a; Figure 9b)

A similar assessment of poor condition sites (Figure 7d; Figure 8e) revealed no relationship between YSLB and PFC Cover Index at three sites (site ID 19, 22, 23) and quite rapid increase in cover in the first three or four years after fire and then a gradual decline at two other sites (site ID 20, 21). Vegetation cover index values 10 years after a fire were nearly always less than 17.

No one single response characterised the variable condition sites (Figure 7c; Figure 8c and d). Some were similar to un-disturbed sites showing a rapid increase in cover in the first seven to ten years then stabilising to a PFC Cover Index value between 15 and 20 (site ID’s 42, 43, 45 – 48). Whilst for others there was no relationship between YSLB and PFC Cover Index values (site ID’s 2, 4, and 5).

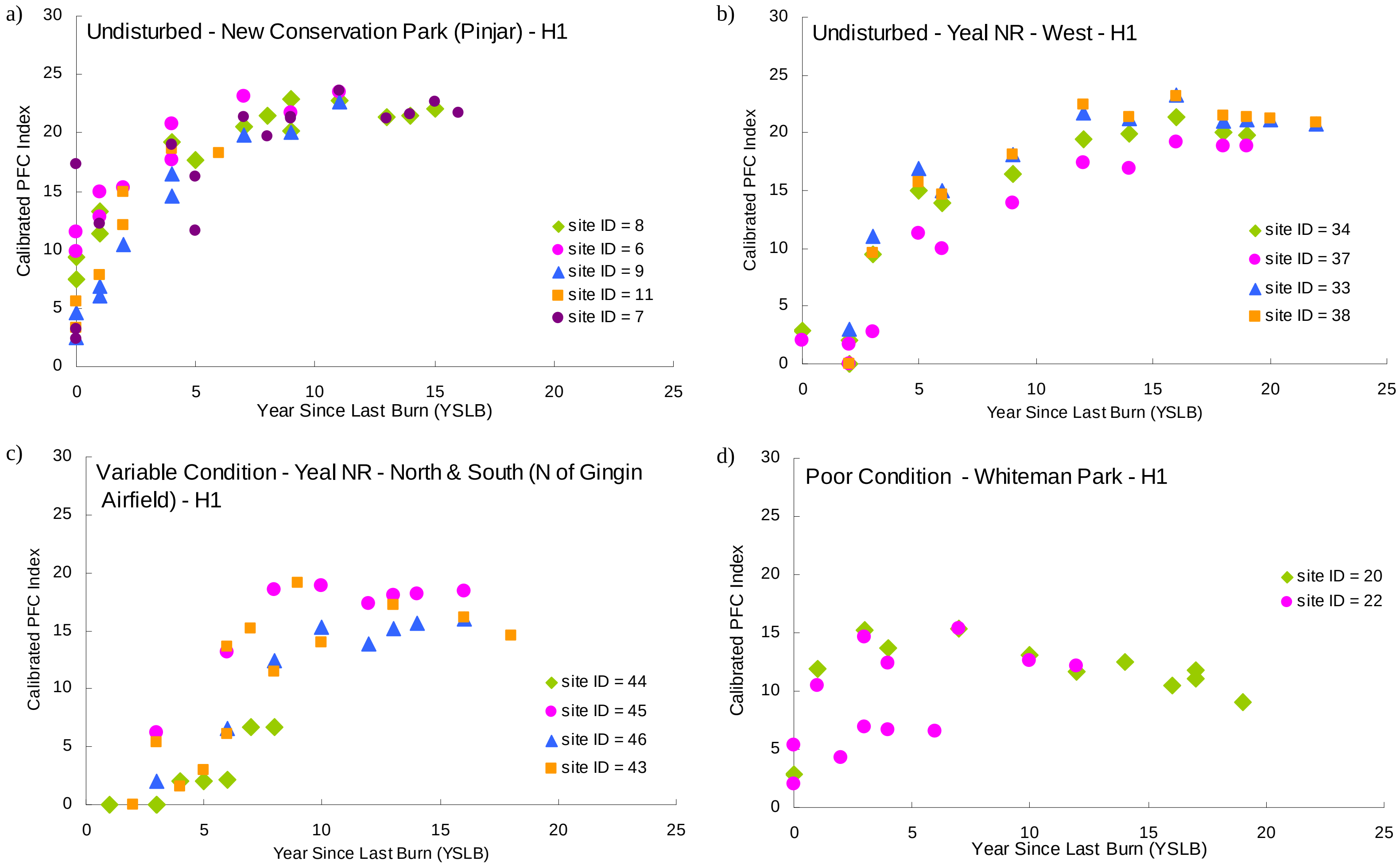
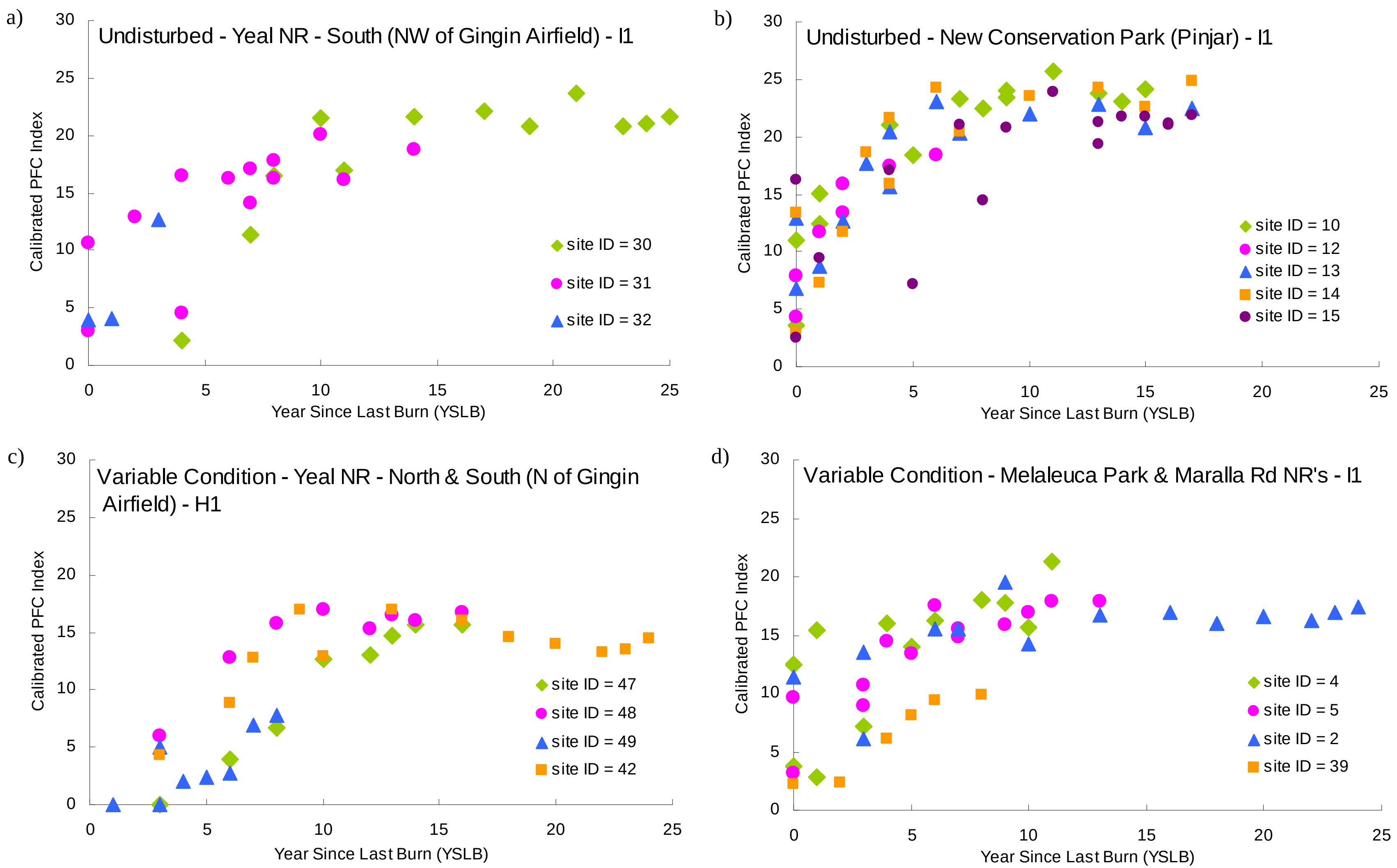


Figure 7: Mean PFC Vegetation Cover Index values in relation to year since last burn (YSLB) for (a) and (b) un-disturbed, (c) variable condition and (d) poor condition sites on vegetation type H1.


a)
Undisturbed - Yeal NR - South (NW of Gingin Airfield) - I1
Calibrated PFC Index
Year Since Last Burn (YSLB)
site ID = 30
site ID = 31
site ID = 32
b)
Undisturbed - New Conservation Park (Pinjar) - I1
Calibrated PFC Index
Year Since Last Burn (YSLB)
site ID = 10
site ID = 12
site ID = 13
site ID = 14
site ID = 15
c)
Variable Condition - Yeal NR - North & South (N of Gingin Airfield) - H1
Calibrated PFC Index
Year Since Last Burn (YSLB)
site ID = 47
site ID = 48
site ID = 49
site ID = 42
d)
Variable Condition - Melaleuca Park & Maralla Rd NR's - I1
Calibrated PFC Index
Year Since Last Burn (YSLB)
site ID = 4
site ID = 5
site ID = 2
site ID = 39

e)

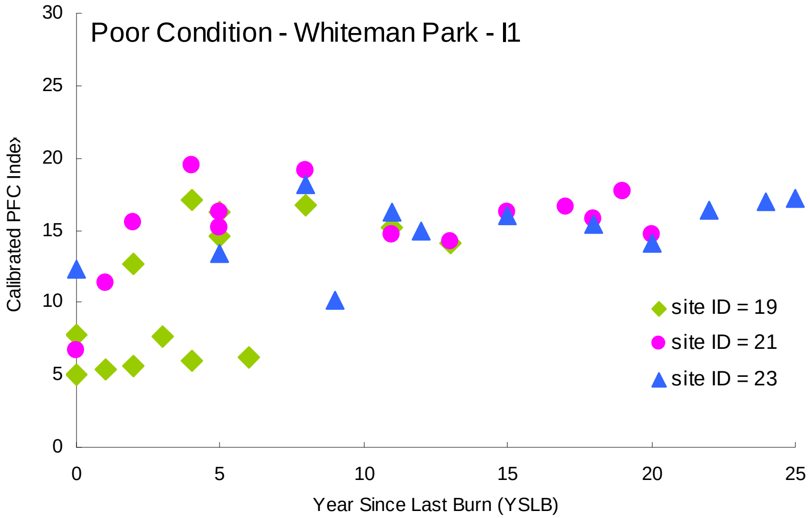


Figure 8: Mean PFC Vegetation Cover Index values in relation to year since last burn (YSLB) for (a) and (b) un-disturbed, (c) and (d) variable condition and (e) poor condition sites on vegetation type I1.

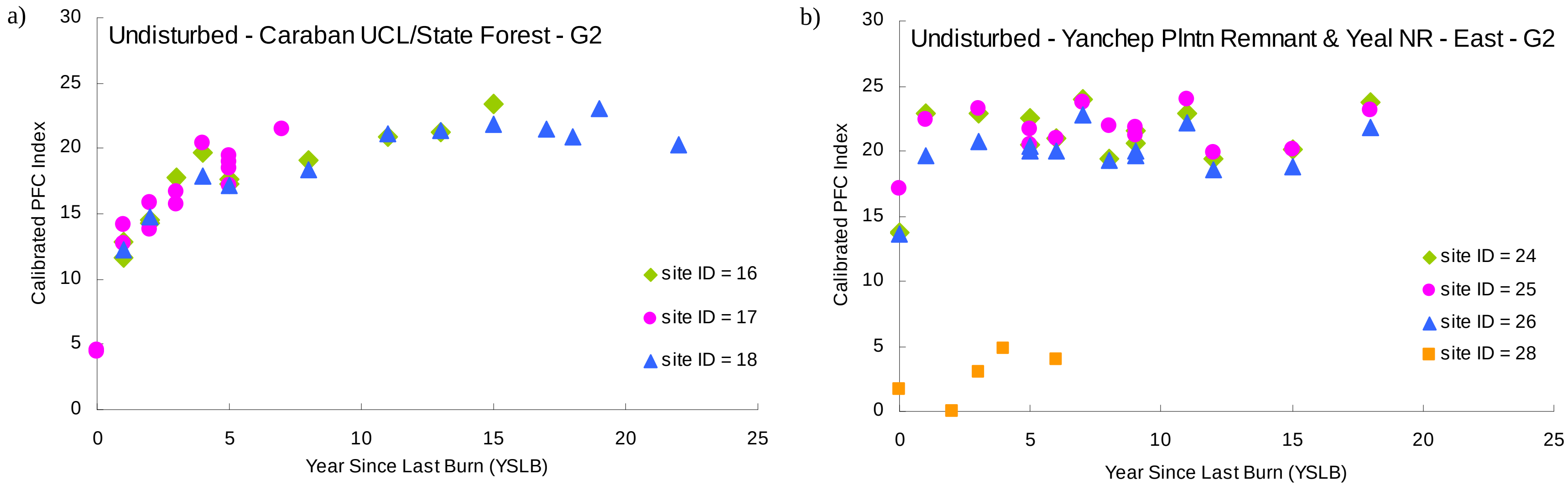


Figure 9: Mean PFC Vegetation Cover Index values in relation to year since last burn (YSLB) for (a) and (b) un-disturbed sites on vegetation type G2.

Vegetation Cover Linear Trends across the Gnangara Mound

Long term (1973 – 2008) Vegetation Linear Trends

The long term 1973 – 2008 Vegetation Linear Trends reveal that the majority of remnant vegetation across the Gnangara Mound has either increased in vegetation cover (35% had a ‘positive trend’) or experienced no major change in vegetation cover since 1973 (Table 3; Figure 10 and Figure 11). The positive trend for much of the area is due to recovery of vegetation cover from fires that occurred prior to 1973. Declining vegetation cover represents just over 7% of the remnant vegetation and is not restricted to any one land use; rather, examples can be found in rural, urban and conservation areas (Figure 10 and Figure 11). Prescribed burns and wildfires are the likely main causes of negative trends on the conservation estate and State Forest (Figure 10). Large patches of remnant vegetation with negative trends near Burns Beach are associated with clearing that has taken place between 2005 and 2007. It should be noted that the lack of availability of historic remnant vegetation extent data inhibited us from being able to incorporate into the analysis an assessment of the amount of remnant vegetation that was cleared between 1973 and 2005.

Table 3: Total area of 2005 extent of remnant vegetation in each linear Landsat trend class for the periods of 1973 – 2008, 1973 – 1992 and 1992 – 2008.

Linear Trend Class	**Total Area of Remnant Vegetation (ha)**		
	1973 – 2008	**1973 – 1992**	**1992 – 2008**
Large Positive Trend	294	45	6
Positive Trend	35 765	40 752	7549
Stable or relatively Stable	57 685	57 362	80 857
Negative Trend	5459	2698	10 701
Large Negative Trend	2020	367	2110
Total Area of Remnant Vegetation (ha)	**101 223**	**101 223**	**101 223**

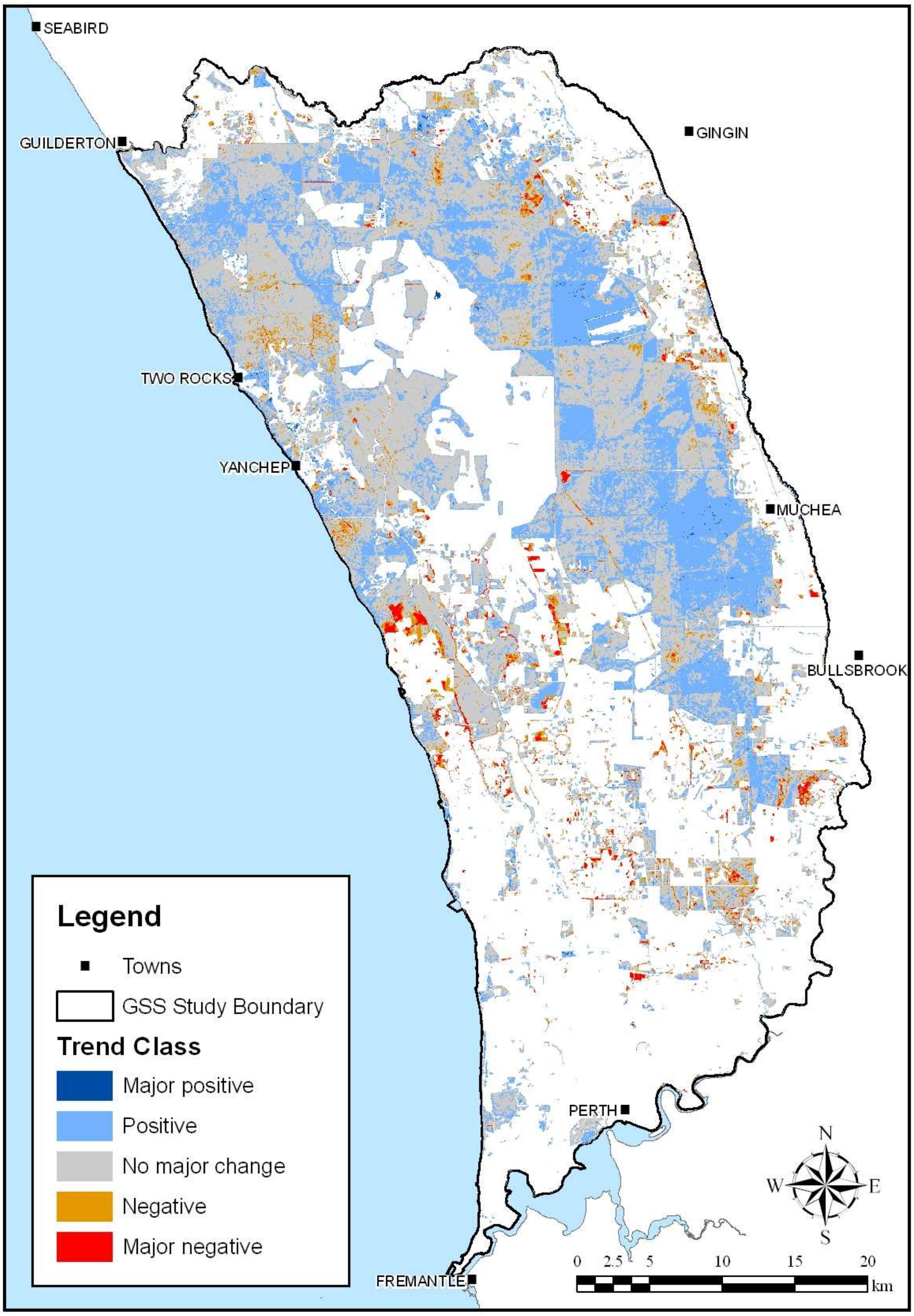


Figure 10: Landsat linear trend classes for 1973 – 2008 for the 2005 extent of remnant vegetation across the GSS study area. Codes on trend classes are major positive: large increasing trend in vegetation cover; positive: increasing trend in vegetation cover; no major change: no major change in vegetation cover; negative: decreasing trend in vegetation cover; major negative: large decreasing trend in vegetation cover.

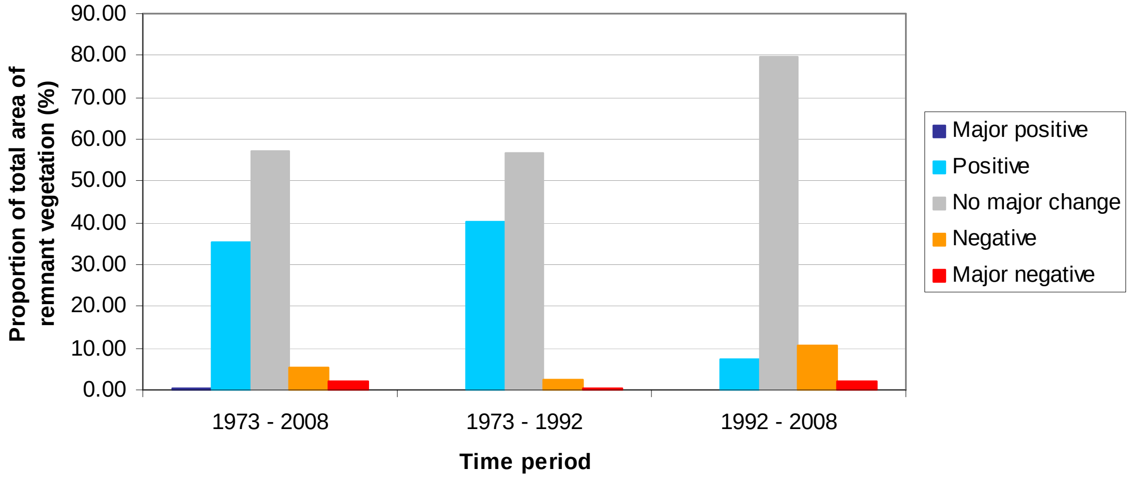


Figure 11: Proportion of total area of 2005 extent of remnant vegetation in each Linear trend class for three time periods 1973 – 2008; 1973 – 1992; 1992 – 2008.

Comparison of Linear Trends over three time periods

An assessment of Vegetation Cover Linear Trends for the period of 1973 to 1992 revealed that the breakdown of the remnant vegetation into each trend class was similar to the 1973 – 2008 long term trends (Figure 11). For the 1992 – 2008 period the breakdowns were different with the majority of remnant vegetation classed as having a ‘stable’ trend (80%) and a larger area (12%) classed as having a ‘negative’ trend in vegetation cover (Figure 11). Maps showing the distribution of Landsat linear trend classes over the GSS study area for the time periods 1973 – 1992 and 1992 – 2008 are provided in Appendix B and Appendix C.

Discussion

Vegetation cover dynamics

The examination of the PFC Cover Index values over the small scale study sites across 35 years has provided some insight into the magnitude of changes in vegetation cover on vegetation types I1 and H1, due to fire, regeneration of vegetation after fire, seasonal differences in rainfall and threatening processes such as grazing and *Phytophthora cinnamomi*. The greatest changes in PFC Cover Index values were related to fire, irrespective of vegetation condition class (Figure 4, Figure 5 and Figure 6). On un-disturbed sites there was a rapid increase in PFC Cover Index values 7 years post-fire (Figure 7a and b; Figure 8a and b; Figure 9a and b). Thereafter the PFC Cover Index values stabilised with small fluctuations related to variable seasonal conditions between years (Figure 4a and b; Figure 5a and b; Figure Figure 6a and b). On poor and variable condition sites the recovery in PFC Cover Index values was more haphazard (Figure 7c and d; Figure 8c to e) and at some sites there was no relationship between YSLB and PFC Cover Index values. If PFC Cover Index values did stabilise after a long period with no fire, the values were not as high as un-disturbed sites (Figure 4b and c; Figure 5c to f). The lower PFC Cover Index values at the poor and variable condition sites indicate that the vegetation structure has been altered resulting in lower vegetation cover and increased amounts of bare soil compared to un-disturbed sites.

It should be noted that the trajectory of vegetation cover in disturbed areas will not necessarily be towards lower vegetation cover. Many disturbed areas are susceptible to invasion by weeds which may lead to an increase in vegetation cover in certain areas of the landscape (Wallace *et al.* 2006). However, the use of late summer Landsat Imagery in this study somewhat minimises the impact of weeds on the PFC Cover Index. This is especially true for the annual weeds that primarily grow in winter, and therefore would be expected to be at their lowest levels of cover at the end of their life cycle at the end of summer. However, woody weeds (i.e. non-annual weeds) would still be detected as increased vegetation cover in late summer.

PFC Cover Index values were determined to be more variable across poor condition sites (higher standard deviation; Figure 4d and Figure 5f) compared to un-disturbed sites (lower standard deviation; Figure 4a and b; Figure 5a and b; Figure 6a to c). This higher variability could be reflecting the trend towards a more patchy distribution of the vegetation once a disturbing process has altered the vegetation structure. In the case of an area that has been impacted by *Phytophthora* dieback the increasing patchiness of the vegetation could also be related to the variation in cover as vegetation susceptible to *Phytophthora* dieback collapse and die and the later the colonisation of resistant vegetation. The disease will also move at varying rates up or down slope which potentially could also increase patchiness. Weed cover could also be higher in different habitats within a landscape, such as low lying areas where water, nutrients and seed accumulates and productivity is higher.

Monitoring vegetation condition using remote sensing tools

The distinct characteristics of the vegetation cover dynamics of each of the vegetation condition states assessed suggests that remote sensing tools could be used to assist in the monitoring of vegetation condition on the *Banksia* woodlands of the Gnangara Mound. Two possible surrogate measures of vegetation condition are:

1. PFC Cover Index with thresholds applied to discriminate between un–disturbed and poor condition areas
2. Variability (standard deviation) of PFC Cover Index values over a defined area.

It should be noted that currently there is limited understanding of the vegetation cover dynamics of *Banksia* woodlands and how multiple threatening processes, which are present on the Gnangara Mound, and regenerative processes translate to changes into PFC Cover Index values. Therefore, at this stage no vegetation condition rating should be applied to an area based on information from the PFC Cover Index and Variability measures alone. Rather these surrogate measures should be used to identify priority areas for on-ground assessment of vegetation condition or be used as part of the on-going monitoring of an area once an on-ground assessment has been completed. Further investigations are needed to determine if the above surrogates can discriminate areas of different vegetation condition on the full range of vegetation types found on the *Banksia* woodland types on the Gnangara Mound. One limitation related to these proposed surrogate measures is that run-on/wetland vegetation types were not included in this study. Additional limitations are discussed below alongside suggestions for potential information products.

This study showed that in the *Banksia* woodlands that the Landsat Linear Vegetation Cover Trends have limited ability to discriminate between poor condition and un-disturbed sites and therefore should not be considered as surrogate measures of vegetation condition (Table 2). The role that Linear Vegetation Cover Trends can play in vegetation monitoring is discussed in more detail below.

PFC cover index condition thresholds (proposed tool)

Distinct differences in PFC Cover Index values between un-disturbed, variable and poor condition sites, on the I1 and H1 vegetation types, were detected only once an area had recovered from a burn and its vegetation cover had stabilised. Therefore the assessment of vegetation condition using this approach may not be appropriate for image dates that are within 7 years of a fire. An initial classification of an area into just burnt, recovering or long un-burnt would therefore be required to determine whether an appropriate Landsat image date can be used to undertake the assessment. If the latest available Landsat date is not used this should be noted in any information product along with a rating of the confidence of the assessment (i.e. if the image dates is greater than 5 years old the condition assessment would be rated as lower confidence).

It would be preferable if the thresholds to discriminate un-disturbed and poor condition areas were determined using ground validated vegetation condition information rather than the desktop approach used in this study. Ideally repeat ground observations of vegetation cover and Projected Foliage Cover (Behn *et al.* 2009) in summer should be undertaken across a number of sites for each vegetation type in the Gnangara Mound to:

1. further refine the regression used to develop the calibrated PFC Cover Index (Behn *et al.* 2009).
2. provide validation of vegetation condition class and PFC Cover Index thresholds for the I1, H1 and G2 vegetation types. Thresholds will change if the regression used to calculate calibrated PFC Cover Index is updated.
3. provide on-ground information to help identify thresholds for other vegetation types or validate whether the thresholds for I1, H1 and G2 are applicable to a wider range of *Banksia* woodland vegetation types.

In the absence of on-ground validated data the following thresholds could be used to classify vegetation in the I1, H1 and G2 vegetation types:

- Un-disturbed - PFC Cover Index values between 17 and 25.
- Poor condition – PFC Cover Index values between 10 and 16.

Stabilised PFC Cover Index values for sites with variable condition (PFC Cover Index of 12 to 22) overlap the un-disturbed and poor condition thresholds. Further investigations including the collection of on-ground data will need to be undertaken to determine if thresholds can be identified.

Variability of PFC cover index values (proposed tool)

Poor condition sites were characterised by having higher standard deviation of the PFC Cover Index values, over the 2.25 ha study area, on all Landsat image dates. A ’variability’ surface could be calculated for each Landsat image date based on the standard deviation of PFC Cover Index values over pixel values using a moving window. The calculation of the ‘variability’ surface would need to be done within vegetation types (stratification of imagery into vegetation types would be required). This will ensure that the variability in vegetation cover being detected is related to impacts of threatening processes or seasonal conditions rather than related to inherent differences in vegetation structure and cover between vegetation types. The size of the moving window (number of pixels used) would be dependent on the size of mapped areas for each vegetation type. If thin strips of remnant vegetation are present then the size of the moving window would need to be quite small (e.g. 3 x 3 pixels).

An example of such a ‘variability’ surface is presented in Figure 12c. In this location areas of low standard deviation are on Unallocated Crown Land, which is not infested with *Phytophthora* dieback and likely to never have been grazed (Figure 12a and c). A pocket of high standard deviation is located on Freehold land, which is likely to have been grazed (and a likely reason why it is categorised as uninterpretable in *Phytophthora* dieback interpretation mapping).

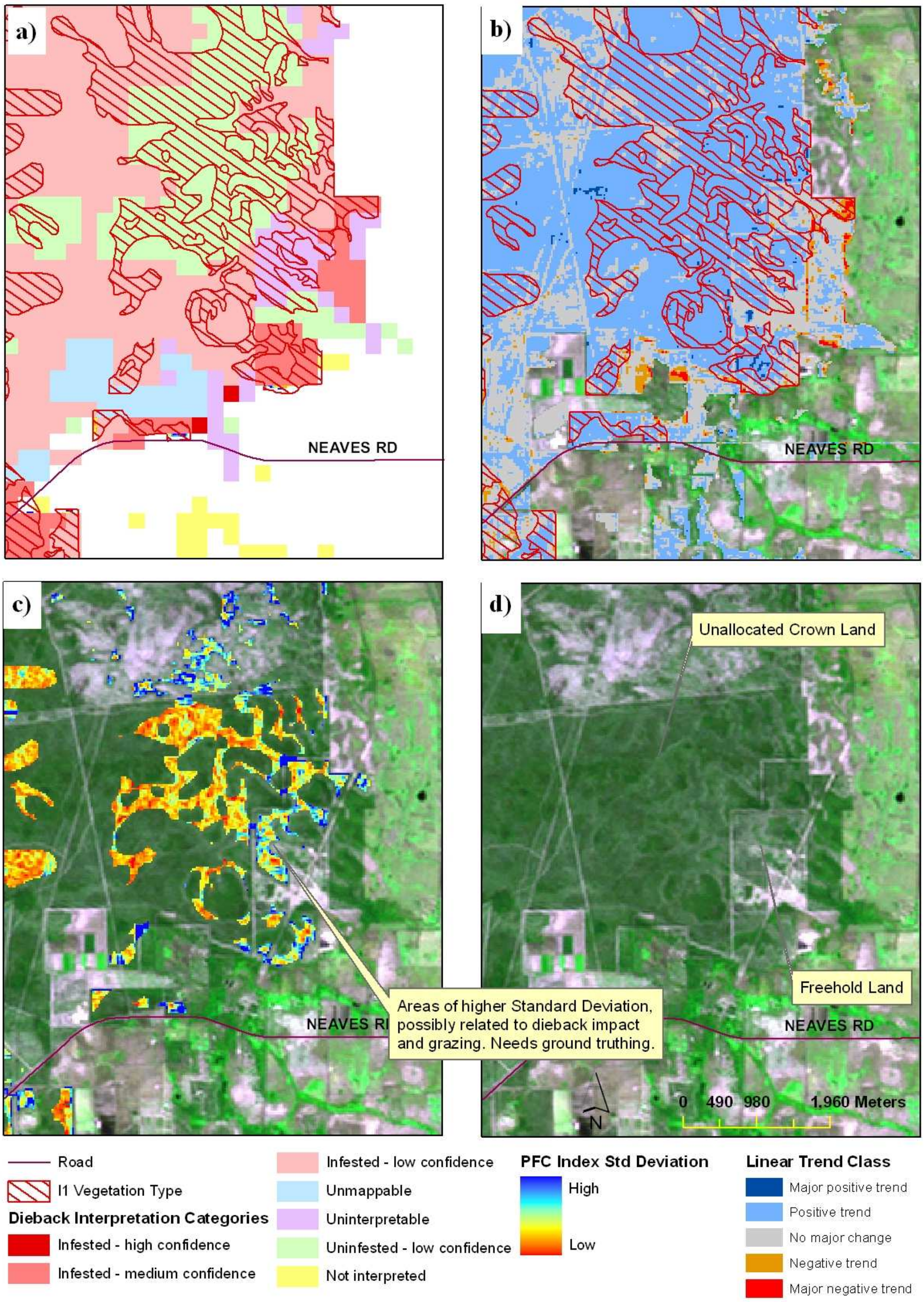


Figure 12: Example 'variability' surface for vegetation type I1 on areas of unallocated crown land and freehold land just north of Neaves Rd. (a) *Phytophthora* dieback interpretation categories; (b) Landsat linear trend class; (c) variability surface (standard deviation over a 3 x 3 moving window) for vegetation type I1; (d) 2008 Landsat imagery.

Vegetation Cover Linear Trends (current tool)

The comparison of Vegetation Cover Linear Trends over three time periods across the Gnangara Mound has revealed that this type of analysis can provide a general picture of the broad levels of vegetation cover gain and loss at a regional scale. However, for the Gnangara Mound, where there are multiple threatening processes impacting on vegetation cover, it is impossible at the regional scale to detect a clear signal of how these threats or any management interventions may be impacting on vegetation cover. The difficulty in pinpointing these clear signals is revealed in the 1992 – 2008 Trend analysis. The increased amount of remnant vegetation in the ‘stable’ and ‘negative’ trend classes in 1992 – 2008 could be related to decreased rainfall over this period (Figure 2 and Figure 11). The clearing of remnant vegetation along the coastal corridor would also be contributing to negative trend class for this time period (Appendix C) as would an increase in fire frequency (prescribed burn fire frequency increased from 2002 onwards (P. Brown pers. comm.)).

Trends analysis is also very dependent on the level of vegetation cover at the first image date used in the time sequence. Optimally a date should be chosen when vegetation cover is high. At the regional scale, where each year there is a mosaic of low and high vegetation cover areas due to fires, identifying one date where cover is high on all areas is not possible.

Therefore it is suggested that Landsat Vegetation Cover Linear Trends analysis is not suitable for a regional level assessment of vegetation cover. Rather this type of analysis should be undertaken at smaller scales, such as within the boundaries of a Conservation Reserve or National Park. By working at this smaller scale outcomes of the Landsat Linear Trends analysis can be related to information (either spatial or anecdotal) on known impact areas from threatening processes or management interventions. Choosing an appropriate image date to start the Trend time sequence will also be more workable over a smaller scale area where at least variability in seasonal conditions will be minimised and the fire history is more likely to be well known. Dates over which to run the Trends analysis could also be matched to management interventions (e.g. changing fire regimes or phosphite and weed control). There is also scope to tie Landsat Linear Trends analysis into the monitoring of vegetation condition over small scale areas. If the boundaries of poor condition areas are known over the Conservation Reserve or National Park, then information on the extent of poor condition areas in the ‘positive’, ‘negative’ or ‘stable’ trends class could be incorporated into a monitoring program. This would allow at least vegetation cover to be monitored on an annual basis and the effectiveness of management interventions to be gauged on more regular basis than is possible with intensive ground based methods.

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Appendices

Appendix A: Small scale study sites: fire history and Landsat Linear Trend class summary information

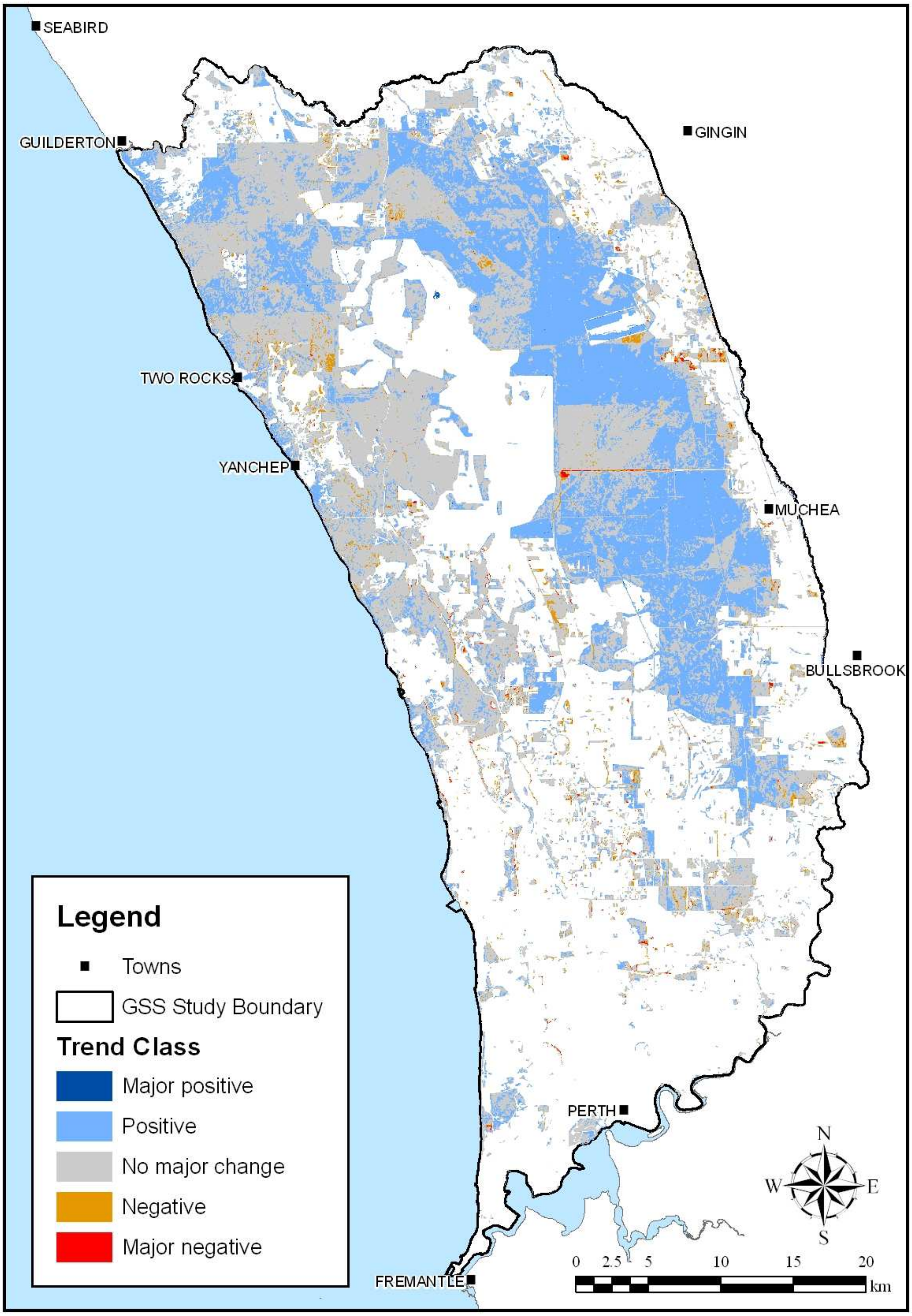
Small Scale Study Sites		Vegetation Type	Condition Class	Dieback Interpretation Category	Fire History				Maximum cover 1973 - 2008	Linear Trend Class
Site Name	ID				Verified YSLB	# of burns 1977 - 2008	1973 burn status	Maximum length of time with no burn		
New Conservation Park (Pinjar)	8	H1	Un-disturbed	Infested (LC)	2	3	not recent - high cover	17	23	no major change (minor positive)
New Conservation Park (Pinjar)	6	H1	Un-disturbed	Uninfested (MC)	5	2	recent burn but recovery evident	>19	23	no major change (minor positive)
New Conservation Park (Pinjar)	9	H1	Un-disturbed	Uninfested (MC)	5	2	recent burn but recovery evident	>19	23	no major change (minor negative)
New Conservation Park (Pinjar)	11	H1	Un-disturbed	Uninfested (LC)	4	2	just burnt	25	26	no major change (minor negative)
New Conservation Park (Pinjar)	7	H1	Un-disturbed	Infested (LC)	17	2	just burnt	16	24	positive
New Conservation Park (Pinjar)	10	I1	Un-disturbed	Uninfested (LC)	2	3	not recent - high cover	17	26	positive/no major change)
New Conservation Park (Pinjar)	13	I1	Un-disturbed	Uninfested (MC)	5	2	recent burn but recovery evident	>19	23	no major change (minor positive)
New Conservation Park (Pinjar)	14	I1	Un-disturbed	Uninfested (MC)	5	2	recent burn but recovery evident	>19	25	no major change (minor negative)
New Conservation Park (Pinjar)	12	I1	Un-disturbed	Uninfested (LC)	4	2	just burnt	~26	25	no major change (minor positive)
New Conservation Park (Pinjar)	15	I1	Un-disturbed	Uninfested (LC)	17	1	just burnt	~19	24	positive
Caraban UCL/State Forest	16	G2	Un-disturbed	Uninfested (MC)	5	2	recent burn but recovery evident	15	23	no major change/positive
Caraban UCL/State Forest	17	G2	Un-disturbed	Uninfested (LC)	5	4	not recent - high cover	7	22	no major change
Caraban UCL/State Forest	18	G2	Un-disturbed	Uninfested (LC)	22	1	recent burn but recovery evident	22	23	positive
Yanchep Plantation Remnant	24	G2	Un-disturbed	Uninfested (LC)/unmappable	9	2	not recent - high cover	18	24	positive/no major change
Yanchep Plantation Remnant	25	G2	Un-disturbed	Uninfested (LC)	9	2	not recent - high cover	18	24	no major change (minor positive)
Yanchep Plantation	26	G2	Un-disturbed	Uninfested (LC)	9	2	not recent - high cover	18	23	positive/no major change

Small Scale Study Sites		Vegetation Type	Condition Class	Dieback Interpretation Category	Fire History				Maximum cover 1973 - 2008	Linear Trend Class
Site Name	ID				Verified YSLB	# of burns 1977 - 2008	1973 burn status	Maximum length of time with no burn		
Remnant										
Yeal NR - East	27	G2	Un-disturbed	Uninfested (LC)	0	1	not recent - high cover	> 35	19	no major change (minor positive)
Yeal NR - East	28	G2	Un-disturbed	Uninfested (LC)/uninterpretable	6	1	fire scar evident - hard to determine how recent	> 30	20	negative/major negative (minor no major change)
Yeal NR - East	29	G2	Un-disturbed	Uninfested (LC)	0	1	fire scar evident - hard to determine how recent	> 35	20	no major change/positive
Yeal NR - South (NW of Gingin Airfield)	31	I1	Un-disturbed	Uninfested (LC)	1	3	just burnt	16	20	positive/no major change
Yeal NR - South (NW of Gingin Airfield)	32	I1	Un-disturbed	Uninfested (LC)	3	1	just burnt	~33	24	no major change
Yeal NR - South (NW of Gingin Airfield)	30	I1	Un-disturbed	Uninfested (LC)	27	1	just burnt	27	24	positive
Yeal NR - West	34	H1	Un-disturbed	Uninfested (LC)	2	2	recent burn but recovery evident or low intensity burn if very recent	20	21	no major change/positive
Yeal NR - West	37	H1	Un-disturbed	Uninfested (LC)	2	2	recent burn but recovery evident or low intensity burn if very recent	20	19	no major change (minor positive)
Yeal NR - West	33	H1	Un-disturbed	Uninfested (LC)	23	1	recent burn but recovery evident or low intensity burn if very recent	22	23	positive (minor major positive)
Yeal NR - West	38	H1	Un-disturbed	Uninfested (LC)	23	1	recent burn but recovery evident or low intensity burn if very recent	22	23	positive
Yeal NR - West	35	H1	Un-disturbed	Uninfested (LC)	36	0	recent burn but recovery evident or low intensity burn if very recent	~36	23	positive
Yeal NR - West	36	H1	Un-disturbed	Uninfested (LC)	36	0	recent burn but recovery evident or low intensity burn if very recent	~36	24	positive
Melaleuca Park NR (proposed)	3	I1	Variable	Uninfested (LC)	>36	0	fire scar present but not recent burn	>36	22	positive/no major change
Melaleuca Park NR (proposed)	4	I1	Variable	Uninfested (LC)	3	3	fire scar present but not recent burn	11	21	no major change/negative
Melaleuca Park NR (proposed)	5	I1	Variable	Infested (LC)	13	2	just burnt	13	18	positive
Melaleuca Park NR (proposed)	1	I1	Variable	Infested (LC)	23	1	fire scar present but not recent burn	22	20	positive (minor no major change)
Melaleuca Park NR (proposed)	2	I1	Variable	Infested (LC)	26	2	fire scar present but not recent burn	26	20	positive (minor no major change)
Maralla Road NR	39	I1	Variable	Uninfested (HC)	8	1	low cover but not neccesarily due to fire	>27	20	negative/major negative (minor no major change)
Maralla Road NR	40	I1	Variable	Infested (MC) (minor uninfested (LC))	> 36	0	low cover but not neccesarily due to fire	>36	21	no major change/negative (minor positive)
Maralla Road NR	41	I1	Variable	Uninfested (LC)	> 36	0	low cover but not neccesarily due to	>36	21	positive (minor no major change)

Small Scale Study Sites		Vegetation Type	Condition Class	Dieback Interpretation Category	Fire History				Maximum cover 1973 - 2008	Linear Trend Class
Site Name	ID				Verified YSLB	# of burns 1977 - 2008	1973 burn status	Maximum length of time with no burn		
							fire			
Yeal NR - South (N of Gingin Airfield)	42	I1	Variable	Infested (MC)	26	1	recent burn	26	17	positive/no major change (minor negative)
Yeal NR - South (N of Gingin Airfield)	43	H1	Variable	Infested (MC)	8	2	recent burn	18	19	no major change (minor negative)
Yeal NR - North	44	H1	Variable	Infested (HC)	7	2	fire scar present but not recently burnt	8	19	negative (minor major negative)
Yeal NR - North	45	H1	Variable	Infested (MC)	16	2	fire scar present but not recently burnt	16	19	positive/no major change
Yeal NR - North	46	H1	Variable	Infested (MC)	16	2	fire scar present but not recently burnt	16	22	no major change
Yeal NR - North	47	I1	Variable	Infested (HC)	16	1	fire scar evident - hard to determine how recent	16	21	no major change (minor negative and positive)
Yeal NR - North	48	I1	Variable	Infested (MC)	16	2	fire scar present but not recently burnt	16	21	Trend information not available for majority of site
Yeal NR - North	49	I1	Variable	Infested (MC) (minor uninfested (LC))	7	2	just burnt	8	22	negative (minor no major change)
Whiteman Park	20	H1	Poor Condition	Uninfested (HC) (Nearby infested areas)	20	2	not recent - high cover	19	16	no major change (minor negative and positive)
Whiteman Park	22	H1	Poor Condition	Uninfested (HC) (Nearby infested areas)	6	2	fire scar hard to determine how recent	14	15	no major change/negative
Whiteman Park	21	I1	Poor Condition	Uninfested (HC) (Nearby infested areas)	20	2	fire scar hard to determine how recent	20	19	no major change/positive
Whiteman Park	23	I1	Poor Condition	Uninfested (HC) (Nearby infested areas)	28	1	fire scar hard to determine how recent	28	18	no major change/positive
Whiteman Park	19	I1	Poor Condition	Uninfested (HC) (Nearby infested areas)	6	3	not recent - high cover	14	17	negative/major negative/no major change

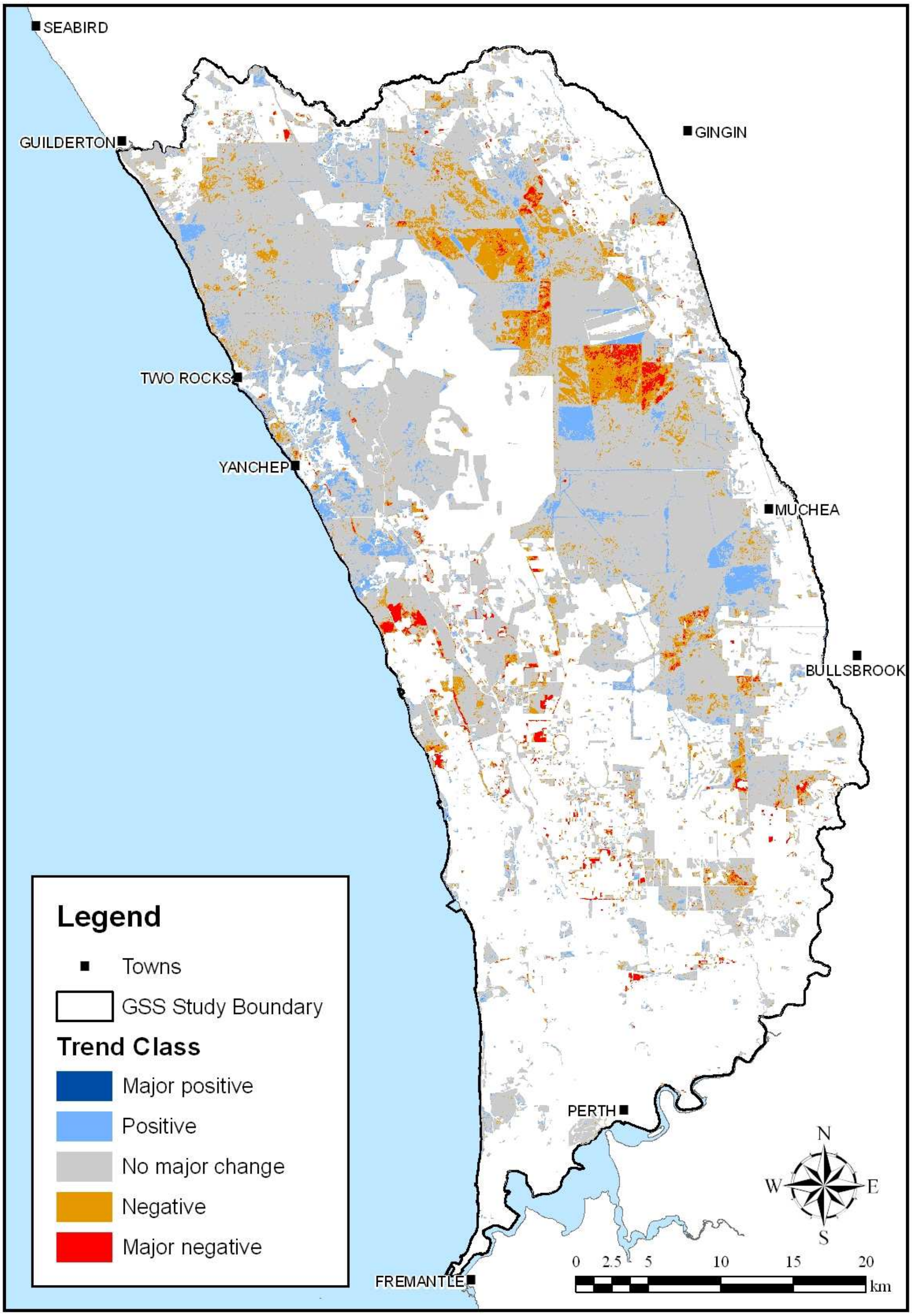
Appendix B: Landsat Linear Trend classes 1973 – 1992

See Figure 10 for details of trend class codes.



Appendix C: Landsat Linear Trend classes 1992 – 2008

See Figure 10 for details of trend class codes



Appendix D: Location information of small scale study sites

Site Name	ID	Location (UTM coordinate in GDA 94 MGA zone 50) of Centre Point of Sites	
		Easting	Northing
Melaleuca Park NR (proposed)	3	397086	6494128
Melaleuca Park NR (proposed)	4	395291	6494575
Melaleuca Park NR (proposed)	5	396115	6493896
Melaleuca Park NR (proposed)	1	397968	6494409
Melaleuca Park NR (proposed)	2	398514	6494414
New Conservation Park (Pinjar)	8	388478	6509560
New Conservation Park (Pinjar)	6	390351	6511571
New Conservation Park (Pinjar)	9	390356	6512238
New Conservation Park (Pinjar)	11	388990	6513162
New Conservation Park (Pinjar)	7	389896	6510627
New Conservation Park (Pinjar)	10	387924	6509676
New Conservation Park (Pinjar)	13	390229	6513667
New Conservation Park (Pinjar)	14	391433	6514057
New Conservation Park (Pinjar)	12	388119	6513930
New Conservation Park (Pinjar)	15	389529	6510938
Caraban UCL/StateForest	16	374208	6527514
Caraban UCL/StateForest	17	374845	6527055
Caraban UCL/StateForest	18	374716	6528782
Whiteman Park	20	400665	6480129
Whiteman Park	22	400260	6479656
Whiteman Park	21	399441	6478895
Whiteman Park	23	395994	6479322
Whiteman Park	19	399761	6480320
Yanchep Plantation Remnant	24	375565	6521717
Yanchep Plantation Remnant	25	376492	6521969
Yanchep Plantation Remnant	26	376607	6522406
Yeal NR - East	27	386821	6524031
Yeal NR - East	28	385702	6526069
Yeal NR - East	29	386573	6524945
Yeal NR - South (NW of Gingin Airfield)	31	388795	6521550
Yeal NR - South (NW of Gingin Airfield)	32	386748	6518826
Yeal NR - South (NW of Gingin Airfield)	30	388606	6521046
Yeal NR - West	34	380683	6524772
Yeal NR - West	37	381410	6524623
Yeal NR - West	33	380867	6525133
Yeal NR - West	38	380443	6525084
Yeal NR - West	35	381761	6525090
Yeal NR - West	36	381435	6525283
Maralla Road NR	39	403094	6487026
Maralla Road NR	40	403629	6487585
Maralla Road NR	41	403019	6487590
Yeal NR - South (N of Gingin Airfield)	42	390912	6520204
Yeal NR - South (N of Gingin Airfield)	43	392325	6521163
Yeal NR - North	44	385972	6528498
Yeal NR - North	45	385067	6528920
Yeal NR - North	46	384379	6528680
Yeal NR - North	47	382921	6527634
Yeal NR - North	48	384007	6529255
Yeal NR - North	49	385641	6527829