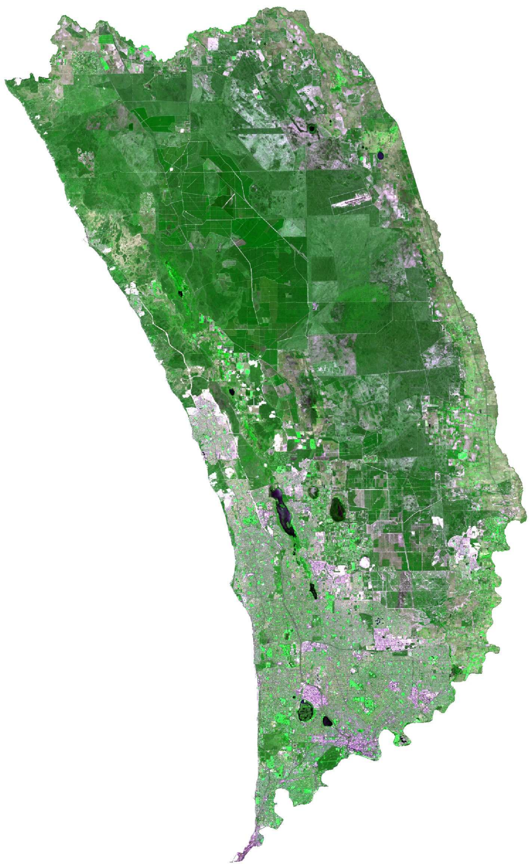
Gnangara Sustainability Strategy

An across-government initiative

Groundwater – Biodiversity – Land use

DEVELOPMENT OF REMOTELY SENSED VEGETATION COVER INDEX AND VEGETATION COVER TRENDS ANALYSIS



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GOVERNMENT OF WESTERN AUSTRALIA

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Development of Remotely Sensed Vegetation Cover Index and Vegetation Cover Trends Analysis

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

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This document has been commissioned/produced as part of the Gnangara Sustainability Strategy (GSS). The GSS is a State Government initiative which aims to provide a framework for a whole of government approach to address land use and water planning issues associated with the Gnangara groundwater system. For more information go to www.gnangara.water.wa.gov.au

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Department of Water
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Introduction

The Gnangara Sustainability Study (GSS), which includes representatives from the Department of Environment and Conservation, Department of Water and CSIRO, was established by the Western Australian Minister for the Environment in 2006. A major aim of the GSS is to address threats to the regional conservation values.

Changes to vegetation as a result of a drying hydrological regime are not fully understood. Previous research has shown that there can be a loss of cover of overstorey and understorey species as a result of groundwater drawdown (Groom *et al.* 2000 and Horwitz *et al.* 2009a) and vegetation composition can also be changed with the potential for terrestrialisation to occur as more xeric species colonise (Froend *et al.* 2004 and Horwitz *et al.* 2009b). Further research is required to gain a better understanding of how declining rainfall and aquifer levels affect vegetation cover and composition and this is being undertaken through other GSS projects. An initial difficulty facing the research was the lack of comprehensive data of the extent of such vegetation changes.

Any form of vegetation monitoring requires measurements to be repeatable, consistent and reliable. The spatial, spectral and temporal resolutions of the Landsat series of satellites are at relevant scales, for accurate on-ground measurements, and are well placed to provide updated information for land managers.

Information on vegetation health, condition and change are of significance for scientists and land managers. Satellite imagery, primarily due to its synoptic views of landscapes and multi-temporal sensing, is suited for monitoring this vegetation information. One of the benefits of continued collection of satellite imagery, by programs like Landsat, is the ability to study changes in landscapes over time, with changes in vegetation cover being among the most common features sort. Skidmore (2002) states, the historical archive of satellite imagery for studying landscape change continues to grow and its duration now covers almost a third of a century. It is unmatched in quality, detail, coverage and importance. The dramatic increase in studies using this archive of historical satellite imagery indicates the growing value of imagery and points to a future where remote sensing data will play a key role in our understanding of how landscapes are changing and how humans are influencing the health of vegetation.

This archive of imagery is a valuable tool for scientists and researchers as they work to gain a better understanding of complexity of our environmental systems. Long-term monitoring information is critical for maintaining the health and safety of our communities, our economy and our environment.

This paper reports on the methods used in the development of a vegetation cover index, to accurately estimate the variation in vegetation cover across the GSS study area, and on the methods used in Vegetation Trend Analysis. A subsequent Technical Report explores in more detail how Remote Sensing Tools can be used to monitor vegetation condition in the Banksia Woodlands of the Gnangara Mound (Kinloch *et al.* 2009).

Background

Over the last decade a number of Landsat-based remote-sensing monitoring programs have been implemented in Australia. These include the Queensland's Statewide Landover and Trees Study (SLATS), the National Carbon Accounting System Land Cover Change Project of the Australian Greenhouse Office and Land Monitor, a multi-agency project producing information products for land management in Western Australia. Land Monitor has mapped and monitored changes in salt-affected land and woody vegetation in the south-west agricultural region since 1988. The method uses long-term sequences of Landsat Thematic Mapper (Landsat TM) and Landsat Multispectral Scanner (Landsat MSS) imagery to provide observations relating to land use and vegetation trends.

The Western Australian Land Monitor Project produces two types of vegetation change products:

- the extent of area of perennial or woody vegetation cover and its change through time, and
- vegetation cover trends over time, which summarizes changes in reflectance of vegetation cover over time (Furby *et al*. 2008).

A methodology developed by staff based at the Remote Sensing and Image Integration Group (CSIRO), located in the Leeuwin Centre for Earth Sensing Technologies in Perth uses multispectral Landsat TM imagery to detect changes in vegetation cover over time (Wallace *et. al*, 1999). The method is called 'Vegetation Trends Analysis'. It uses a 'Vegetation Index', which has been shown to relate to vegetation cover, to estimate vegetation cover variations. 'Vegetation Trends Analysis' has the capacity to detect not just changes in woody vegetation cover, but to also identify areas of woody vegetation where there is a permanent or long-term decrease in vegetation cover.

The open woodlands of Gnangara Groundwater System are of significant importance within the region. Knowledge of changes in its condition is required of public agencies and private landholders charged with the management the natural environment. Currently information on the condition of vegetation and where changes have occurred is only available for a small area of the Gnangara Groundwater System and is from one off vegetation assessment programs or from anecdotal knowledge. The need to locate and identify where vegetation change is occurring has been identified as a priority so remnant vegetation can be more effectively managed.

Satellite remote sensing technologies are an appropriate means of monitoring the vegetation cover dynamics (Pickup *et al* 1993 and Furby *et al* 2004) as it can provide an 'historical look' at vegetation cover trends. Landsat data provides the areal capability plus has the spectral sensitivity to accurately discriminate different levels of vegetation cover.

The historical sequences of satellite imagery now provide a means of monitoring the vegetation cover dynamics and offer an alternative to that of traditional one-off static approach to mapping. Ground based methods are not well suited to estimate the areal extent of vegetation cover and variations, and along with aerial photography are labour intensive, time consuming and expensive. The potential to use remote sensing methods in monitoring lies in being able to discriminate vegetation cover classes using an vegetation index, applying this index to sequential image dates and then developing methods to compare levels of vegetation cover between image dates in order to determine areas of vegetation cover change.

Imagery

Satellite

The satellite imagery data from the two Landsat series of satellites Multispectral Scanner (MSS -1973-1992) and Thematic Mapper (TM and ETM+ 1988-ongoing), provide routine broad-scale coverage and have been shown to be ideal for mapping and monitoring vegetation (Furby 2004). The moderate level spatial resolution of the data (50m pixel size for MSS imagery and 25m pixel size for TM imagery) cannot distinguish the crowns of individual trees but is of a high enough resolution to be able to detect broad changes in vegetation cover.

Landsat MSS imagery has four spectral bands – bands one and two in the visible green and red portion of the spectrum and bands three and four in the near infrared, while Thematic Mapper (TM and ETM+) imagery has seven bands - bands one, two and three in the visible parts of the spectrum, band four in the near infrared and bands five and seven in the short-wave infrared portions of the spectrum (Lillesand & Kiefer 1987; USGS http://edc.usgs.gov/products/satellite.html)

The imagery is owned by DEC and Australian Greenhouse Office (AGO) within the Australian Department of Climate Change. The dates of the imagery range from 14/12/73 to 17/01/08 (Table 1). The imagery is obtained where possible in the summer dry season. This time of year provides the best opportunity to separate perennial woody vegetation from other land cover types. For ease of processing and registration the Landsat MSS imagery was re-sampled to 25m pixels, corresponding with the Landsat TM.

Table 1: Dates of Satellite imagery used. Major scene date refers to the Landsat scene that covers the majority of the GSS area.

Epoch	Scene Date		Landsat Sensor	Pixel Size (m)
	Major	Minor		
1973	14/12/1973	NA	MSS	50 (resampled to 25)
1977	19/11/1976	NA	MSS	50 (resampled to 25)
1980	01/12/1979	NA	MSS	50 (resampled to 25)
1985	26/01/1985	14/11/1984	MSS	50 (resampled to 25)
1988	03/01/1988	26/01/1988	MSS	50 (resampled to 25)
1989	30/01/1990	NA	TM	25
1991	18/01/1991	27/01/1991	TM	25
1992	07/01/1993	NA	TM	25
1995	07/02/1995	28/12/1994	TM	25
1998	05/01/1998	NA	TM	25
2000	20/02/2000	NA	ETM+	25
2002	09/02/2002	NA	ETM+	25
2004	23/02/2004	NA	TM	25
2005	09/02/2005	NA	TM	25
2006	05/02/2006	12/02/2006	TM	25
2008	17/01/2008	NA	TM	25

Aerial Photos

Aerial photos were used to estimate crown cover, over selected 1 ha field sites, as part of the development of the vegetation cover index (see below for more information on sites). Scanned orthorectified aerial photography captured in the December 2007/January 2008 time period was used.

Development of Vegetation Index

The spectrum reflected by any pixel which represents areas of remnant vegetation is a combination of the relative spectral combinations from trees, understorey, other types of ground cover (such as litter) and exposed soil within the pixel. When the vegetation cover is not dense, as is the case in GSS study area, the background spectral reflection from soil can dominate the pixel characteristics. The analysis of remotely sensed data in such environments involves understanding the spectral responses and variation of the components, and developing techniques that explain these variations.

The crucial factor in producing vegetation spectral maps or enhancements is that the spectral separation of the dense vegetation cover from sparse to no vegetation cover is large compared to the vegetation variation within classes. If this can be established then mathematical combinations of the spectral bands can be used to derive vegetation indices which can discriminate between vegetation of different cover levels. These indices can be a very effective in measuring the amount of green vegetation cover over the soil (Lillesand & Kiefer 1987; Jensen 1996) and can be utilized to produce vegetation spectral maps or enhancements.

Two vegetation indices that have been used extensively in Australia to assess vegetation cover include:

- (TM Band 3 + TM Band 5)/2. This index utilises bands from both the visible red portion of the spectrum (TM Band 3) and short-wavelength infrared (TM band 5). See table 2 for details of projects and programs which have utilised this index;
- The single band index of TM Band 3 and MSS Band 2. Both bands are from the visible red portion of the spectrum. Previous research has shown that these single bands indices are highly correlated with vegetation cover (Pickup *et al.* 1993). Additional internal research by DEC (Zdunic 2009) has confirmed this relationship.

Table 2: Australian projects or programs which have utilised the vegetation index of (TM b3 + TM b5)/2

Project/Program	URL
AGO NCAS Landcover Change Program	www.greenhouse.gov.au/ncas/activities/landcover.html
Land Monitor Project	http://www.landmonitor.wa.gov.au/
Statewide Landcover & Trees Survey (SLATS)	http://www.nrm.qld.gov.au/slats/

The steps involved in developing a vegetation index, by calibrating a Landsat estimate of vegetation cover (hereafter referred to as a Spectral Image Index) with ground measurements, are outlined in Figure 1. The process applied follows that described in Behn *et al* (2001; 2003) and more detail of the methods used are provided in the sections below. The Spectral Image Index provides an estimate of the foliage projected cover (FPC) which is the projection on the ground of the extent of the vegetations foliage (Behn 2000). This is calibrated with field estimates of Projected Foliage Cover (PFC) which is the percentage of the field site occupied by the vertical projection of foliage and branches (derived from McDonald et al. 1990)

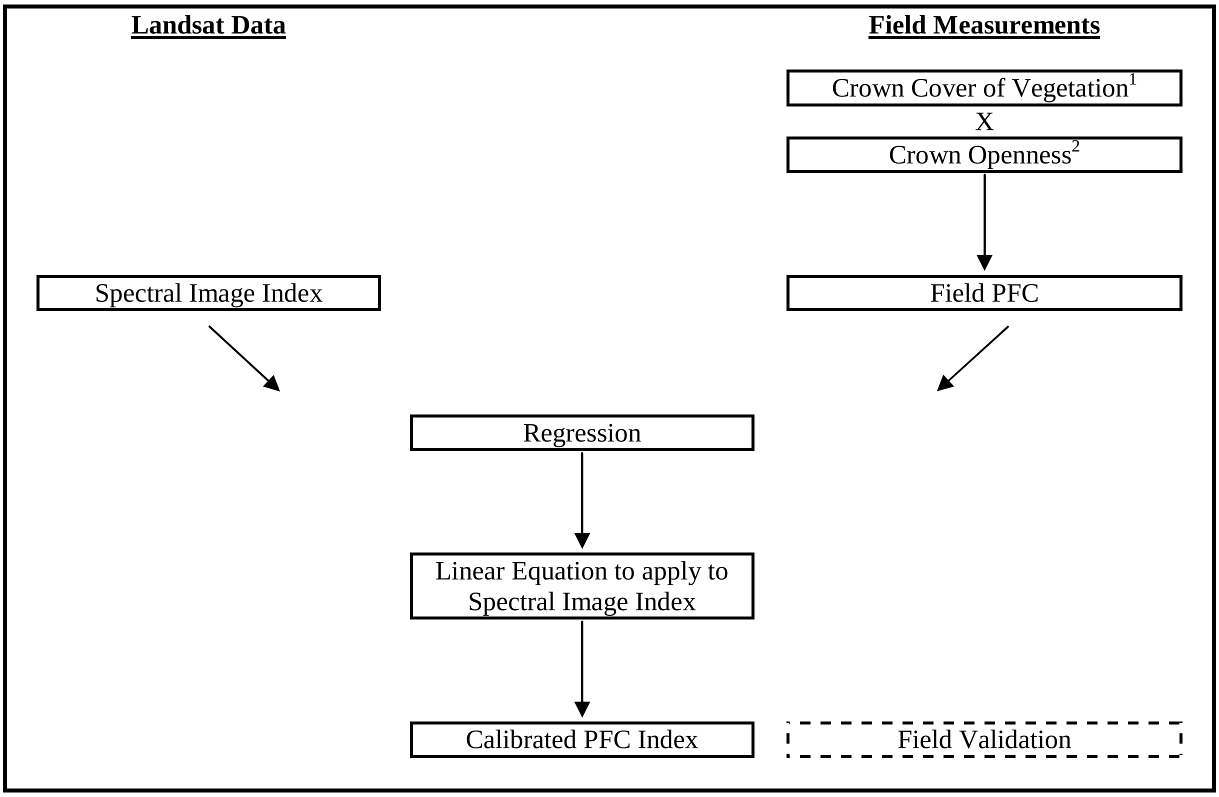

Figure 1: Diagram outlining the broad process of calibrating Landsat estimates of vegetation cover with ground measurements. Definitions of items in superscript are as follows:

[1]Measure of the ground area within the vertical projection of the periphery of the crown and assumes that tree crowns are opaque (taken from McDonald *et al.* 1990)

[2]Estimate of the openness of individual tree crowns (taken from McDonald *et al.* 1990)

Spectral Image Index

The GSS sought to evaluate changes in vegetation cover, on the Gnangara groundwater system, for the full time period of 1973 to 2008. This required data from both Landsat platforms to be utilised as pre 1989 only Landsat MSS data was available (Table 1). Therefore a Spectral Image Index using spectral Band 3, from Landsat TM, and Band 2, from Landsat MSS, was utilised.

The band 3 Spectral Image Index, captured on the 17/01/08, was used in the calibration as it was the closest date to the fieldwork data capture (July 2008). The image is displayed in shades of grey (Figure 2). Areas of white have little to no cover, while darker areas have the greatest vegetation cover. These variations are easily observable.

Figure 2: Band 3 of 2008 Landsat TM imagery.

Estimation of Field PFC

Using the aforementioned orthorectified aerial photography, 26 one hectare homogeneous sites with varying crown distributions and levels of vegetation cover were selected. Crown cover was visually estimated from the aerial photography, by experienced personnel, using templates devised by McDonald *et al.* (1990). Field estimates of crown openness, across the sites, were then recorded in the field by experienced ground personnel. This was done by standing under a tree crown and visually comparing the aerial cover of leaves within the crown outline with that in the photographic standards of 'crown type' provided in Australian Soil and Land Survey Field Handbook (McDonald *et al*. 1990). Three representative points within each one hectare site were assessed. These were then averaged to give a mean field estimate of crown openness for each one hectare site. Field projected foliage cover (PFC) for each of the 26 one hectare sites was then calculated as the product of crown cover and mean crown openness.

Calibrated PFC Index

The next stage was to convert the Spectral Image Index into a Calibrated PFC Index by establishing the relationship between it and the field measured PFC. Once established this relationship can be used with confidence to produce a PFC image for the entire project area.

The mean Spectral Image Index image values for each of the 26 one hectare field sites were extracted from the 2008 Landsat image. A linear equation was then derived from the regression of the Spectral Image Index and field measured PFC (PFC – F) estimate (Figure 3). The graph shows that there is some variation in the cover estimates for ground sites of similar vegetation cover (Figure 3). This variation can be related to a number of factors one of which is the significant difference in the non-vegetated cover classes (eg., bare soil, fallen tree litter). Despite the variation a strong relationship between the Spectral Image Index and PFC – F is evident ($R^2 = 0.6396$). The resultant linear regression equation is as follows:

$$\mathbf{-0.9262 \times Band3 + 44}$$

This index was then applied to the 2008 Spectral Image Index image to produce an image of Calibrated PFC for the entire GSS (see sample area in Figure 4). The image of calibrated PFC has a value range from 0 (low vegetation cover) to 33 (high vegetation cover).

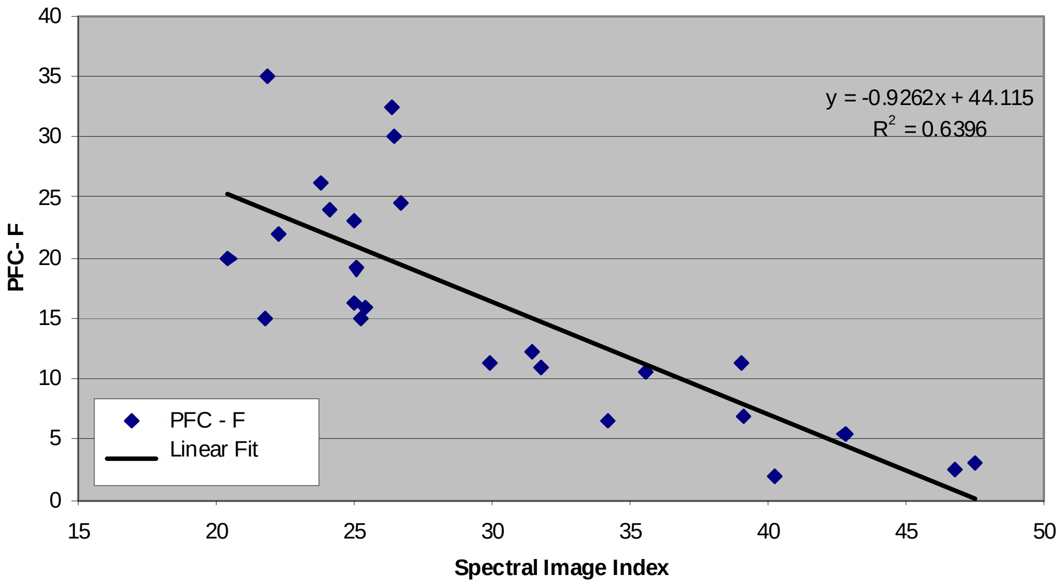

Figure 3: Mean values of the field Cover Estimates for each site were regressed against the estimated PFC values from the Band 3 image.

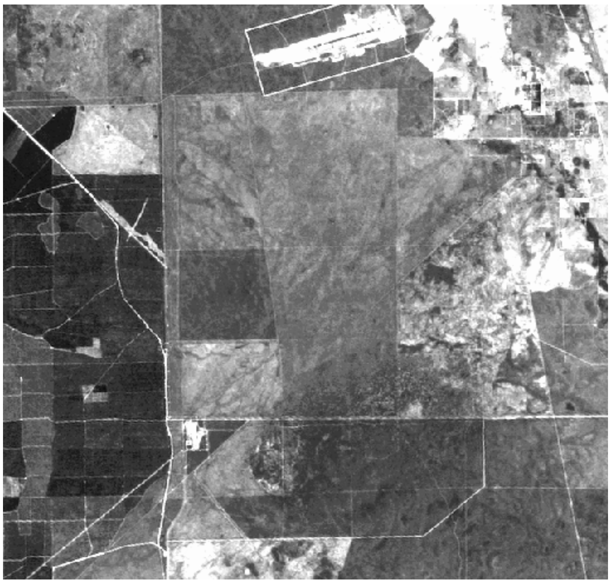

Figure 4: Image of projected foliage cover for 2008 for a portion of the GSS Study Area. Darker areas indicate high values of calibrated PFC while light areas have low values of calibrated PFC.

Field Validation of the Calibrated PFC Index

Field validation of the PFC image was undertaken in October 2008. Six validation locations were selected to represent each of the major vegetation types that occur on the Gnangara Mound. At each location two or more one hectare sites were selected to represent the range of crown cover levels at the location (crown cover was assessed using the methods stated above). A total of 14 sites were assessed.

Field visits were then undertaken where a visual estimate of total aerial vegetation cover (leaves and branches) was undertaken at two 5 m x 5 m quadrats. The mean calibrated PFC index values for each of the one hectare sites were extracted from the 2008 image and compared with mean field total aerial vegetation cover estimates (Figure 5). Generally there was good alignment between the field and PFC cover values (high field cover sites had higher PFC index values and vice versa). At a couple of the locations the magnitude of the difference between the sites in the PFC index was a lot greater compared to the field estimates of cover (sites 16 vs 17 and sites 23 & 26 vs 25). This can be attributed to seasonal differences as the field validation occurred after the winter rains so some sites which had relatively low cover in summer had a lot higher cover post winter. Field inspection also revealed that sites 21 and 22 had no cover. This loss of cover was a result of a fire after the capture of the Landsat data in February 2008.

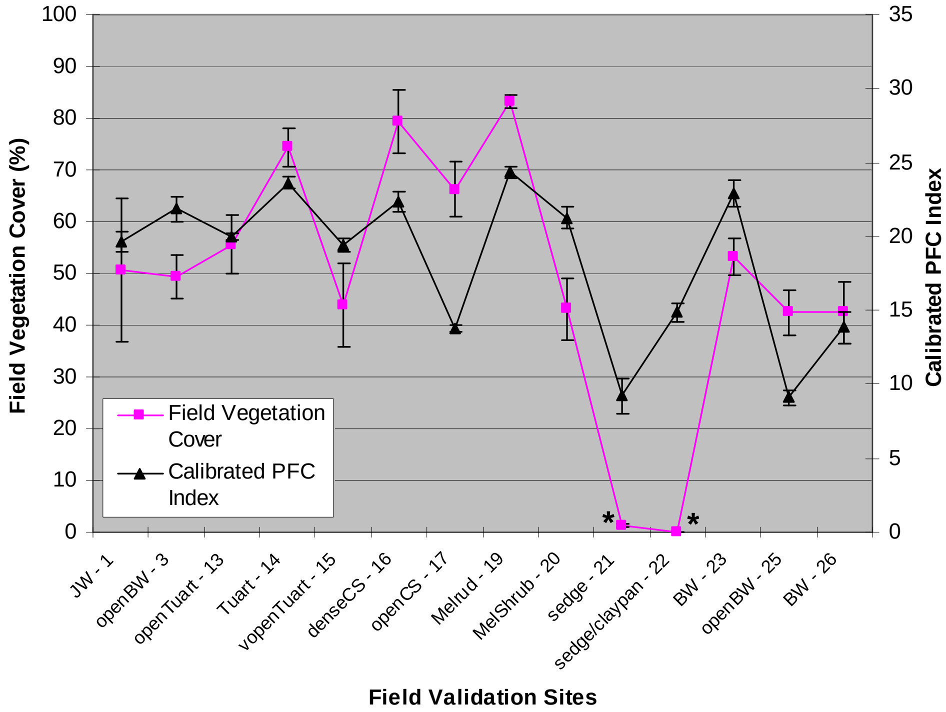

Figure 5: Mean field Total Aerial Vegetation Cover estimates and Calibrated PFC Index values for field validation sites. Vegetation Type codes are: JW = Jarrah Woodland, BW = Banksia Woodland, CS = Coastal Scrub, Sedge, Tuart, Melrud = Melaleuca rudis woodland, Melshrub = Melaleuca shrubland. Recently burnt sites are denoted with an astericks.

Applying Calibrated PFC Index to all Image Dates

Once the calibrated PFC Index was field-validated it was applied to all Landsat TM image dates. This direct application of the 2008 calibrated index to previous dates is possible as all image dates have been radiometrically calibrated so that numerical band values through time can be compared (Furby *et al.* 2008). Due to the sensor change from TM to MSS in 1988 the linear regression equation required calibration to the different sensor. This was achieved by comparing the 1989 TM image to a simulated version of the 1989 image as MSS and generating a regression that produced the same calibrated PFC values.

Vegetation Cover Trends

Vegetation Cover Trends provide summaries of the temporal change in vegetation cover for each pixel over time (Wallace *et al.* 2006). In a full Vegetation Cover Trends analysis six bands are produced each summarising vegetation cover change using different methods (Furby *et al.* 2008). One method which has been used extensively in the South West of WA is Linear Trends. In this method, regression analysis measures the slope of the vegetation cover response over time. A positive linear slope indicates increasing vegetation cover, a negative slope declining vegetation cover and no slope indicates stable vegetation cover. Quadratic Trends have also been used to assess changes in vegetation cover in the South West of WA. This method detects areas where vegetation cover has gone through a single cycle of decline and recovery such as after a single fire. Alternatively it can detect a single cycle of increasing then decreasing vegetation cover often associated with dry-wet-dry periods (Wallace & Thomas 1998). The Quadratic Trends method cannot detect multiple fluctuations in vegetation cover response.

In this study Linear Trends have been calculated from the calibrated PFC images so we can investigate the nature of any long term changes in vegetation cover for the full Landsat image archive (1973 – 2008). Annual average rainfall has declined over the Gnangara Groundwater System during this period so the Trends were also calculated for the years 1973 – 1992 (average rainfall similar to the long term average) and 1992 – 2008 (average rainfall below the long term average). It was deemed that the Quadratic Trend method was not suitable for this study as the length of the assessment period (minimum of 16 years and maximum of 36 years) meant that multiple fires could have occurred in some areas.

Calculation of Linear Trends

Vegetation Cover Trends are based on the careful processing of Landsat images for the years listed in Table 1. The methods used to calculate Linear Trends are detailed in Wallace *et al*.(1999) and Furby *et al*. (2008) and are summarised in the steps below.

1. Calibrated PFC images for each date in the sequence (described above) are compiled into a sequence file.
2. Scaled temporal summaries of the calibrated PFC index for 1973 – 2008, 1973 – 1992 and 1992 – 2008 time periods were then calculated. Linear components of the response (slope over time) were estimated independently using orthogonal

polynomials (Draper & Smith 1981). The following scaling and translation is applied for Linear Trends: **Lin coeff * (255/10) + 127.5** (scales slopes from –5 to +5 into the 0-255 range).

3. Areas that were classified as never having perennial vegetation cover were masked out
4. Linear 'Trendclass' classification images are produced by applying thresholds to the scaled linear trend image. Threshold values were based on those published in Furby *et al.* (2008).

Summary Image of Linear Trends

The Linear Trend data can be displayed as a single image to summarise vegetation cover over time, as measured by the index, and in particular to highlight areas with different patterns of change. Simple summaries of Linear Trends over the period can be made by displaying positive and/or negative linear trends in different colours. An example of such a summary is illustrated in Figure 6.

The classification of vegetation as having a positive, negative or stable trend is particularly sensitive to the level of vegetation cover in the image dates at the start and end of the assessment period. The example area in Figure 6 illustrates this. The 1992 Landsat image (Figure 6a) shows fire impact in the southern part of the image. In the linear trend image (Figure 6c) this area has a positive linear trend (displayed as blue) due to the recovery in vegetation cover in the subsequent years after the fire. The 2008 Landsat image (Figure 6b) shows fire impacts across the majority of the area except for parts of the south and north. These areas show a negative trend in the linear trend image (Figure 6c; displayed as red) as these area have shown a net loss of vegetation cover over the trend time period. Areas where vegetation cover levels were similar in 1992 and 2008 are dark in the trend image (Figure 6c). Vegetation cover may have fluctuated in the intervening years between 1992 and 2008 but at the start and finish of the time period the vegetation cover levels were similar.

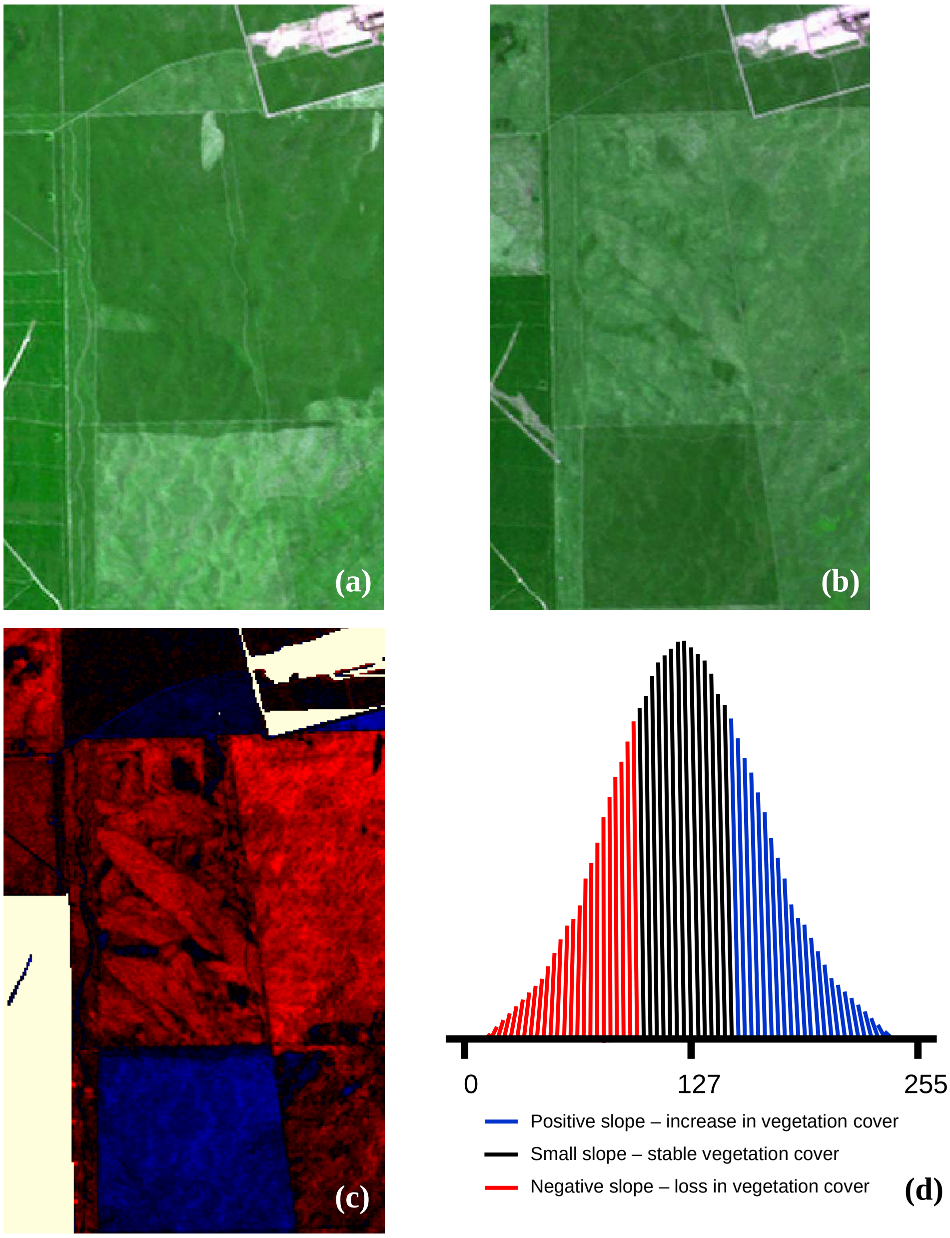

Figure 6: Satellite imagery and linear trends for remnant vegetation south west of the Gingin Airfield: (a) 1992 Landsat image bands 3,4,2 in red, green, blue; (b) 2008 Landsat image bands 3,4,2 in red, green, blue; (c) Linear Trend image 1992 to 2008 displaying negative linear trend in red, positive linear trend in blue and stable trends in black; (d) Histogram displaying how values of slope are attributed to colours in the linear trend image.

The time periods used in trend analysis can be aligned to management interventions or the onset of changed environmental conditions so the impact on vegetation can be ascertained. Similarly by varying the length of the assessment period used in the calculation of linear trends information on short and long term changes in vegetation cover can be determined.

This is illustrated in the example in Figure 7. The majority of remnant vegetation in the 1973 – 1992 linear trend image is showing a positive linear trend as vegetation cover was low in 1973, more than likely as a result of fires prior to 1973, and has then increased until 1992 (Figure 7b). Fires subsequent to 1992, in some areas, has meant that vegetation cover has decreased resulting in the majority of the area showing a negative linear trend in the 1992 – 2008 linear trend image (Figure 7c). The long term linear trends (1973 – 2008; Figure 7a) has smoothed out some of the short term fluctuations in vegetation cover and shows that in the majority of areas vegetation cover has increased (positive trend) or remained stable since 1973. In only a few areas has vegetation cover decreased (negative trend) since 1973 (Figure 7a).

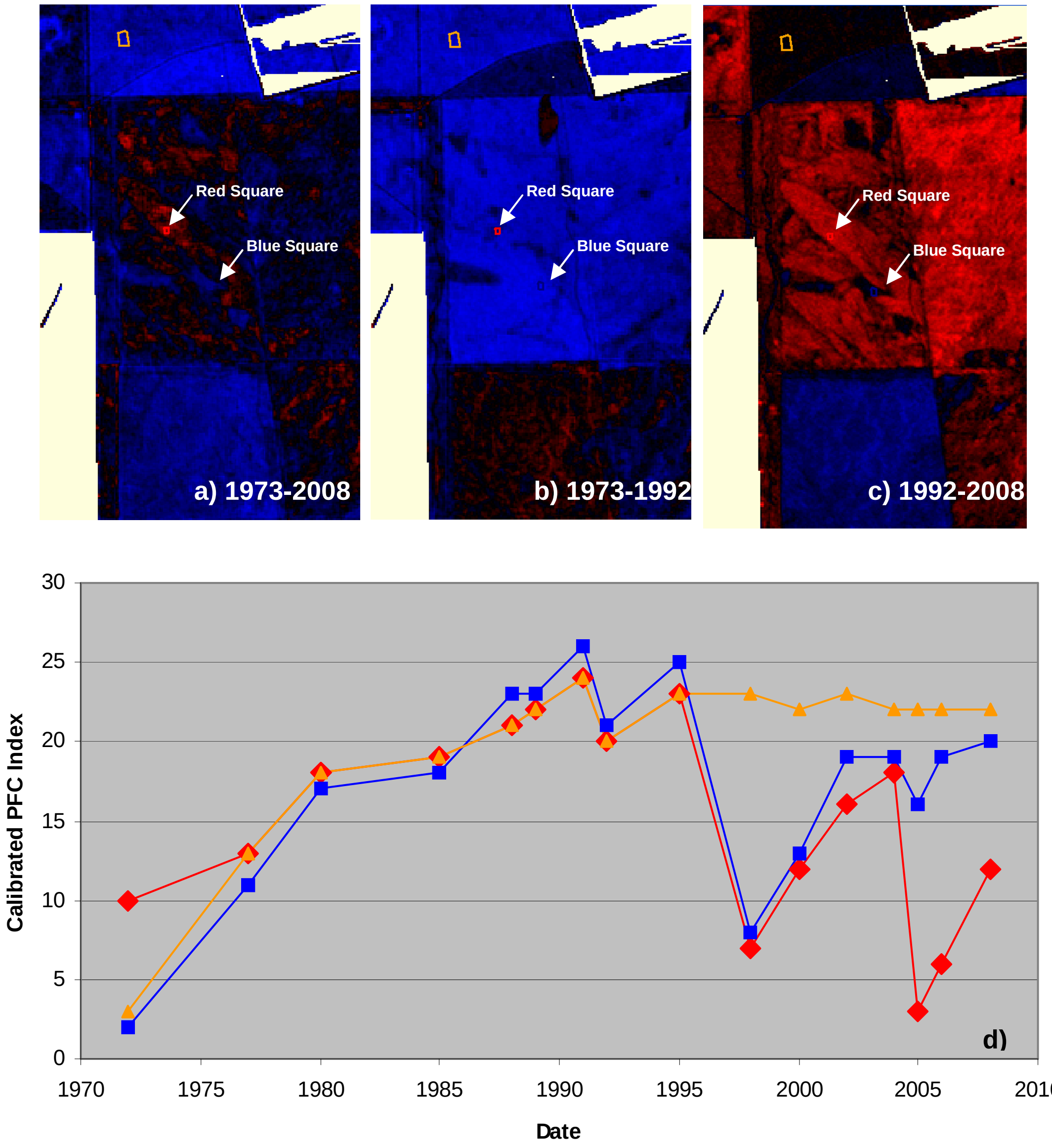

Figure 7: Linear trends for the remnant vegetation south-west of the Gingin airfield for a) 1973 – 2008, b) 1973 – 1992, c) 1992 – 2008 and a plot of calibrated PFC Index values for all image dates, in the image archive, for remnant vegetation within the selected areas outlined by the red, orange and blue squares. For the linear trend images positive trends are blue, negative trends are red and areas with stable vegetation cover are black. In all selected areas vegetation cover was low in 1973 probably due to fire impacts. For the orange square cover gradually increased until 1992 and then remained stable. In the corresponding trend images this area is shown as having a positive trend for 1973 – 2008 and 1973 – 1992 and a stable trend for 1992 – 2008. Two fires (1998 and 2005) for the red square resulted in vegetation cover in this area declining and by 2008 it had only just reached 1973 levels (overall negative trend 1973 – 2008). For the blue square, vegetation

cover by 2008 was well above 1973 levels despite a fire in 1998 (overall positive trend 1973 – 2008).

Discussion

Satellite imagery has been used to provide valuable information on changes in vegetation cover across the project area from 1973-2008. The information is derived from a Landsat satellite data archive which is jointly supported by state agencies, CSIRO, and Federal Department of Climate Change. The information is provided as maps and digital data which indicate where and when changes in vegetation cover have occurred. The changes in vegetation cover at particular sites can be quantified and compared using graphical plots of the responses over time.

This information and data can be used to direct ground work and site selection, to extrapolate from limited field observations, and to locate sites for detailed research work. Knowing the location of where changes in vegetation cover has occurred over particular time periods may assist in identifying the threatening process(es) that may have caused these changes.

A second Technical Report “Monitoring Vegetation Condition in the Banksia Woodland of the Gnangara Mound: the Role of Remote Sensing Tools” reports on a study which utilised the calibrated PFC Index and vegetation trends analysis to explore vegetation cover dynamics on good and poor condition sites on a range of ages since last fire. It also investigated at what scale the information products from Vegetation Trends Analysis could be utilised to part of a monitoring system for Banksia Woodlands (Kinloch *et al.* 2009).

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