Remote Sensing Vegetation Condition Assessment
Case Studies in Western Australia

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Prepared for
Department of Environment and Conservation

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1 Introduction

1.1 Background

The potential for the application of remote sensed tools to provide measures of vegetation condition as a part of nature conservation management measures has long been recognised in Australia (Gullen 1991). Despite the recognition of the potential offered by remotely sensed data, no rigorous or routine application of remote sensing to assist in monitoring vegetation condition has been implemented in Western Australia. However, there have been a number of important projects measuring vegetation attributes that have used remotely-sensed data in their analyses. The aim of this report is to compile and review a number of these projects as case studies for the application of remotely sensed data for vegetation condition assessment.

1.2 Scope and Objectives

This report:

- Outlines the conservation management framework that provides a structured approach to assessing case studies and will guide future application of remotely sensed tools;
- Introduces the remote sensing assessment criteria being applied;
- Develops an assessment criteria matrix that lists case studies and their alignment with these criteria;
- Uses the assessment criteria matrix to discusses the gaps in application of remotely-sensed tools for vegetation condition assessment in Western Australia; and
- Introduces options and recommendations for a way forward in developing a structured application of remote-sensed data for routine vegetation condition assessment that assists in evaluating the success of vegetation management in Western Australia.

This report does not intend to:

- Provide a technical review of remote sensing, Geographical Information Systems or the associated hardware;
- Explore data modelling or data reporting tools such as Generalised Regression and Spatial Prediction (GRASP) or Environmental Control Charts;
- Review the World Conservation Union/IUCN *Management Effectiveness Framework*;
- Review Pressure-State-Response models, Adaptive Management; or
- Undertake a review of the measurements of vegetation condition, ‘Long Asset Targets’, ‘Immediate’ or ‘Intermediate Asset Targets’.

Where appropriate the reader is referred to the relevant scientific or technical publication or to the relevant Native Vegetation Integrity Project (NVIP) or Department of Environment and Conservation (DEC) report.

2 Native Vegetation Integrity Project Reports Relevant to this Current Review

The Following documents should be read in conjunction with this report:

- DEC (2009a). *Biodiversity Conservation Appraisal System*: A framework to measure and report on biodiversity conservation achievements and management effectiveness of the Western Australian Department of Environment and Conservation. Nature Conservation Division, Crawley. WA.
- DEC (2009b). Draft: *A Review of NRM Regional Resource Condition Targets*. Draft Report as part of the *Resource Condition Monitoring - Native Vegetation Integrity Project*.
- DEC (2009c). Draft: Framework for Monitoring Vegetation Condition in Western Australia. Nature Conservation Division, Department of Environment and Conservation. Kensington. WA.
- DEC (2009 *in prep*.). Draft: Vegetation Condition Assessment. Procedures for Measurement. Department of Environment and Conservation. Kensington. WA.

3 The Framework for the Management of Vegetation Integrity

Ad hoc application of any technology outside of the objectives that are targets for vegetation management is unlikely to succeed. If the tool does not answer the questions that managers require to assist them in managing vegetation, then its application is not relevant. Therefore, this first aim of this report is to align the Draft DEC vegetation management (sic. Biodiversity monitoring and evaluation) framework within which remotely sensed data must be applied. Only when the following criteria have been addressed can decisions regarding remotely sensed tools to be used for monitoring and evaluation be made.

The Draft DEC vegetation management framework follows the DEC Biodiversity Conservation Appraisal System (DEC 2009a). This system aligns with World Conservation Union/IUCN monitoring and evaluation framework, and allows reporting at State, National and International levels through State of the Environment reporting mechanisms. The prerequisite steps to address to satisfy this framework are:

- Identification of the Vegetation Condition Management **CONTEXT**. What is the current state of vegetation; possible scales from patch size to landscape. Remote sensed data may provide data informing or measuring current vegetation condition (States) and threats (Pressures).
- Management planning to implement on-ground actions (including do nothing) that aim to achieve a **TARGET** vegetation condition. This will be:
    - Improvement; or
    - No change.
- Identify the **INPUTS** required to manage the vegetation condition towards the target state.
- Validate the **PROCESS** by which areas are prioritised and check on the feasibility of the management actions.
- **OUTPUT** reporting on activity.

- **OUTCOME** reporting on the effectiveness of the vegetation condition management. This is the second point where remote sensing tools will be applicable.
- **EVALUATION** of the effectiveness of the management of vegetation condition.

The Framework is cyclic, repeating the **CONTEXT** step once evaluation is completed and reported (DEC 2009a, Figure 1 below).

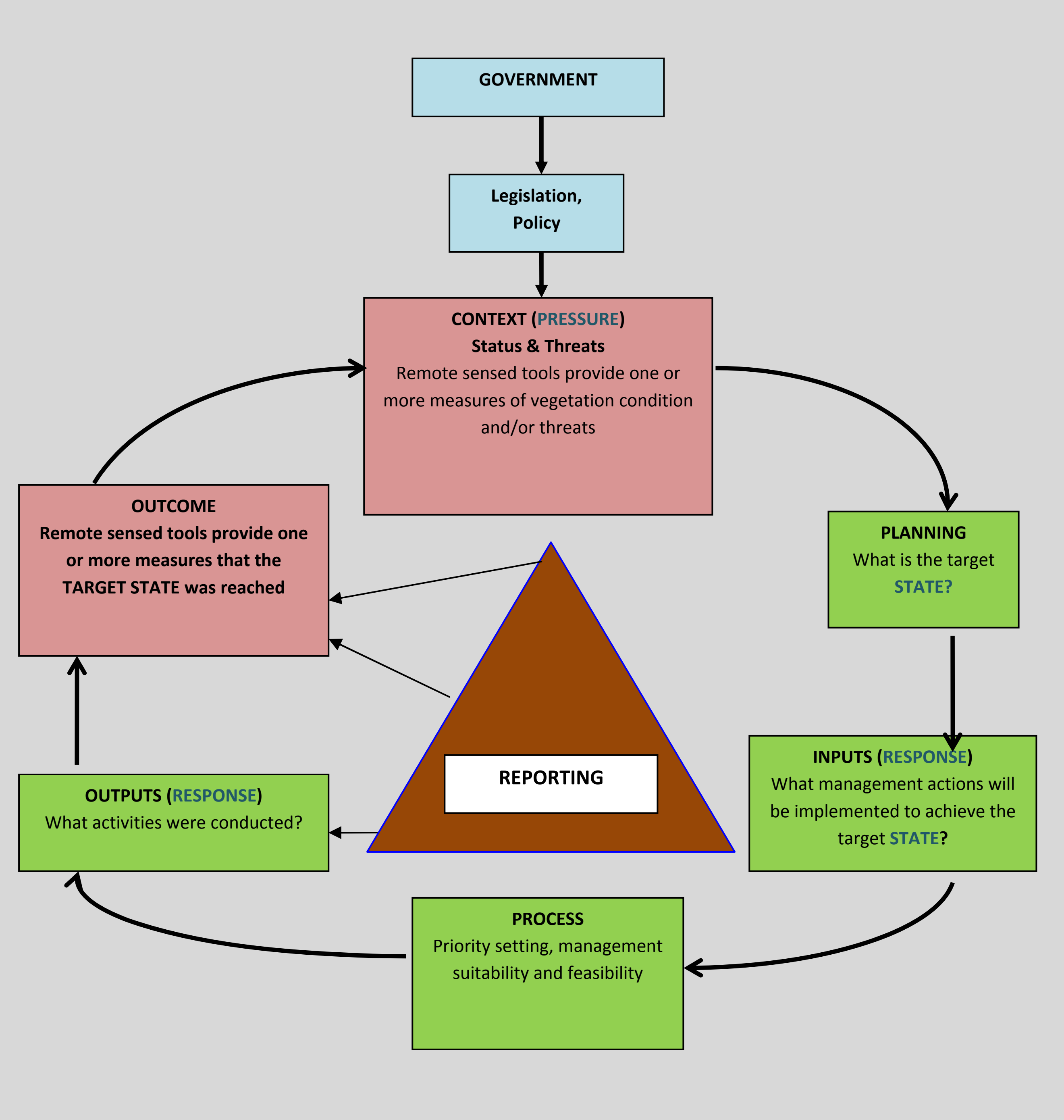


Figure 1. Schematic representation of the IUCN framework for monitoring and evaluating the management of vegetation condition. Pink boxes relate to the parts of the framework where remote sensing tools may be of use (from DEC 2009a).

Clearly this is a process that involves the commitment of resources across several providers, and an implementation and evaluation process that is likely to take several years. This suggests that the system must be overseen by Managers with the authority to mobilise resources, including the application of remote sensing, and to commit to reporting. The logical choice of custodian or responsibility is for officers at a Regional Manager level to fulfil this role.

4 Prerequisites for Application of Remote Sensing Tools for Vegetation Condition Monitoring and Evaluation

Monitoring changes in vegetation condition assumes that the target for vegetation condition change is improvement in condition or no change in condition. Simply monitoring a decline in the vegetation condition of an area without any decision regarding a management action (including do nothing or assessing a managed patch in comparison to an unmanaged patch) is not logical. The resources are better utilised in managing and monitoring areas where clear goals for the vegetation condition have been identified. Therefore, the first prerequisite for applying remote sensing tools is that the investment is made to support management actions of vegetation condition in areas prioritised for management.

> ***PREREQUISITE 1****:* *Remote sensing tools must only be applied to monitoring vegetation condition change within an approved vegetation condition management, monitoring and evaluation plan. This plan may be for patch, reserve, catchment, lease, Region or Whole-of-State.*

Monitoring must include at least two time series samples (say T0 and T1 sometime in the future). To be useful for monitoring purposes, the remote sensing tool(s) must provide data that covers at least two sampling times.

> ***PREREQUISITE 2:*** *Remotely-sensed monitoring data must satisfy the criteria of consistent, repeated time series data.*

5 Remote Sensing Case Study Assessment Criteria

In addition to the prerequisite conditions discussed above, the following assessment criteria are used in developing a review of case studies vegetation remote sensing that identifies where there are gaps in their application within a monitoring and evaluation framework. Many are self-evident; however, additional reasoning is considered with several criteria. The case study identifiers and assessment criteria are:

- *Project Name*:
- *Project Report Author(s)*:
- *Vegetation condition Data Custodian*: Interpretation of remotely-sensed data requires links to measured on-ground vegetation condition indices (ground-truthing). Departmental (or other jurisdictional) officer position responsible for the ground-truthed vegetation condition measurements should be identified. In this report, the officer position and name of the officer involved in the particular case study are listed.

- *Remote sensed vegetation condition Data Custodian*: Departmental (or other jurisdictional) officer position responsible for the remotely-sensed vegetation condition measurements should be identified. In this report, the officer position and name of the officer involved in the particular case study are listed.
- *Vegetation Cover monitoring question*: Is the aim of the remote sensing analysis to determine the spatial extent of vegetation or vegetation community?
- *Vegetation condition monitoring*: Is the aim of the remote sensing analysis to detect changes in the condition of vegetation?
- *Explicit identification of the vegetation asset*: What is the identified vegetation asset?
- *Legislation by which the asset is defined*: For example, the *WA Wildlife Conservation Act* or the *EPBC Act*.
- *Explicit identification of the vegetation asset State*: Pressure-State-Response model.
- *Explicit identification of the threat(s) to the vegetation asset*: What are the threatening process (ranked) that are degrading the vegetation asset? Pressure-State-Response model.
- *Explicit identification of response to manage the threat to vegetation condition*: Adaptive management following IUCN Monitoring and Evaluation framework and the Press-State-Response model.
- *Vegetation condition spatial scale*: At what scale (area, Ha) is the remote sensing assessment made?
- *Vegetation condition asset scale*: Is the asset a species, ecosystem or landscape-scale?
- *Case study Bioregion*: Which Bioregion was the remote sensing project applied.
- *Applicable Bioregions*: Which Bioregions is the application of the technique applicable for the same vegetation condition assessment monitoring question?
- *Vegetation condition ground-truthing*: Once a spatial model of the vegetation condition assessment has been produced, was its accuracy determined by follow-up ground-truthing?
- *Reported error*: Based on ground-truth survey, was an error or tolerance for the remote sensing technique reported?
- *Management Effectiveness Evaluation*: Was the case study used to assist managers in evaluating the effectiveness of specific management actions (including ‘no change to management’)?
- *Future application*: Does the technique have application in monitoring and evaluating the effectiveness of vegetation management by providing measurements of vegetation condition indicators?

6 Case Studies

The remote sensing vegetation condition assessment case studies used in this current review have been applied to a range vegetation condition questions and over most bioregions in Western Australia. The aim of this section is to provide a one paragraph summary of each study prior to an assessment of their application to measurement of:

- Vegetation condition; and
- Application to vegetation condition monitoring.

This report is geared towards monitoring and evaluation. Therefore a case study may have demonstrated the application for a remote sensing tool that measured a vegetation condition criterion. However, its application to vegetation monitoring may not have been achieved. In these instances, great value may be obtained with a simple repeat-measure of the vegetation condition criterion using exactly the same procedure applied in the case study discussed.

6.1 Case Study 1: Assessment of *Eucalyptus wandoo* (Wandoo) and other tree canopy decline using Landsat trend analysis

Program authors: Behn, G., Bland, L. and Garkaklis, M.

During the 1990s and early 2000, public concern was expressed regarding the condition (or state) of the *Eucalyptus wandoo* woodlands in the southwest of Western Australia. A number of projects were initiated under the Wandoo Decline Group, a multi-stakeholder panel, tasked with providing direction to research efforts on Wandoo decline. The objective of the Landsat remote sensing project in assessing wandoo decline was to identify the spatial distribution of:

- Declining *Eucalyptus wandoo* canopy;
- Stable (no change) *E. wandoo* canopy; and
- Increasing (sic: regenerating) *E. wandoo* canopy.

Review of this case study suggests the project was established to understand the context of the vegetation condition assessment – what is the current state of wandoo canopy. The project did not explicitly inform management response or action and was established outside of formal management targets for wandoo canopy. However, a number of vegetation condition monitoring criteria are met by this case study. In addition, targets for acceptable levels of canopy change are set as part of future monitoring using Landsat TM trend analysis (these are *no increases in the proportion of canopy loss*).

Repeated monitoring has not been indicated within the case study. This current review recommends repeat measures be undertaken to establish temporal trends towards the target of *no increase in the proportion of canopy loss*.

6.2 Case Study 2: Gnangara Sustainability Strategy – Vegetation Cover Assessment

Program authors: Behn, G., Zdunic and Wilson, B.

The Gnangara Sustainability Strategy (GSS) was a multi-agency project aimed to address issues of water abstraction on the Gnangara Mound Aquifer. The project considered issues of environmental, economic and social trade-offs for various water abstraction scenarios. The aim of the GSS remote sensing study was to examine the usefulness of Landsat in assessing changes in vegetation condition in an environment where frequent fires occur. The project was focused on Proof-of-concept, the frequency of fire being an important issue that complicated assessments of vegetation sustainability on the Gnangara Groundwater Mound.

Examination of the Vegetation Cover Linear Trends at small scale study sites revealed this tool has limited ability to discriminate between poor and undisturbed sites in Banksia woodlands. 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 a regional scale. This implies an application in setting targets for vegetation canopy cover loos and gain at this scale is possible. However, targets for vegetation condition trends measured as a change in vegetation cover at reference sites were not set as part of this project.

6.3 Case Study 3: Monitoring Riparian Vegetation Health within Millstream-Chichester National Park

Program authors: Behn, G., Kendrick, P. and Bowman, M.

This case study aimed to measure the riparian vegetation change in ‘area’ and ‘canopy density’ in an inland Pilbara National Park. The scale is larger than ecosystem, but less than entire National Park. The remote sensing used was Landsat TM, with change data processed as time series information. It demonstrated changes in vegetation condition as a resulting of increases in Pressure from an ‘altered hydrology’ threatening process. It’s only gap in a monitoring sense is that evaluation of the 2003 context did not lead to setting of new targets for vegetation condition change in the future (both ‘area’ and ‘condition’).

6.4 Case Study 4: Mapping Forest Cover – Kimberley Region of Western Australia

Program authors: Behn, G., McKinnell, F.H., Caccetta, P. and Verne, T.

This project aimed to assess the current state of forest cover in the Kimberley Region of Western Australia (NORFOR, an initiative of the National Forest Inventory). Landsat TM was the instrument applied. Although the technique successfully provided a measure of cover and extent, future management targets or monitoring regimes were not part of the project. This project satisfied the contextual aspect of the management framework. Repeated measures could be undertaken.

6.5 Case Study 5: Rangelands Monitoring – Landsat Monitoring of Woodlands Regeneration

Program authors: Curry, P., Zdunic, K., Wallace, J. and Law, J.

This study, in the north-eastern Goldfields, aimed to measure the success of woodland vegetation regeneration using Landsat TM as one measure of management effectiveness. It was a Proof-of-Concept project for applying Landsat TM in this specific case. However, future targets for vegetation response, or replanting success target measured by Landsat were not developed.

6.6 Case Study 6: Vegetation Monitoring Using Satellite Imagery – The Wongan Hills Ecoscape

Program authors: Behn, G. and Steward, I.

The aim of this project was to measure historical long-term trends in vegetation cover densities in the Central Wheatbelt region of Western Australia. It satisfied the contextual aspect of the vegetation condition monitoring framework by measuring the current state of the vegetation. How this information translated to setting management targets and actions is not reported. However, given this baseline information, future monitoring is appropriate using Landsat TM trend analysis.

6.7 Case Study 7: The PLAGA Project – An Approach for Remote Sensing-Based Rangeland Condition Assessment in North Western Australia

Program authors: Robinson, T.P., Novelly, P., Watson, I., Corner, R., Thomas, P. Schut, T. Jansen, S. and Shepherd, D.

PLAGA is an acronym for the Pastoral Lease Assessment using Geospatial Analysis and is an ARC-Linkage funded project at Curtin University of Technology, Western Australia. In this article, an assessment of the approach to measuring vegetation condition change in various rangelands landscapes is evaluated. It is Proof-of-Concept of trend analysis and uses Landsat as the case study example. Monitoring and setting management targets were not within the scope of this paper.

A summary of the alignment of each case study against the assessment criteria is presented in Table 1 (below). In summary, the application of remote sensed tools within a complete vegetation condition management program, with specific time bound targets, has not been undertaken. However, the tools to achieve this as part of vegetation monitoring currently exists, and are likely to improve with future technological developments.

Table 1. Case Studies Assessment Matrix

Project name	**Report Author(s)**	**Condition Data Custodian**	**Remote Data Custodian**	**Monit. Question: Cover?**	**Monit. Question: Condition?**	**Explicit ID of Asset**	**Legislat.**	**Explicit ID of STATE**	**Explicit ID of PRESS.**	**Explicit ID of RESP.**	**Spatial Scale**	**Asset scale**	**IBRA**	**Poss. IBRA**	**Truth**	**Error**	**M.E.**	**Applicn.**
Wandoo Decline	Garkaklis, Behn	Swan Regional Ecologist	DEC Leeuwin	Yes	Yes	Partly	Not ID	Yes	No	No	Several Reserves	Several Reserves	Swan, Wheatbelt	ALL	Yes	70%	Partly – future target	Landsat Trend Analysis
Gnangara Sustain. Strat. Veg Cover	Behn, Zudnic, Wilson	? – Regional Services?	DEC Leeuwin	Yes	No	No	Not ID	No	Partly	No	Reserve	Reserve	Swan	ALL	Partly	No	No	Landsat Trend Analysis
Millstream - Chichester	Behn, Kendrick	Pilbara Region	DEC Leeuwin	Yes	Partly	Yes	Not ID	Yes	Yes	Partly	Reserve	Reserve	Pilbara IBRAs	ALL	Partly	No	Partly	Landsat Trend Analysis
Kimberley Forest Cover	Behn, McKinnell	Unknown	DEC Leeuwin	Yes	No	Yes - Forest	Not ID	Partly	No	No	IBRA	IBRA	Kimberley IBRAs	ALL	No	No	No	Aerial Photo. Landsat TM
Rangelands Monitoring	Curry, Zdunic, Wallace, Law	Not clear	DEC Kensington	Yes	Partly	Yes – sequestered Carbon	Not ID	No	No	Partly	Patch within lease			ALL				Landsat TM
Wongan Hills Ecoscape	Behn, Steward	Avon Catchment Council	DEC Leeuwin Centre	Yes	Not explicit	Partly	Partly - Policy	Partly	No	Partly	Catchments	Remnant vegetation	Avon	ALL				Landsat TM
Goldfields Forest Cover	Behn, Stoneman	SFM Directorate	DEC Leeuwin Centre	YES	YES	YES	Partly	Aim to establish	No	NO	REGION	LANDSCAPE	Goldfields	ALL	YES	PARTLY	Not stated	Landsat TM
Rangeland Condition Assessment (PLAGA)	Shepherd, Robinson, Watson *et al.*	DAFWA	CSIRO Sustainable Ecosystems	No	Partly	No	Not ID	No	No	No	Lease	Several leases	Kimberley	ALL	Yes	Accuracy 85%		Proved concept using Landsat TM – instrument fit for purpose

7 Remote-sensed Vegetation Condition Assessment Gap Analysis - Recommendations on Planned Introduction of Remote Sensing Tools for Vegetation Condition Monitoring

A range of remote sensed tools are currently available and applicable to monitoring vegetation condition criteria across a range of scales. New technologies, at least equally applicable, will become available in the future. However, the gap analysis of case studies in Western Australia indicates the primary issues with regard to the application of remote sensing for vegetation condition monitoring is the lack of a structured selection process. This has led to 'one-off' evaluation of vegetation condition as a function of time, even when the remote sensing data are available in existing programs. Single time-point analyses using any vegetation condition measurement, including remote sensing, violate the first assumption of monitoring. That is, repeated measurement to detect trends in condition.

As a way forward for the application of remote sensing in Western Australia, a Natural Resource Managers Remote Sensing Tool selection procedure should be considered. Table 2 is a draft decision flowchart recommended for use in the selection of remote sensed data for vegetation condition monitoring and vegetation management effectiveness evaluation. The intent of the draft flowchart is to provide a tool for Natural Resource Managers with a uniform selection process for the application of remote sensed data. It guides the management team to identify appropriate monitoring scales and to focus the application of remote sensing tools toward the specific vegetation condition management targets. It assumes the application of a vegetation condition management effectiveness monitoring and evaluation framework, such as the IUCN Framework (Hockings *et al*. 2006, DEC 2009a).

However, although simple in layout and detail, workshop training for managers in the application of this flowchart to select remote sensed tools is strongly recommended. A number of training personnel from NRM Regions, CSIRO, Department of Environment and Conservation, Department of Water and the Department of Agriculture and Food would provide excellent resources and skills to this training program. Included in any workshop training for Natural Resource Managers should be staff from the Leeuwin Centre, CSIRO, Floreat, Western Australia. Their role would be to assist in identifying tools and data currently available under Australian Government programs and managed by CSIRO as data custodian, and to act as guides in the selection of tools for vegetation condition monitoring.

Other recommendations resulting from this review are as follows.

Recommendation 1: Adoption of vegetation condition management effectiveness monitoring and evaluation framework – set management targets that remote sensing tools are to measure.

Application of an accepted monitoring and evaluation of management effectiveness framework should form the basis for selecting any monitoring tool or procedure in vegetation management in Western Australia. Suitable frameworks can be found in State of the Forests reporting, State of the

Environment reporting and the IUCN (World Conservation Union) framework for assessing management effectiveness of protected areas.

Recommendation 2: Commitment to Senior Manager level approval for the application of remote sensing tools for vegetation condition monitoring.

Identification of, and commitment to, senior manager level sign-off for the selection of remote sensing tools for monitoring vegetation condition within each region (NRM or State agency) is crucial. Monitoring requires repeat measurements, and managers must have the authority to commit to this acquisition of data over the long-term. A failure to obtain repeat measured data will be a failure in the monitoring program.

Recommendation 3: Reporting of vegetation condition management effectiveness.

An agreed reporting timeframe and structure for vegetation condition monitoring following the monitoring and evaluation of management effectiveness framework. A structure that dovetails with Sate of the Environment (or State of the Forests) reporting is appropriate. This is an effective mechanism to allow audit of the application of remote-sensed data for vegetation condition assessment.

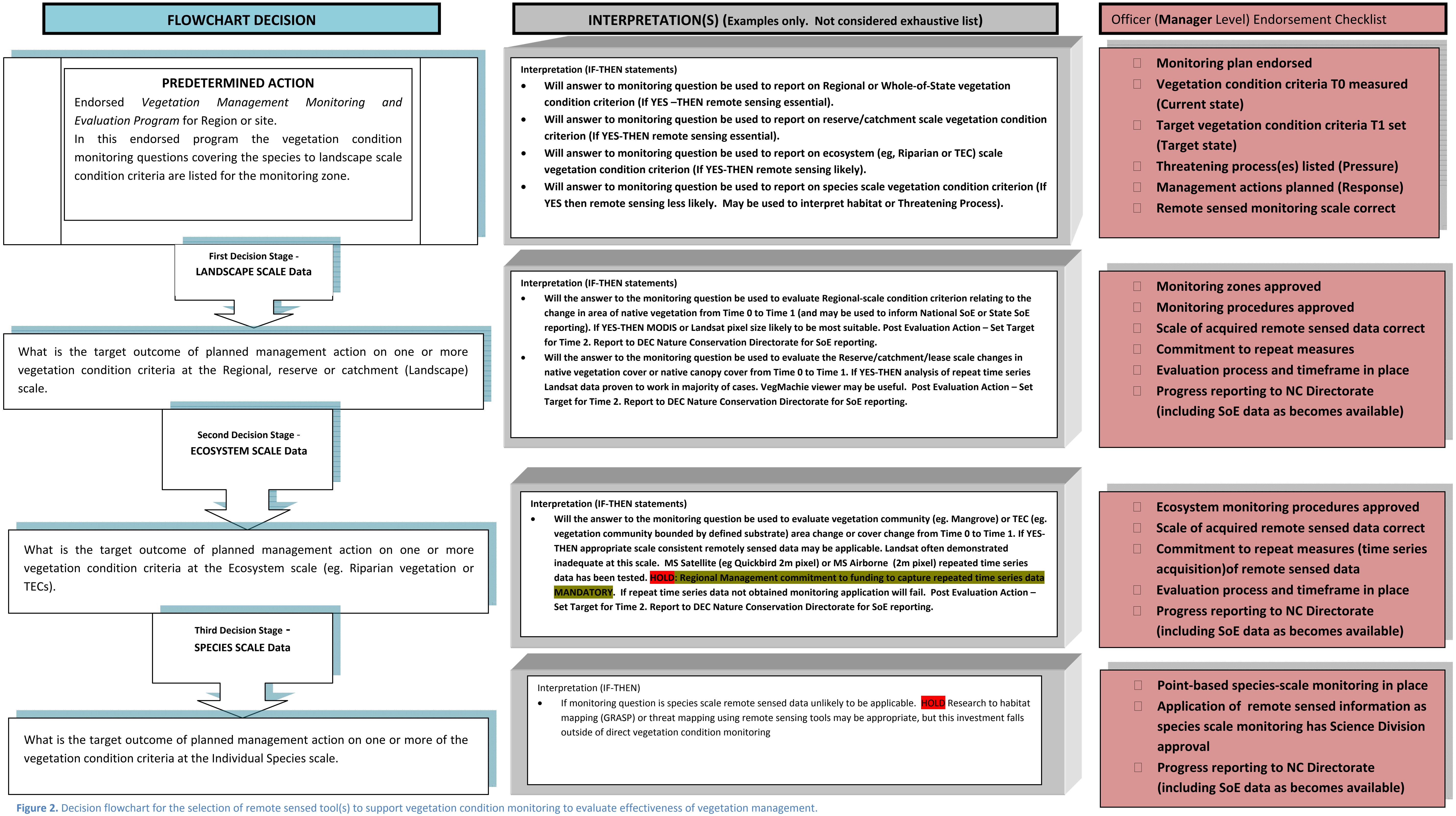
8 Conclusion

Remote sensing to assist in the measurement of vegetation condition trends is essential for the management of vegetation across Western Australia. Case studies in Western Australia demonstrate its suitability for measuring vegetation condition criteria; however, gaps in the use of remote sensing for monitoring currently exist. The opportunity now exists for Natural Resource Managers in Western Australia to adopt a structured and auditable approach to the selection and implementation of remote sensed to remote sensing as a monitoring tool simply requires application following the recognised management structure.

Primary criteria for each type of remotely sensed data used in monitoring vegetation condition:

- Addresses one or more vegetation management (including do nothing) monitoring and evaluation question(s). Vegetation management action and monitoring endorsed by Manager level officer.
- Spatial scale (sic: minimum pixel size) validated as appropriate to address scale of vegetation condition monitoring question.
- Remotely sensed monitoring data satisfies criterion of consistent, repeated time series data that is not subjective.
- Temporal scale for repeat capture of consistent time series data is validated as appropriate to identify changes in the condition of vegetation.

The decision flowchart (Figure 2) is a guide to selection of remotely sensed tool to assist in evaluating predetermined vegetation condition criteria. Selection of individual criterion for interpretation without reference to whole monitoring program may be misleading.



FLOWCHART DECISION

INTERPRETATION(S) (Examples only. Not considered exhaustive list)

Officer (**Manager** Level) Endorsement Checklist

PREDETERMINED ACTION

Endorsed *Vegetation Management Monitoring and Evaluation Program* for Region or site.

In this endorsed program the vegetation condition monitoring questions covering the species to landscape scale condition criteria are listed for the monitoring zone.

Interpretation (IF-THEN statements)

- **Will answer to monitoring question be used to report on Regional or Whole-of-State vegetation condition criterion (If YES –THEN remote sensing essential).**
- **Will answer to monitoring question be used to report on reserve/catchment scale vegetation condition criterion (If YES-THEN remote sensing essential).**
- **Will answer to monitoring question be used to report on ecosystem (eg, Riparian or TEC) scale vegetation condition criterion (If YES-THEN remote sensing likely).**
- **Will answer to monitoring question be used to report on species scale vegetation condition criterion (If YES then remote sensing less likely. May be used to interpret habitat or Threatening Process).**

- ☐ **Monitoring plan endorsed**
- ☐ **Vegetation condition criteria T0 measured (Current state)**
- ☐ **Target vegetation condition criteria T1 set (Target state)**
- ☐ **Threatening process(es) listed (Pressure)**
- ☐ **Management actions planned (Response)**
- ☐ **Remote sensed monitoring scale correct**

First Decision Stage -
LANDSCAPE SCALE Data

What is the target outcome of planned management action on one or more vegetation condition criteria at the Regional, reserve or catchment (Landscape) scale.

Interpretation (IF-THEN statements)

- **Will the answer to the monitoring question be used to evaluate Regional-scale condition criterion relating to the change in area of native vegetation from Time 0 to Time 1 (and may be used to inform National SoE or State SoE reporting). If YES-THEN MODIS or Landsat pixel size likely to be most suitable. Post Evaluation Action – Set Target for Time 2. Report to DEC Nature Conservation Directorate for SoE reporting.**
- **Will the answer to the monitoring question be used to evaluate the Reserve/catchment/lease scale changes in native vegetation cover or native canopy cover from Time 0 to Time 1. If YES-THEN analysis of repeat time series Landsat data proven to work in majority of cases. VegMachie viewer may be useful. Post Evaluation Action – Set Target for Time 2. Report to DEC Nature Conservation Directorate for SoE reporting.**

- ☐ **Monitoring zones approved**
- ☐ **Monitoring procedures approved**
- ☐ **Scale of acquired remote sensed data correct**
- ☐ **Commitment to repeat measures**
- ☐ **Evaluation process and timeframe in place**
- ☐ **Progress reporting to NC Directorate (including SoE data as becomes available)**

Second Decision Stage -
ECOSYSTEM SCALE Data

What is the target outcome of planned management action on one or more vegetation condition criteria at the Ecosystem scale (eg. Riparian vegetation or TECs).

Interpretation (IF-THEN statements)

- **Will the answer to the monitoring question be used to evaluate vegetation community (eg. Mangrove) or TEC (eg. vegetation community bounded by defined substrate) area change or cover change from Time 0 to Time 1. If YES-THEN appropriate scale consistent remotely sensed data may be applicable. Landsat often demonstrated inadequate at this scale. MS Satellite (eg Quickbird 2m pixel) or MS Airborne (2m pixel) repeated time series data has been tested. HOLD: Regional Management commitment to funding to capture repeated time series data MANDATORY. If repeat time series data not obtained monitoring application will fail. Post Evaluation Action – Set Target for Time 2. Report to DEC Nature Conservation Directorate for SoE reporting.**

- ☐ **Ecosystem monitoring procedures approved**
- ☐ **Scale of acquired remote sensed data correct**
- ☐ **Commitment to repeat measures (time series acquisition)of remote sensed data**
- ☐ **Evaluation process and timeframe in place**
- ☐ **Progress reporting to NC Directorate (including SoE data as becomes available)**

Third Decision Stage -
SPECIES SCALE Data

What is the target outcome of planned management action on one or more of the vegetation condition criteria at the Individual Species scale.

Interpretation (IF-THEN)

- If monitoring question is species scale remote sensed data unlikely to be applicable. HOLD Research to habitat mapping (GRASP) or threat mapping using remote sensing tools may be appropriate, but this investment falls outside of direct vegetation condition monitoring

- ☐ **Point-based species-scale monitoring in place**
- ☐ **Application of remote sensed information as species scale monitoring has Science Division approval**
- ☐ **Progress reporting to NC Directorate (including SoE data as becomes available)**

Figure 2. Decision flowchart for the selection of remote sensed tool(s) to support vegetation condition monitoring to evaluate effectiveness of vegetation management.

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Appendix
Case Studies

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Assessment of *Eucalyptus Wandoo* (Wandoo) and other tree canopy decline using Landsat Trend Analysis

by

M. Garkaklis and G. Behn

April 2009

Department of Environment and Conservation (DEC)
Western Australia

EXECUTIVE SUMMARY

Within this project the objective was to evaluate the effectiveness of using a time sequences of satellite imagery to locate trends in vegetation cover across nominated locations of *Wandoo* woodlands within the south-west of Western Australia. The evaluation required the implicit use of Landsat Thematic Mapper (TM) data to generate spectral indices which then could be displayed to highlight anomalies in spectral responses of the *Wandoo* cover. The time sequence of the imagery was from 1988 – 2005 and had been pre-processed and calibrated to ground Percentage Foliage Cover (PFC) prior to producing Trend Cover Maps for each of the locations.

The locations were the forest blocks and forest areas of the south-west known as, Helena Forest block, Julimar Conservation Park, Drummond Nature Reserve and Dryandra Woodland Reserve. All locations are characterised by mixed woodlands of either heath, Wandoo, Marri, Jarrah and Mallet trees.

An established method was applied to the satellite imagery to detect long-term changes in woody vegetation cover and clear trends in vegetation cover densities were established from the analysis. A key factor in using satellite imagery for this purpose is to calibrate the satellite image with data obtained from field observations of crown cover and density. Additionally, stratification of the landscape based on the Wandoo boundaries greatly aided the process. The final product was ground validated for accuracy and was considered to be an effective and useful means of interrogating vegetation changes over time.

Methods developed uses multispectral Landsat TM imagery to detect changes in vegetation density or cover over time. This has the capacity to detect not just changes in vegetation cover, but to also identify areas of vegetation where there is a permanent or long-term decrease in vegetation density. The information is provided as *vegetation trend maps* (see below) which indicate where and when changes in vegetation have occurred. The changes at particular sites can be quantified and compared using *graphical plots* of the responses over time.

INTRODUCTION

Over the last decade a number of Landsat Thematic Mapper (TM) satellite imagery based remote-sensing monitoring programs have been implemented in Australia. These include the Queensland's Statewide Landover and Trees Study (SLATS), the Landcover Change Project of the Australian Department of Climate Change and Land Monitor, a multi-agency project producing information products for land management in Western Australia.

Landsat (TM) satellite imagery has been used to provide valuable monitoring information of changes in vegetation across the region from 1988-2006. The information is derived from the data archive of the Land Monitor Project and jointly supported by 7 state agencies and CSIRO www.landmonitor.wa.gov.au. One of the information products is provided as *vegetation trend maps* which indicate where and when changes in vegetation have occurred (described below). The changes at particular sites can be quantified and compared using *graphical plots* of the responses over time.

Land Monitor produces two types of vegetation change products;

- the extent of perennial or woody vegetation cover and its change through time and,
- vegetation trends over time (vegetation status), which summarises vegetation history from multiple changes.

The vegetation trends use multispectral Landsat TM imagery to detect changes in vegetation density or cover over time. The method uses a developed 'Vegetation Index', which is related to vegetation cover to show or estimate cover variations. This method 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 density.

Tree deaths and declines are worldwide phenomena, and linking causal agents to decline events are problematic. In some instances, such a sudden oak death (SOD) caused by *Phytophthora ramorum* and chestnut blight (*Cryphonectria parasitica*), identifiable pathogens causing the death of trees could be isolated (Gilbert 2002; Rizzo *et al*. 2002). However, the interaction between host, pathogen, environment and the complexity of multiple-abiotic causes makes it unlikely that attributing a single factor to a tree decline event is possible. Indeed, expression of the diseases caused by pathogens, even when well understood, often requires the favourable interaction between pathogen, host and environment. For example, in modelling landscape-scale spread of SOD in the western United States, expression of the disease was highly clumped, and models clearly showed that forest edges (that promoted high-light requiring understorey host species) predicted disease expression (Holdenrieder *et al.* 2004). In this case fragmentation of oak forests has provided an important role in dispersing and progressing the disease (Holdenrieder *et al.* 2004). The spatial component was the key to understanding the characteristics of deaths across the landscape.

Forest ecologists recognise that together with anthropogenic factors (such as land clearing), the interplay between environment, herbivores and pathogens can help explain the community characteristics and functionality of forested ecosystems (Holdenrieder *et al*. 2004; Davis et al. 1994). It is a dynamic view of forests and one that accepts the role of disturbance in developing spatial and temporal heterogeneity. This is a conceptual model for the development of forest communities, but it is a model that requires an understanding of the distribution of both species and events at a landscape-scale. Managing unwelcome environmental events when they occur, such a tree decline or mass deaths, also requires a clear understanding of the spatial and temporal distribution of the event. Obtaining spatial data, in the form of topographic maps, aerial photography (including high resolution) and remotely sensed information, is now almost routine in managing natural ecosystems, including assessments of tree declines and large-scale deaths such as the wandoo.

Landscape-scale assessments using remote sensing

In recent years remote sensing has been applied to the assessments of vegetation structure and condition for natural resource management over wide areas of southeastern Australia. For example, Catling *et al.* (2001), Coops and Catling (2000;

2004), and Gibson *et al*. (2004) describe procedures for the use of Multispectral Airborne Videography that allow the interpretation of fauna habitat in forests, damplands and heathlands in New South Wales and Victoria. The drawback of these techniques is cost and a very limited archive. The data are often available at very fine scale (as low as 1 metre pixels) and acquisition of high-resolution multi-spectral and hyper-spectral data, and manipulation of the spatial data are both very expensive (Stone and Haywood 2006).

An alternative approach uses satellite remote sensed imagery. Landsat Thematic Mapper (TM) imagery has been used to map forest inventory and change in East Timor (Bouma and Kobryn 2002); the Philippines (Baynes 2004), and in Australia in Queensland (Bruce and Hilbert 2006), New South Wales and Victoria (Lee *et al*. 2002). In Western Australia, Landsat TM has been successfully used to map forest cover in the Kimberley (Behn *et al*. 2001) and in the Midwest, Murchison and Goldfields Regions (Behn *et al*. 2003).

Standard Landsat TM analysis provides a spatial distribution of landscape-scale data, although mapping temporal change has been more difficult to achieve. However, recent developments undertaken by the CSIRO has provided the Department of Environment and Conservation (DEC) with the opportunity to assess vegetation cover changes at landscape-scales by allowing trend analysis of Landsat TM data for the period 1988 – 2005. Recent software developments have provided a landscape-scale monitoring tool for the pastoral industry in the Northern Territory rangelands (Karfs et al 2004). The procedure involves three stages of analysis and interpretation. Firstly, the trend in vegetation at single point reference sites is examined by interpreting the reflectance of two band-widths that relate directly to vegetation cover. The changes observed over time are related to actual events that have occurred at the reference points. For example, the occurrence of fire is clearly visible in these trend analyses. Once on-ground data that describes the strata where vegetation decline has occurred is gathered, interpolation models are developed that extrapolate the point-based spectral data across the entire landscape that is being assessed. An image showing the spatial distribution of decline (and recovery) can then be produced. The final stage involves ground truth assessment of the vegetation cover change images.

This current project aimed to assess this approach to map the epicentres of wandoo (*Eucalyptus wandoo*) decline in the four locations above. These are:

- Helena Valley Forest block;
- Julimar Conservation Park;
- Drummond Nature Reserve; and
- Dryandra Woodland Reserve.

METHODOLOGY

Satellite Imagery

TM data provide routine broad-scale coverage of an area and is ideal for mapping and monitoring change. The ground picture element (pixel) size (25m) is practical for broad-area surveys and gives results appropriate for resolution with at least several trees and shrubs per pixel and several pixels per homogeneous area. The ability to monitoring change also becomes possible with the ability to co-register and analyse imagery from various dates.

Thematic Mapper (TM) 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. Band six is located in the thermal infrared part of the spectrum whilst Multispectral (MSS) imagery had 4 four band, bands one and two in the visible, band three in the near-infrared and band four in the short-wave infrared.

It is important to note that there are many causes and interpretations of changes in reflectance that can be seen in the imagery, particularly when dealing with vegetation, and that the physical changes which result in a similar numerical reflectance response will vary with vegetation type and background. As mentioned above, the 25m pixel can contain several trees and shrubs but also background information on soil, shadow and grasses. As the primary aim of the imagery is to provide monitoring data of the perennial vegetation, image capture dates are limited to summer dates when the grasses are in a cured state.

The cloud-free Thematic Mapper images were geometrically rectified to the GDA94 datum and in MGA50 map projection, using nearest neighbour transformation.

Date	Landsat	Pixel Size (m)
20/02/88	TM	**25**
25/02/90	TM	**25**
30/01/92	TM	**25**
19/01/94	TM	**25**
25/01/96	TM	**25**
29/12/97	TM	**25**
13/02/00	TM	**25**
16/12/01	TM	**25**
5/02/03	TM	**25**
19/03/04	TM	**25**
2/02/05	**TM**	**25**

Table 1: Satellite imagery used

The crucial factor in producing spectral maps or enhancements which reliably display vegetation 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 important band combinations or indices, which provide the vegetation density discrimination, can be identified and appropriate enhancements produced.

Index Images

Several large scale projects within Australia, (see below) have incorporated a vegetation index (TM Band 3 plus TM Band 5)/2 with TM Band 3 being the visible red waveband (VIS) and TM Band 5 being in the short-wavelength infrared (SWIR), within their vegetation surveys. In this project the Index image was made from each date using this linear combination and complied into a sequence file.

The calibration of the Index image to ground-cover is required. A technique by Behn 1991, showed a good relationship between measured ground foliage cover to the spectral information of the Index image. The first stage was to use the most current aerial photography to locate a number of ground sites within the study area to give a range of cover densities within the wandoo.

Projected Foliage Cover Images

The best available aerial photography covering each of the study sites was obtained from CALM Geographic Information Services section. The dates of the photography for each site were varied, from 1999 to 2001.

Aerial photography and Arc View (3.2) was used to determine different areas of homogeneous vegetation densities, according to dot grid templates (Figure 2), to locate prospective field sites.

Field Sites

Each of the four locations had a unique number of field sites depending on size, topography, vegetation and access. Enough field sites were chosen at each study site to give an accurate representation of ground information in order to calibrate the satellite imagery with ground measurements. In total there were 92 field sites (ground-truthed reference points) across the five study areas.

Crown Cover Estimates

Crown cover is a measure of the ground area within the vertical projection of the periphery of crowns in an area, assuming that tree crowns are opaque (Behn *et al* 2003). Using this same method Crown Cover for the prospective field sites was estimated on aerial photographs using dot grid templates (Figure 2). The template assumes an open opaque crown. To convert the crown cover to projected foliage cover (which is what the satellite imagery responds to), ground measurements in the field sites were used to establish the degree of actual crown density. Crown cover was also estimated in the field to double check desktop measurements and account for any change or error in aerial photography.

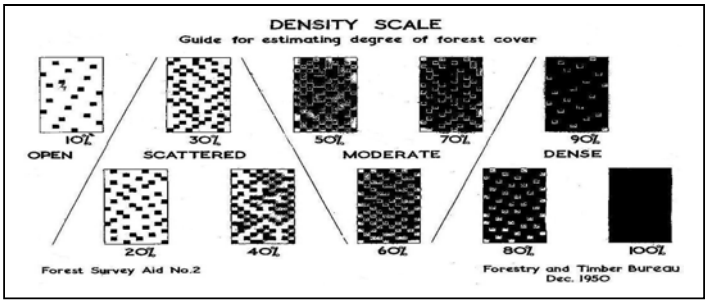


Figure 2: Crown density template (Forestry and Timber Bureau 1950)

For example, Figure 3 demonstrates a field site at Dryandra Woodland Reserve, chosen as it represents an area of homogeneous vegetation cover. Using the density template (Figure 2) this site was estimated at 30% forest cover.

Figure 3. Field site at Dryandra which demonstrating homogeneous vegetation cover at 30% crown density.

Projected Foliage Cover (PFC)

PFC is the percentage of the field site occupied by the vertical projection of foliage. PFC is the product of crown cover and crown density (Behn *et al* 2003). Using the crown cover and density estimates, a PFC value was determined for a number of reference points in each field site (McDonald *et al* 1990).

30 % Crown Cover X 75% Crown Density = 22.5% PFC

Figure 4: Projected foliage cover (PFC) is determined using the values of crown cover and crown density,

Regression

To determine the relationship between on-ground measurements and the Landsat imagery, a regression equation of the mean spectral information from the cover index image was determined as a function of the on-ground values of PFC at the ground-truthed reference points. The regression value is then applied to the cover index image to relate the image reflectance to the predicted PFC.

A Percentage Foliage Index (PFI) image is then created for each site from 1988 – 2005. This gives a 17-year historical sequence of imagery, and the changes or trends over time are then summarised for the time period into linear and quadratic components and estimated independently using orthogonal polynomials (Draper & Smith, ch 5).

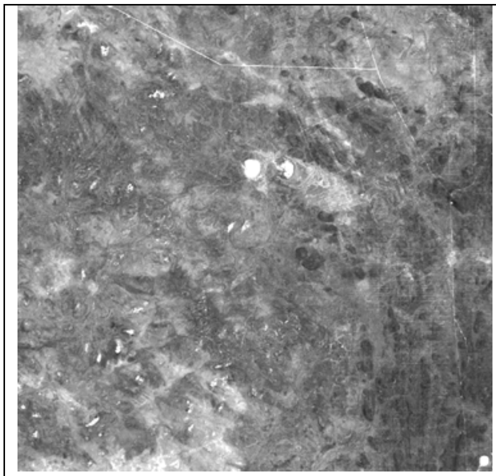
Trend Image

The ‘Trend Image’ is used to calculate trends (e.g. slope over time) (Wallace et. al, 1999) and any deviations are real numbers and are changes that are produced for each pixel and scaled to fit the 1-byte range of 0-255 for the temporal indices over time.

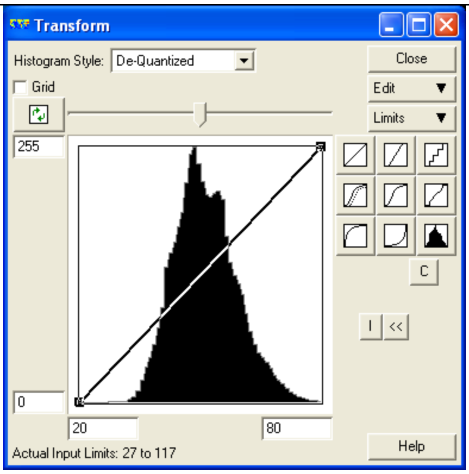
Slope (linear trend over time)	**Lin coeff * (255/10) + 127.5** *[scales slopes from –5 to +5 into the 0-255 range]*

Note that the input values are the PFC values at different dates, so the units for (e.g.) the slope are foliage counts per year.

The ‘Trend Image’ can be displayed to summarise trends and stability of vegetation over time as measured by the PFC index, and in particular to highlight areas with different patterns of change. For this project simple summaries of trends over the period can be made by displaying positive and/or negative linear trends in different colours (see below) while other bands can be used to examine deviations from these trends.



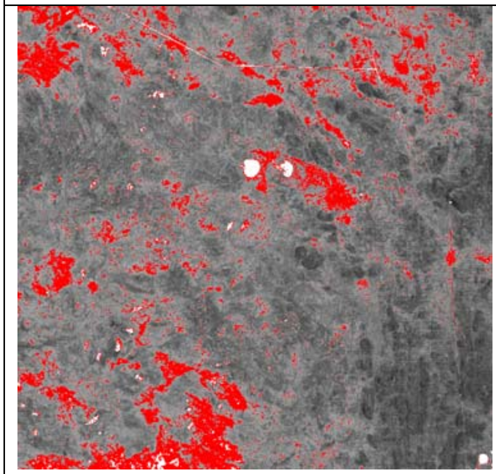
Linear Trend Image **(a)**



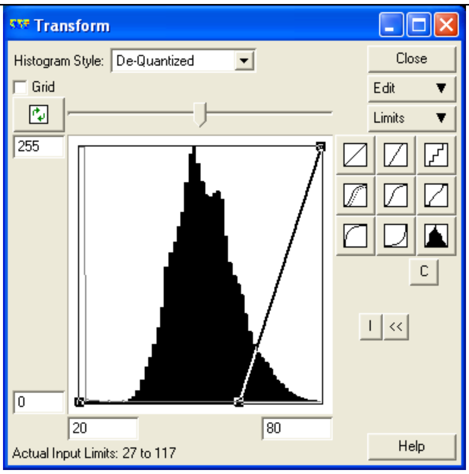
Histogram Style: De-Quantized

☐ Grid

Actual Input Limits: 27 to 117



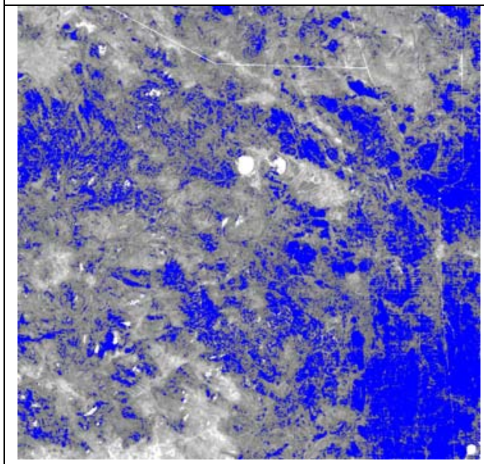
Negative cover trend **(b**



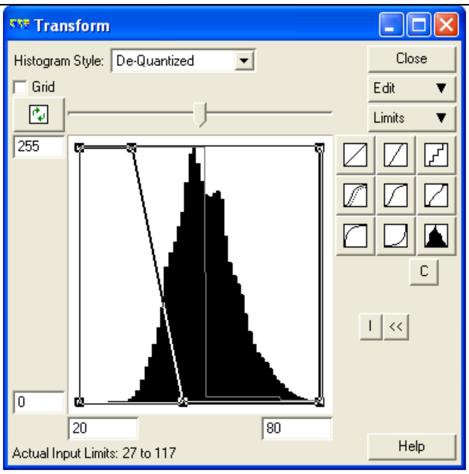
Histogram Style: De-Quantized

☐ Grid

Actual Input Limits: 27 to 117



Positive cover trend **(c)**



Histogram Style: De-Quantized

☐ Grid

Actual Input Limits: 27 to 117

Figure 5: The Linear Trend Image, (a) above shows the vegetation trend cover, for a particular time period and location, with areas of light or white being negative cover trends (shown as red in (b)) and areas of dark or black are positive cover trends (shown as blue in (c)).

RESULTS

Trend Maps

Trend image maps covering the project locations of Helena Valley Forest block (Figure 6); Julimar Conservation Park (which also included the small Drummond Nature Reserve to the east) (Figure 7), and Dryandra Woodland Reserve (Figure 8), were produced.

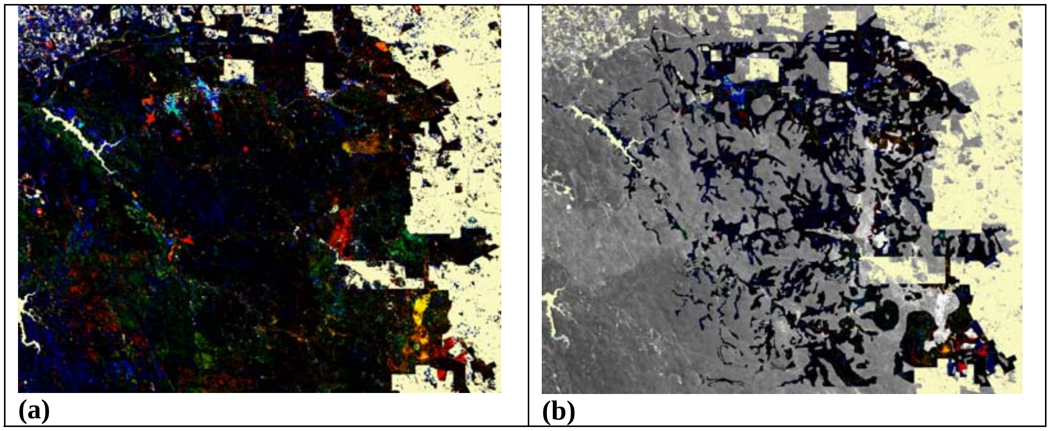


Figure 6. Helena Valley Forest block Trend map **(a)** Entire forest block with red areas indicating vegetation cover loss or decline, blue cover gain and black as stable cover. Causal agents of change can not be determined from this image alone. The forest block was then stratified with existing wandoo boundaries **(b).**

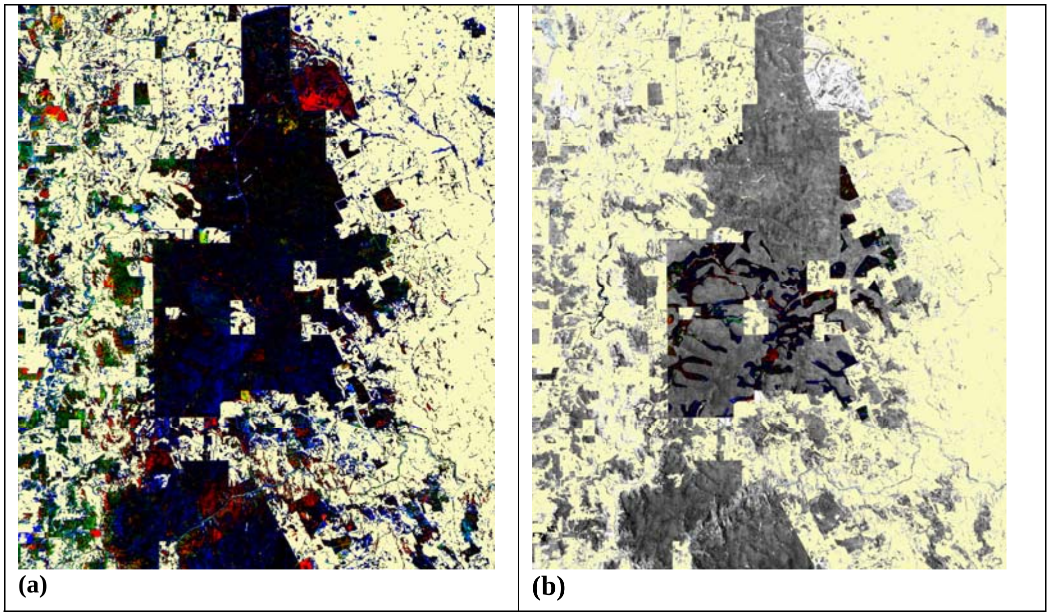


Figure 7: Julimar Conservation Park Trend map **(a)** Entire park with red areas indicating vegetation cover loss or decline, blue cover gain and black as stable cover. Causal agents of change can not be determined from this image alone. The park was then stratified with existing wandoo boundaries **(b).**

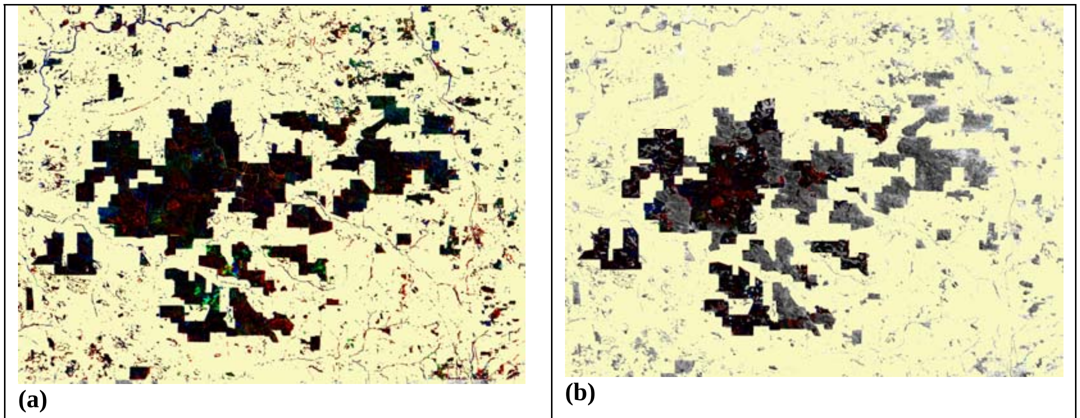


Figure 8: Dryandra Woodland Reserve Trend map **(a)** Entire reserve with red areas indicating vegetation cover loss or decline, blue cover gain and black as stable cover. Causal agents of change can not be determined from this image alone. The reserve was then stratified with existing wandoo boundaries **(b).**

Accuracy

The proportion of declining, recovering and stable vegetation was assessed for the total area of each site, (Table 2 below) giving the following values. It should be noted that fie boundaries and other known causes of gross canopy change (such as clearing) were ignored in this analysis.

Site	% Increase	% Decline	% Stable
Helena Catchment	4	13	83
Julimar State Forest	8	13	79
Drummond Nature Reserve	4	30	66
Dryandra	14	10	76

Table 2: Proportions of vegetation change at each project study site

The proportion of declining, recovering and stable vegetation was assessed for each site, for the Wandoo occurrence area only, giving the following values:

Site	% Increase	% Decline	% Stable
Helena Catchment	11	17	72
Julimar State Forest	4	17	79
Dryandra	23	18	59

Table 3. Proportions of vegetation change within Wandoo occurrence areas only, at each project study site

Accuracy of the technique was based on *A Priori* selection of ground-truth sites using the spatial models to predict points of canopy loss, canopy increase and no change. On ground assessments of these selected points were then made to determine the accuracy of the spatial model.

Based on the wandoo vegetation community data available within the Department of Environment and Conservation, areas of decline and increase in wandoo canopy are smaller than the areas of stable canopy. Proportions (percentage area) of increasing wandoo canopy in the period 1988 to 2005 range from 4% at Julimar Conservation Park to 23% at Dryandra Woodland Reserve. Proportions of decreasing canopy in the period 1988 to 2005 in wandoo vegetation range from 17% at Helena and Julimar to 18% at Dryandra. Stable (no change) proportions range from 59% at Dryandra to 79% at Julimar.

The trends indicate that canopy loss or decline in wandoo has occurred at a number of locations. The procedure also identified that canopy increases also have occurred. In some of these ‘canopy increase’ sites it would appear that wandoo crowns are re-establishing from epicormic growth. However, over most of the areas (60 – 70%), the canopy appears to be stable.

A Priori selection of trends indicates the technique was correct in predicting a recently declined, an increasing or stable tree canopy (regardless of which *Eucalyptus* or *Corymbia* species) in 60 to 70% of occasions. Reasons identified for failure to correctly predict an event were:

- Incorrect delineation of vegetation communities, or insufficient mapping data defining vegetation communities. For example, significant declines in canopy are apparent at Drummond Nature Reserve. Vegetation data indicated this change was likely to be a decline in wandoo canopy. On-ground assessments determined that gross canopy decline had occurred but that Marri was the species affected. Wandoo canopy in this reserve is healthy.
- Incorrect record or mapping of fire events. If not mapped, fire scars are assumed to be a decline. This occurred at one site in Julimar.
- Boundaries between vegetation communities. Incorrect predictions of canopy loss occurred at several sites in Dryandra at boundaries between mallet plantation and natural vegetation, and also at one boundary between an *E. accedens* and *E. wandoo* community.

Gross changes to canopy are accurately identified using this technique. However, predictions of changes that are related to particular tree species rely on accurate delineation of vegetation communities within the survey areas.

CONCLUSION AND DISCUSSION

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 scales particularly relevant, for which these on-ground measurements can be accurately made, and so are well placed to provide necessary and updated information for land managers.

The methodology described here provides a sound basis for rapid, accurate mapping tree cover trends across large areas where the use of conventional aerial photography cannot be economically justified.

Relevant information on vegetation cover trends has direct links to health, condition and change and are of great interest from a variety of perspectives. 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. Sidmore *et al* (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. This 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.

Satellite imagery has been used to provide valuable monitoring information of changes in vegetation across the project area from 1977-2009. The information is derived from an archive w*hich 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 have occurred.

This information provides a means to produce a comprehensive assessment of the problem, to direct ground work and site selection, to extrapolate from limited field observations, and to locate sites for detailed research work. Knowing the location and timing of affected and unaffected areas may assist in identifying causes of the problem.

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Vegetation Cover Trends

Gnangara Sustainability Study

by

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1.0 Introduction

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Relevant information on vegetation health, condition and change are of great interest from a variety of perspectives. 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. Sidmore *et al* (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. This 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 a developed technique, using this image archive, for the Gnangara Sustainability Study.

2.0 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 Landcover Change Project of the Australian Greenhouse Office Carbon Accounting System 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 TM and 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 perennial or woody vegetation cover and its change through time and,
- vegetation trends over time (vegetation status), which summarises vegetation history from multiple changes. *This portion of the project is based on this technique.*

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 density or cover over time. The method uses a developed 'Vegetation Index', which is related to vegetation cover to show or estimate cover variations. This method 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 density.

The open woodlands of Gnangara 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. To-date only isolated monitoring or knowledge of the whereabouts of vegetation changes has occurred. The need to locate and identify these changes (negative, stable or positive) for resource and environmental management purposes has been identified.

Satellite remote sensing technologies are an appropriate means of monitoring the vegetation dynamics as it can provide an 'historical look' at vegetation trends. It provides the areal capability plus has the spectral sensitivity to accurately discriminate density of vegetation cover.

The historical sequences of satellite imagery now provide a means of monitoring the vegetation 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 density and variations, and along with aerial photography are labour intensive, time consuming and expensive.

A key factor in using satellite imagery for this purpose is to calibrate the satellite image with data obtained from field observations of crown cover and density.

Additionally, a stratification of the landscape based on vegetation or soils types would greatly aid this process. A ground-truth exercise would add validation to the result.

3.0 Satellite Imagery

Both the Landsat Multispectral (MSS -1977-1987) and Thematic Mapper (TM 1988-ongoing) satellite imagery data provide routine broad-scale coverage and have been shown to be ideal for mapping and monitoring vegetation, (Furby, 2004). The ground picture element (pixel) size (50m for MSS imagery and 25m for TM imagery) is practical for broad-area surveys and gives results appropriate for resolution with at least several trees and shrubs per pixel and several pixels per homogeneous area. (Reference)

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) 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).

3.1 Time Sequence of Imagery

The potential use of Landsat imagery to discriminate vegetation cover variations from non-vegetation and then apply the findings to sequential image dates, located on the same area, is attractive in terms of a monitoring tool, provided that the relevant information on cover can be extracted from it. In this context the project looked at the summary of vegetation indices and known spectral bands from various dates of imagery to develop methods for the extraction of vegetation cover information from sequences of image data. For ease of processing and registration the Landsat MSS imagery was re-sampled to 25m pixels, corresponding with the Landsat TM.

The imagery is owned by CALM, and Australian Greenhouse Office. The dates of the imagery range from 19/11/77 to 05/02/06 (Table One). Reasons why?

Date	Landsat	Pixel Size (m)
19/11/76	MSS	50m-resampled-25m
01/12/79	MSS	50m-resampled-25m
26/01/85	MSS	50m-resampled-25m
30/01/88	TM	25m
31/01/90	TM	25m
18/01/91	TM	25m
07/01/93	TM	25m
07/02/95	TM	25m
05/01/98	TM	25m
19/01/00	TM	25m
09/02/02	TM	25m
23/02/04	TM	25m
09/02/05	TM	25m
05/02/06	TM	25m

Table One Satellite imagery used

3.2 Determine Spectral Image Index

The reflectance, which is the spectrum displayed by any pixel representing natural vegetation is a combination of the relative spectral combinations from trees, understorey, ground cover and exposed soil within the pixel. When the vegetation cover is not dense, such as the vegetation composition within the Gnangara project 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 spectral maps or enhancements which reliably display vegetation 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 important band combinations or indices, which provide the vegetation density discrimination, can be identified and appropriate enhancements produced.

Vegetation indices, or mathematical combinations of spectral bands, are derived to express spectral differences that are unique to specific target materials. These indices can be a very effective in measuring the amount of green vegetation cover over the soil.

Several large scale projects within Australia, (see below) have incorporated a vegetation index (TM Band 3 plus TM Band 5)/2 with TM Band 3 being the visible red waveband (VIS) and TM Band 5 being in the short-wavelength infrared (SWIR), within their vegetation surveys. Earlier research has also shown the significance of single bands TM Band 3 and MSS Band 2 (the red portion of the spectrum from both instruments) as having high correlations to vegetation density (Pickup, et al 1993). Additional internal research by DEC (Zdunic, 2008) has confirmed this relationship.

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

The project sort to evaluate and extend time period so as to summarise the vegetation changes from 1977 to 2006 and as such spectral Band 3 from Landsat TM and Band 2 from Landsat MSS platforms were used as the default Index.

3.3 Conversion to Percentage Foliage Image

As mentioned earlier the basic objective of the project was to accurately estimate the variation in crown cover across the landscape and as such a key factor in using satellite imagery for this purpose is to calibrate the satellite image with ground measurements. The process for this followed previous successful projects described by Behn, *et al* (2001, 2003).

In summary, a range of sites with varying crown-cover (a measure of the ground area within the vertical projection of the periphery of crowns in an area, assuming that tree crowns are opaque) was estimated using templates devised by McDonald, (1990). From these sites the crown density (a measure of the ground area within the outline of a tree crown that is occupied by leaves) was recorded. Crown density was estimated by standing under a tree crown and visually comparing the density of leaves within the crown outline with that in the photographic standards of 'crown type' provided by McDonald, (1990).

Once the crown cover and crown density were known the Projected Foliage Cover (the percentage of the field site occupied by the vertical projection of foliage) is calculated as the product of crown cover and crown density.

To estimate the Projected Foliage Cover (PFC) for each of the field sites required a consistent and repeatable technique. Using the aerial photography and crown cover estimates as described above, together with standard diagrams that identify varying crown openness (McDonald *et al*, 1990) experienced ground personnel assisted in completing the visual interpretation.

Band 3 of Landsat TM imagery, (captured 26/01/08 and shown below), was used for the interpretation as it was captured as close as possible to the date of fieldwork. The resultant image is displayed in shades of grey (Figure One). Areas of white have little to no cover, while darker areas have the greatest vegetation density. These variations are obvious.

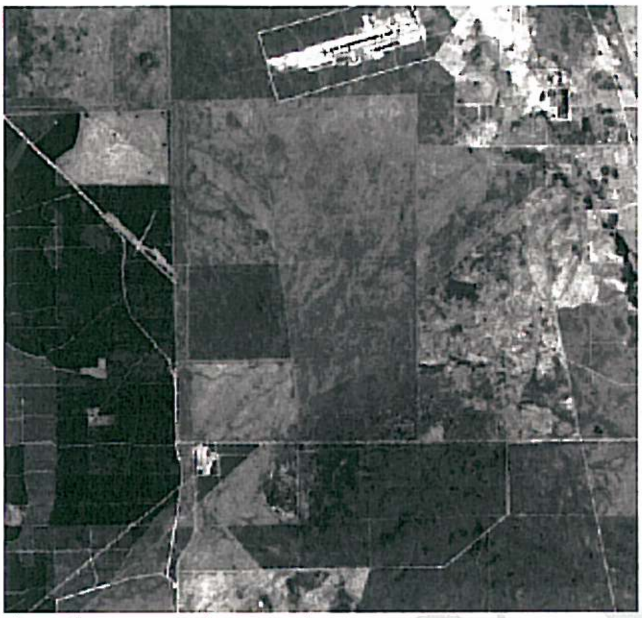


Figure One: Band 3 of 2008 Landsat TM imagery.

The next stage was to convert this Band 3 image into a PFC image 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 values for each of the field sites were extracted from the 2008 image (Figure One). The relationship between these values and projected foliage cover measured in the field (PFC-F) was established (Figure Two). The resultant linear equation was applied to the 2008 Band 3 image to produce an image of Projected Foliage Cover.

Figure Two below shows the linear regression of the ground PFC estimates against the site mean values extracted from the Band 3 image.

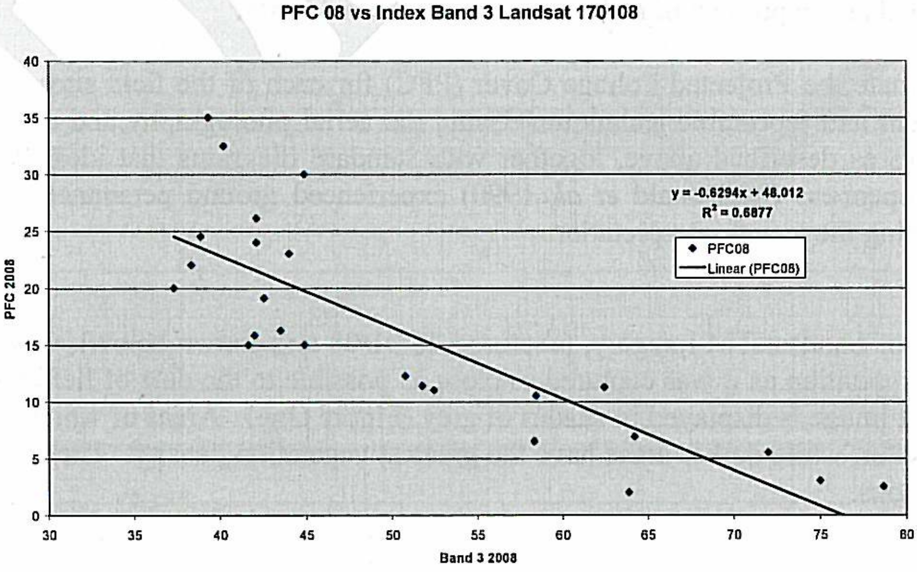


Figure Two: Mean values of the field Cover Estimates for each site were regressed against the estimated PFC values from the Band 3 image. The R^2 being 0.69 and the linear equation being y =-0.63 x Band3 + 48.

From the graph we observe that there is considerable variation in the cover estimates for ground sites of similar vegetation cover. The sites can vary because of a number of reasons; one which is significant is the ground responses of soils, debris and grasses. However in this case, a strong relationship exists.

The resultant linear equation (Figure Two above) *-0.63 x Band3 + 48* was applied to all pixels within the Band 3 image to produce the PFC image (Figure Three below).

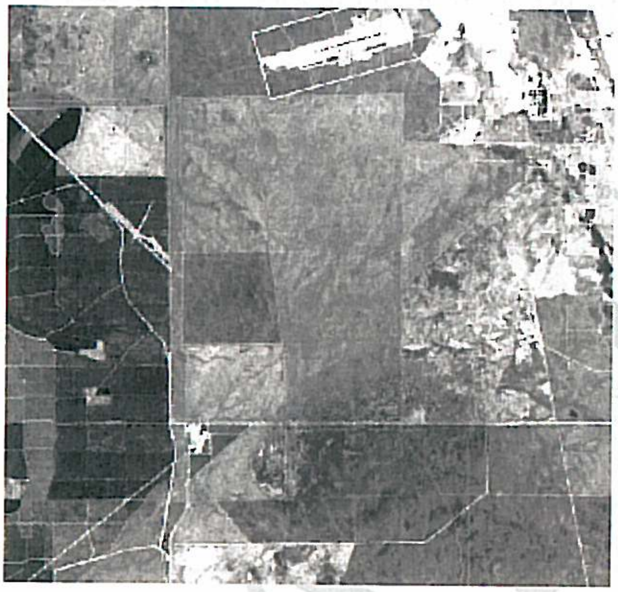


Figure Three: Image of projected foliage cover. Darker areas indicate high values of projected foliage cover.

Dark areas have relatively high values of PFC whilst the light areas have relatively low values of PFC. The image of PFC has a value range from 0 (white) to 33 (black).

Once the method was field-validated (might have to add something here) all fourteen dates of imagery were subjected to the same processing.

3.4 Vegetation Cover Trends

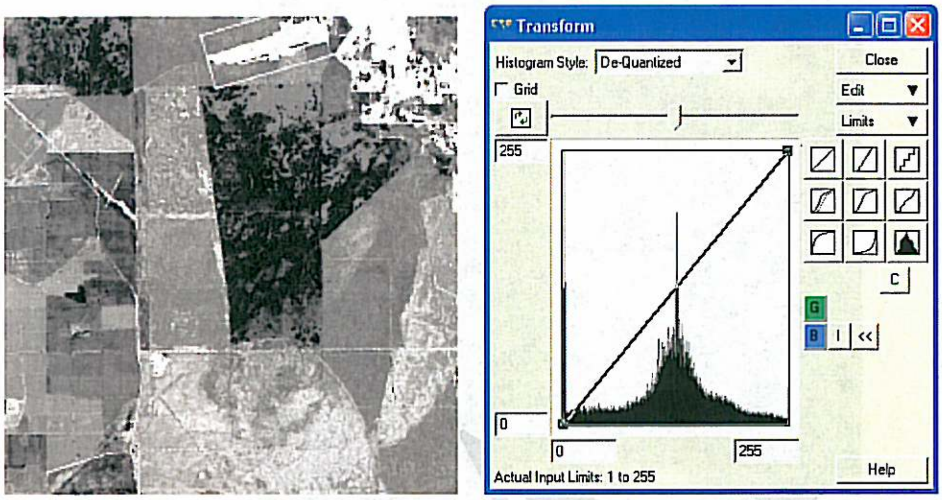
To produce the vegetation trend images the PFC images for each date in the sequence (described above) are complied into a sequence file.

The 'Vegetation Cover Trend' image' is used to calculate trends (e.g. slope over time) and follows work by (Wallace *et. al*, 1999). Changes in pixel values within the time-sequence are deviations of real numbers and so the changes that are produced for each pixel and scaled to fit the 1-byte range of 0-255 for the temporal indices over time.

Slope (linear trend over time)	**Lin coeff * (255/10) + 127.5** *[scales slopes from –5 to +5 into the 0-255 range]*

The linear component of the response is estimated independently using orthogonal polynomials (Draper & Smith, ch 5). Inversion of the scaling will recover the real values if required for quantitative analysis. Note that the input values are the index values of TM Band 3 and MSS Band 2 at different dates, so the units for (e.g.) the slope are index counts per year.

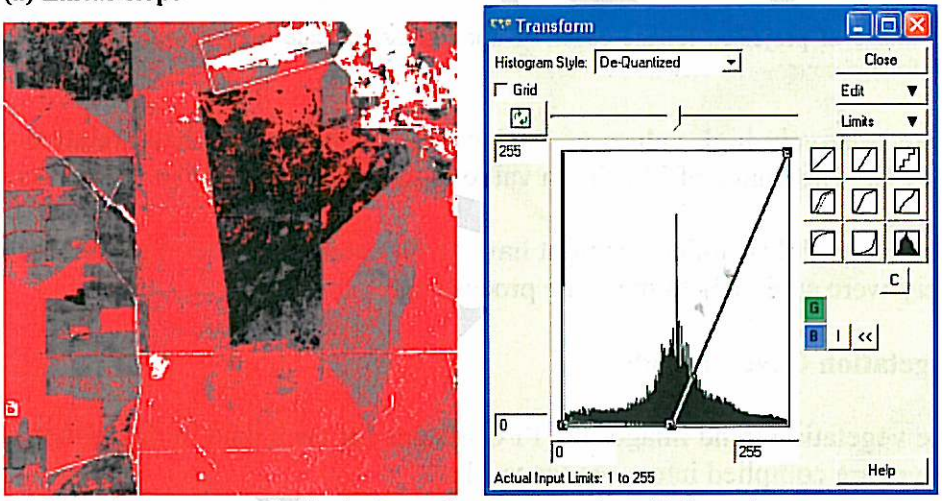
The 'Vegetation Cover Trend' image can be displayed to summarise trends and stability of vegetation over time as measured by the index, and in particular to highlight areas with different patterns of change. Simple summaries of trends over the period can be made by displaying positive and/or negative linear trends in different colours (see below) while other bands can be used to examine deviations from these trends.



Histogram Style: De-Quantized

Actual Input Limits: 1 to 255

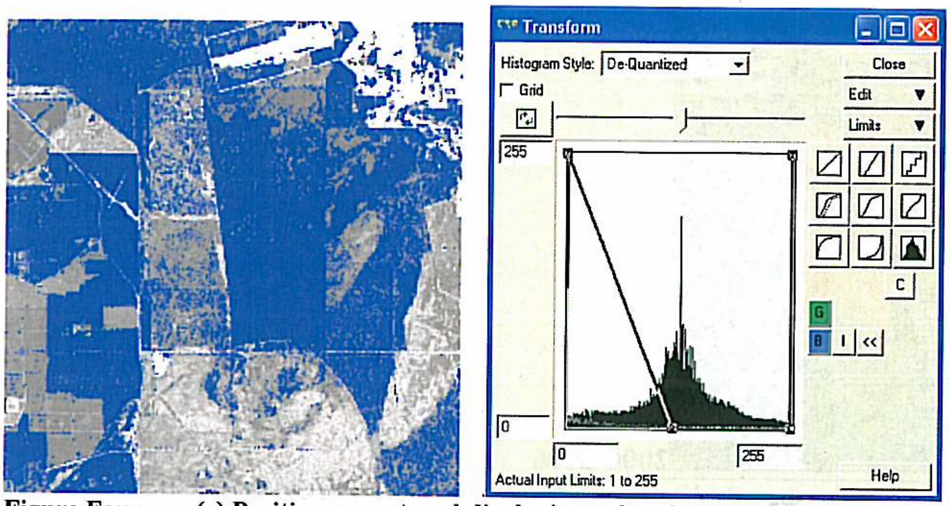
(a) Linear slope



Histogram Style: De-Quantized

Actual Input Limits: 1 to 255

(b) Negative cover trend, displaying values greater than 127 in red.



Histogram Style: De-Quantized

Actual Input Limits: 1 to 255

Figure Four: (c) Positive cover trend displaying values less than 127

The Linear Slope (a) above shows the vegetation trend cover, for a particular time period and location, with areas of light or white being negative cover trends (red) and areas of dark or black are positive cover trends (blue).

Figure Five below shows Vegetation Cover Trend image for the three nominated time periods, 1977-2006, 1996 – 2006 and 2000 – 2006 produced from the satellite image archive. The results display negative and positive linear cover index trends in red and blue respectively, recovering trends shown in green, stable as dark or black and yellow (red+green) being cover loss with partial recovery.

1977-2006

1996-2006

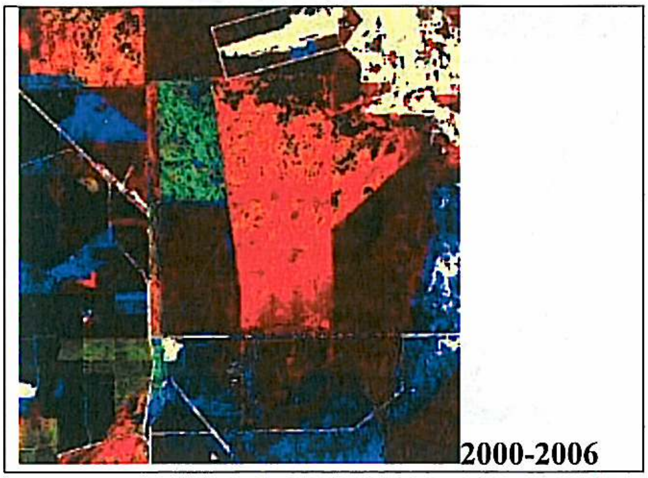


Figure Five Three time periods showing vegetation trends in various colours.

Discussion

The Gnangara Sustainability Study (GSS), which includes representatives from DEC, Dept. of Water, CSIRO, research institutions and individuals with an interest in vegetation monitoring, was established by the Western Australian Minister for the Environment, in 2006. The Gnangara Sustainability Study aim is to address this threat to the regional conservation values.

The causes of the problem and the mechanisms by which vegetation is affected are not yet understood. The Gnangara Sustainability Study is conducting research on these fundamental questions. An initial difficulty facing the research effort was the lack of a comprehensive picture of the location and extent of the problem.

Satellite imagery has been used to provide valuable monitoring information of changes in vegetation across the project area from 1977-2006. 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 have occurred. The changes at particular sites can be quantified and compared using graphical plots of the responses over time.

This information provides a means to produce a comprehensive assessment of the problem, to direct ground work and site selection, to extrapolate from limited field observations, and to locate sites for detailed research work. Knowing the location and timing of affected and unaffected areas may assist in identifying causes of the problem.

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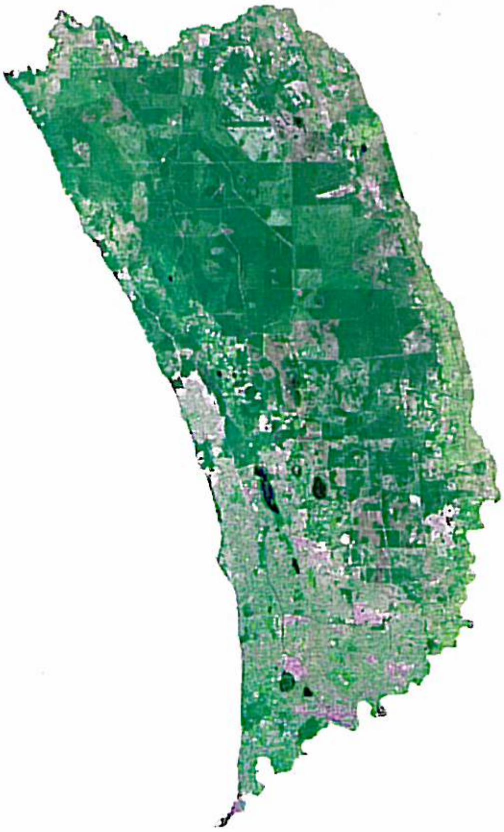
Gnangara Sustainability Strategy
An across-government initiative

Groundwater - Biodiversity - Land use

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



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Department of Environment and Conservation

September 2009

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WATER CORPORATION
CSIRO
Forest Products Commission WESTERN AUSTRALIA

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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Gnangara
Sustainability
Strategy

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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Contents

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

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)

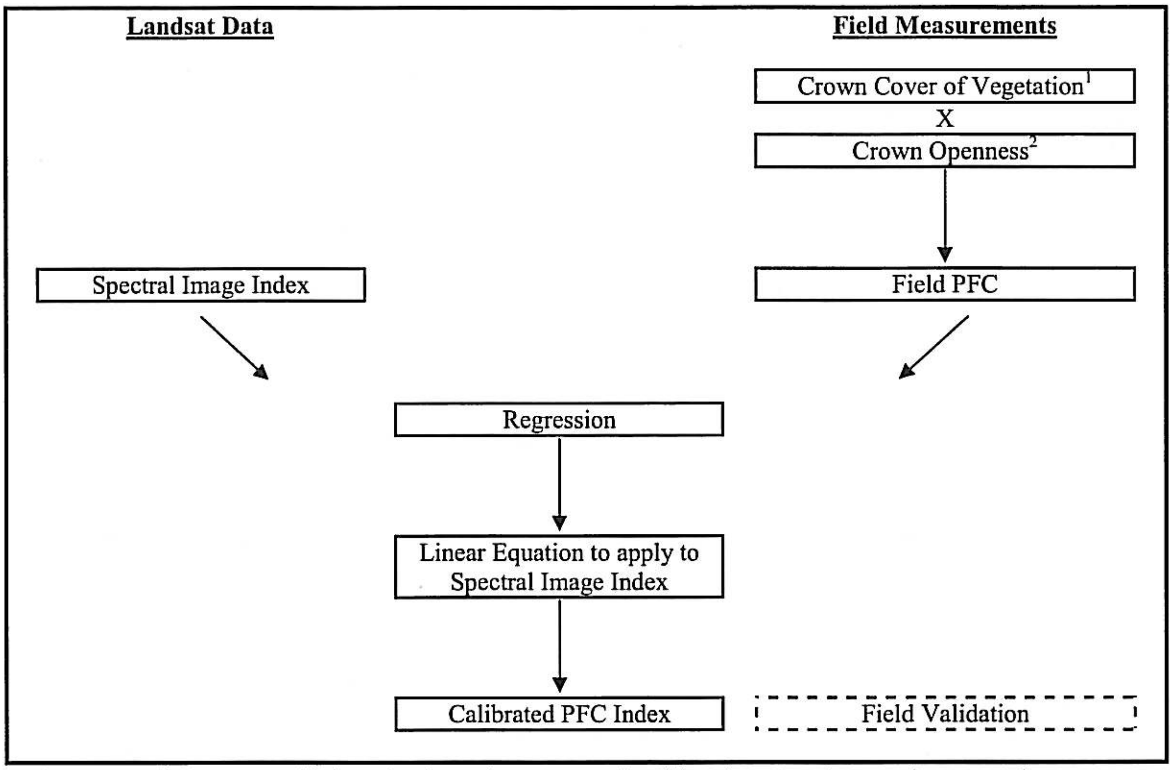

Figure 1: Diagram outlining the broad process of calibrating Landsat estimates of vegetation cover with ground measurements. Definitions of items in superscript are as follows:

[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.

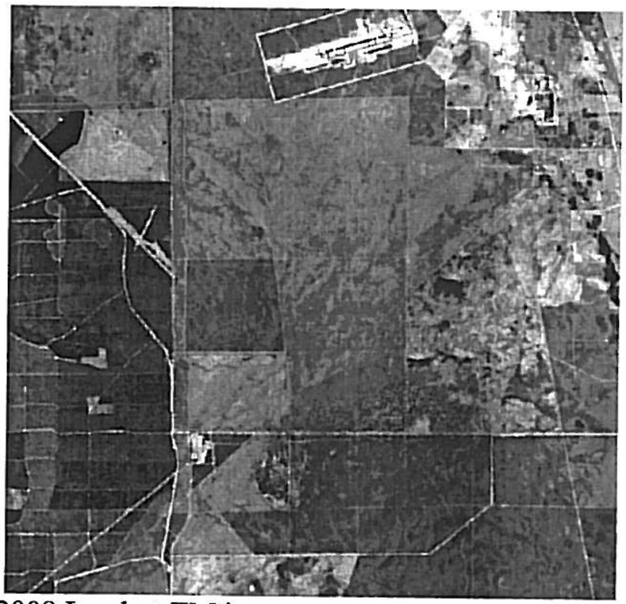

Figure 2: Band 3 of 2008 Landsat TM imagery.

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:

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

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).

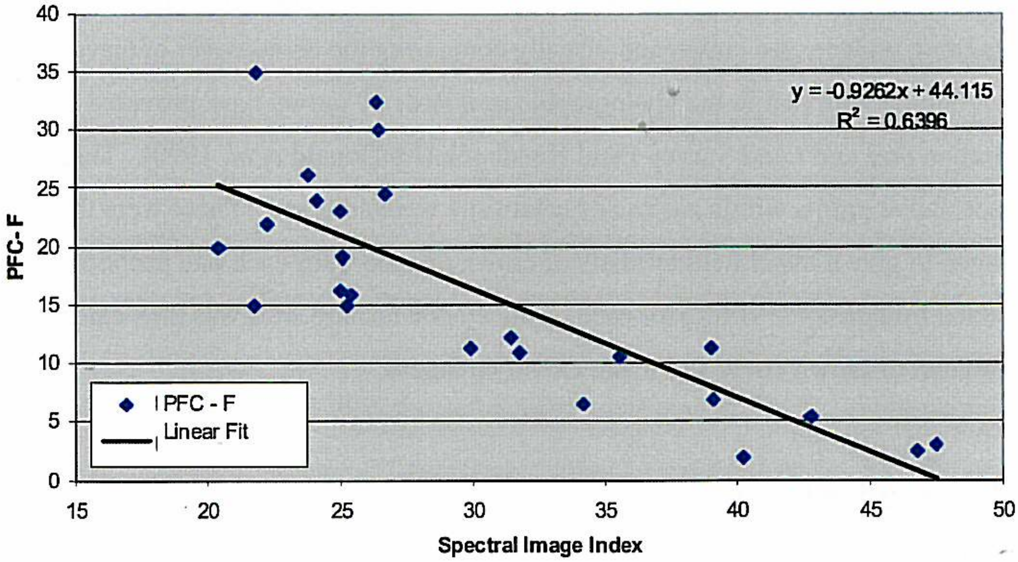

Figure 3: Mean values of the field Cover Estimates for each site were regressed against the estimated PFC values from the Band 3 image.

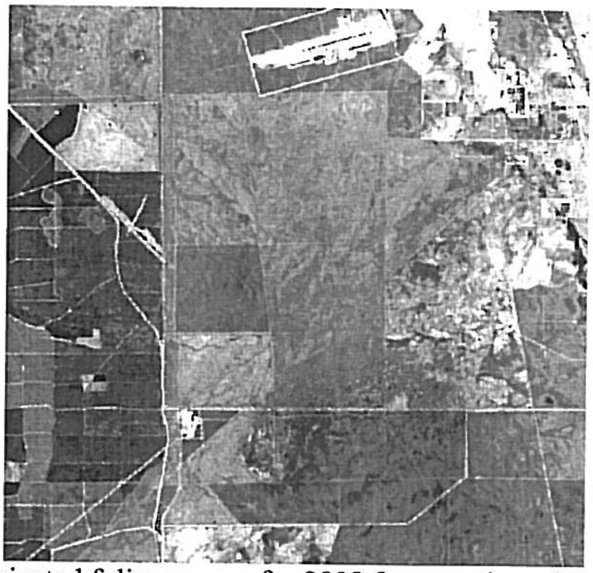

Figure 4: Image of projected foliage cover for 2008 for a portion of the GSS Study Area. Darker areas indicate high values of calibrated PFC while light areas have low values of calibrated PFC.

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.

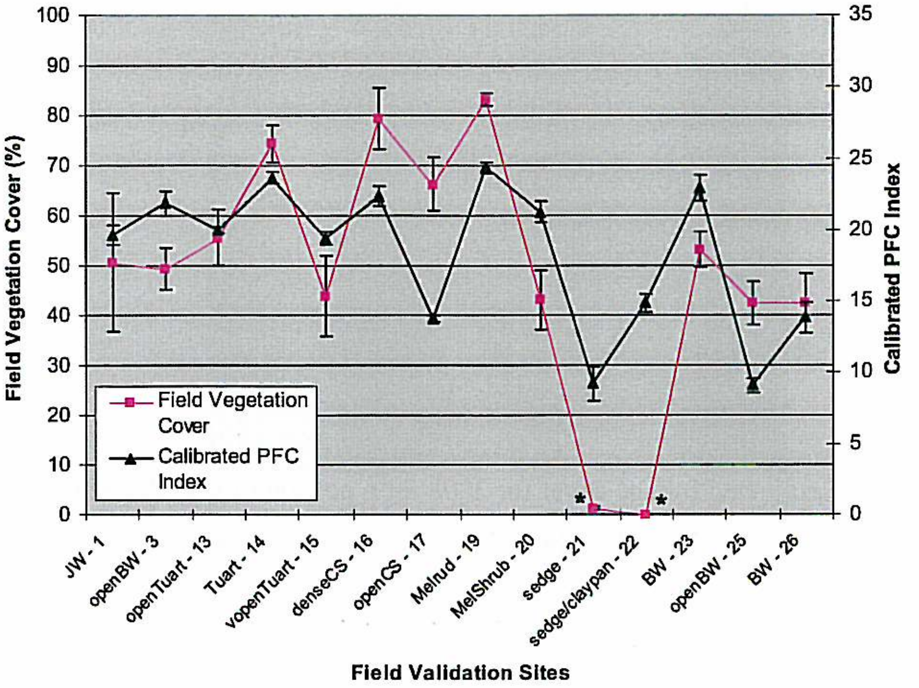

Figure 5: Mean field Total Aerial Vegetation Cover estimates and Calibrated PFC Index values for field validation sites. Vegetation Type codes are: JW = Jarrah Woodland, BW = Banksia Woodland, CS = Coastal Scrub, Sedge, Tuart, Melrud = Melaleuca rudis woodland, Melshrub = Melaleuca shrubland. Recently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

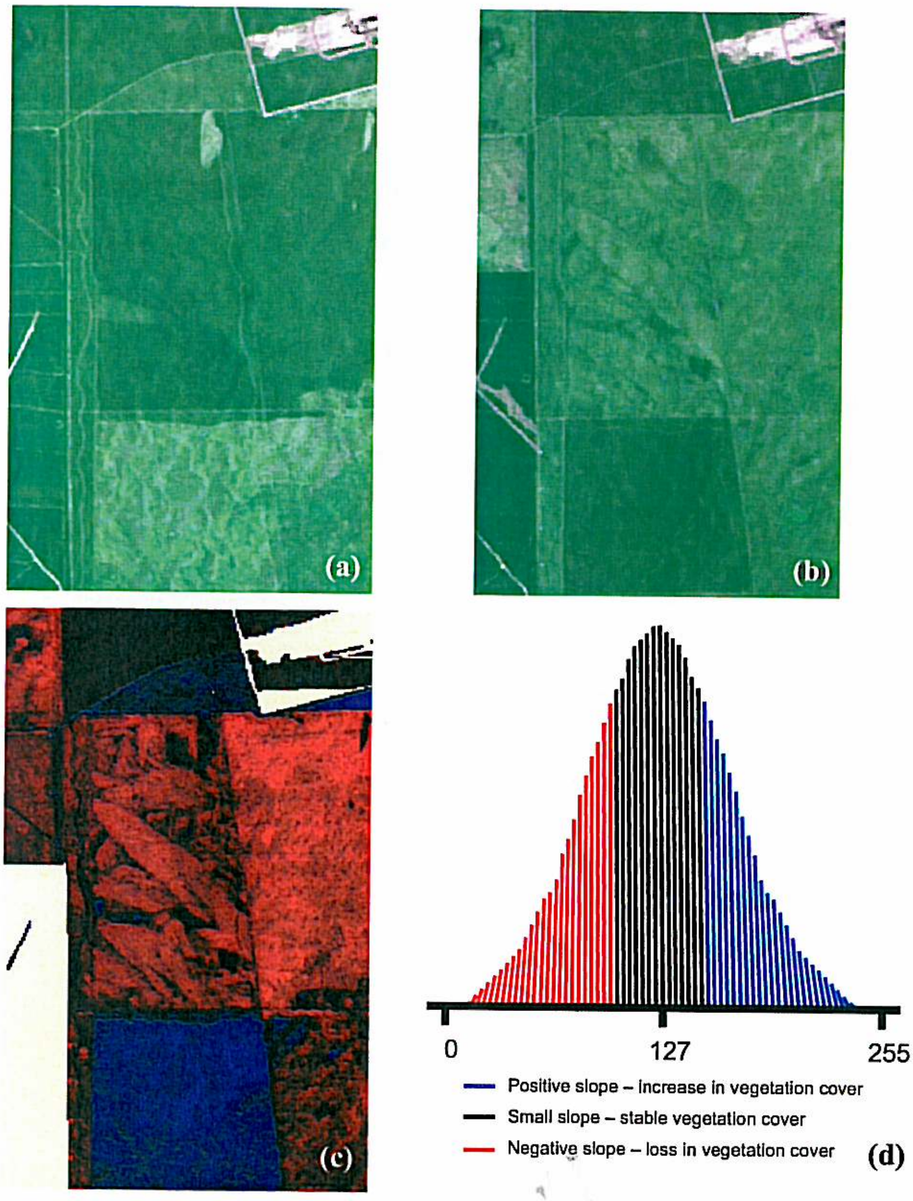

Figure 6: Satellite imagery and linear trends for remnant vegetation south west of the Gingin Airfield: (a) 1992 Landsat image bands 3,4,2 in red, green, blue; (b) 2008 Landsat image bands 3,4,2 in red, green, blue; (c) Linear Trend image 1992 to 2008 displaying negative linear trend in red, positive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

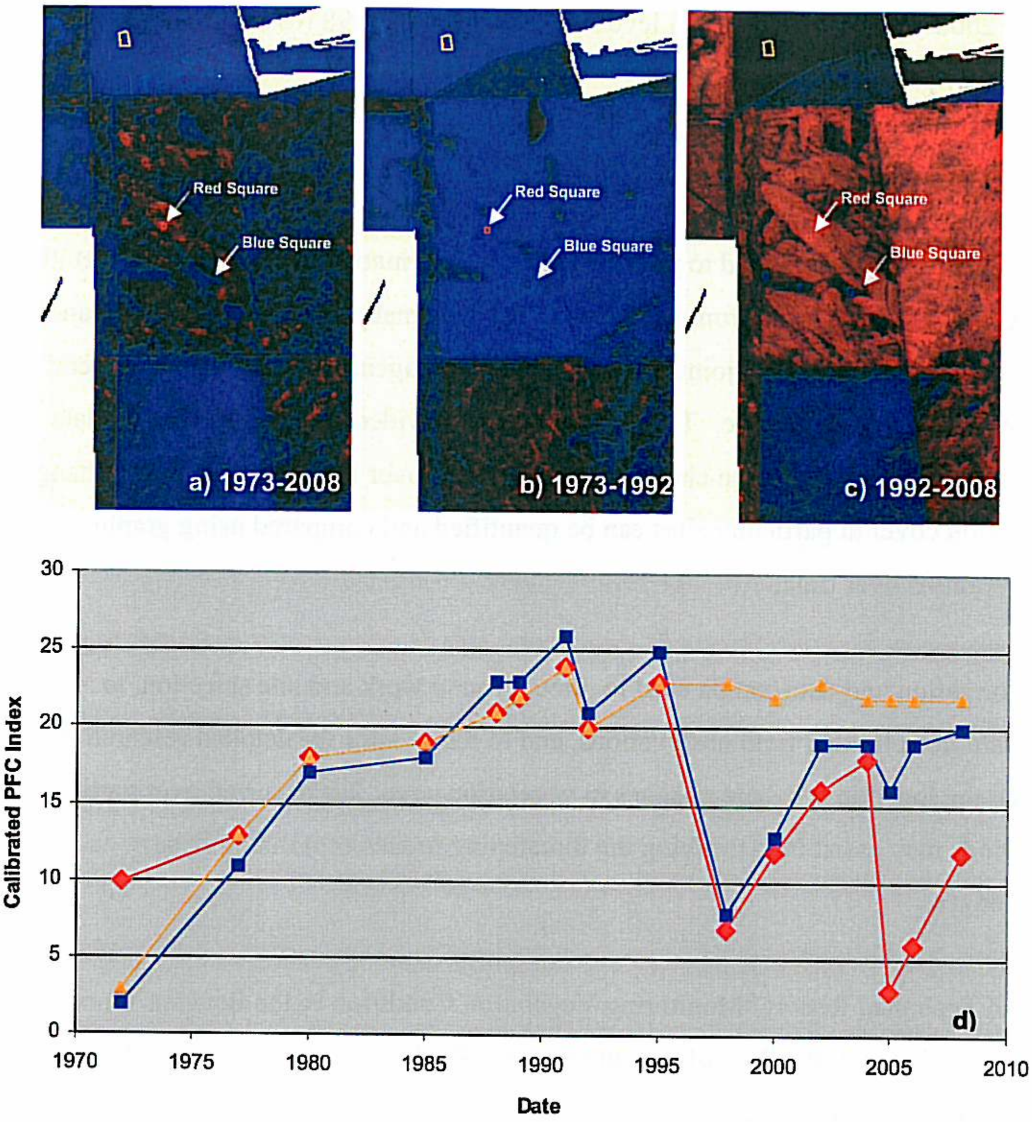

Figure 7: Linear trends for the remnant vegetation south-west of the Gingin airfield for a) 1973 – 2008, b) 1973 – 1992, c) 1992 – 2008 and a plot of calibrated PFC Index values for all image dates, in the image archive, for remnant vegetation within the selected areas outlined by the red, orange and 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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Gnangara
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Groundwater - Biodiversity - Land use

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

Janine Kinloch, Katherine Zdunic, Graeme Behn and Barbara Wilson

Department of Environment and Conservation

November 2009

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Monitoring Vegetation Condition in the *Banksia* woodland of the Gnangara Mound: the role of Remote Sensing Tools

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

Janine Kinloch, Katherine Zdunic, Graeme Behn and Barbara Wilson

Department of Environment and Conservation

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November 2009

Gnangara
Sustainability
Strategy

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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Contents

Monitoring Vegetation Condition in the *Banksia* Woodlands of the Gnangara Mound: the Role of Remote Sensing Tools

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)

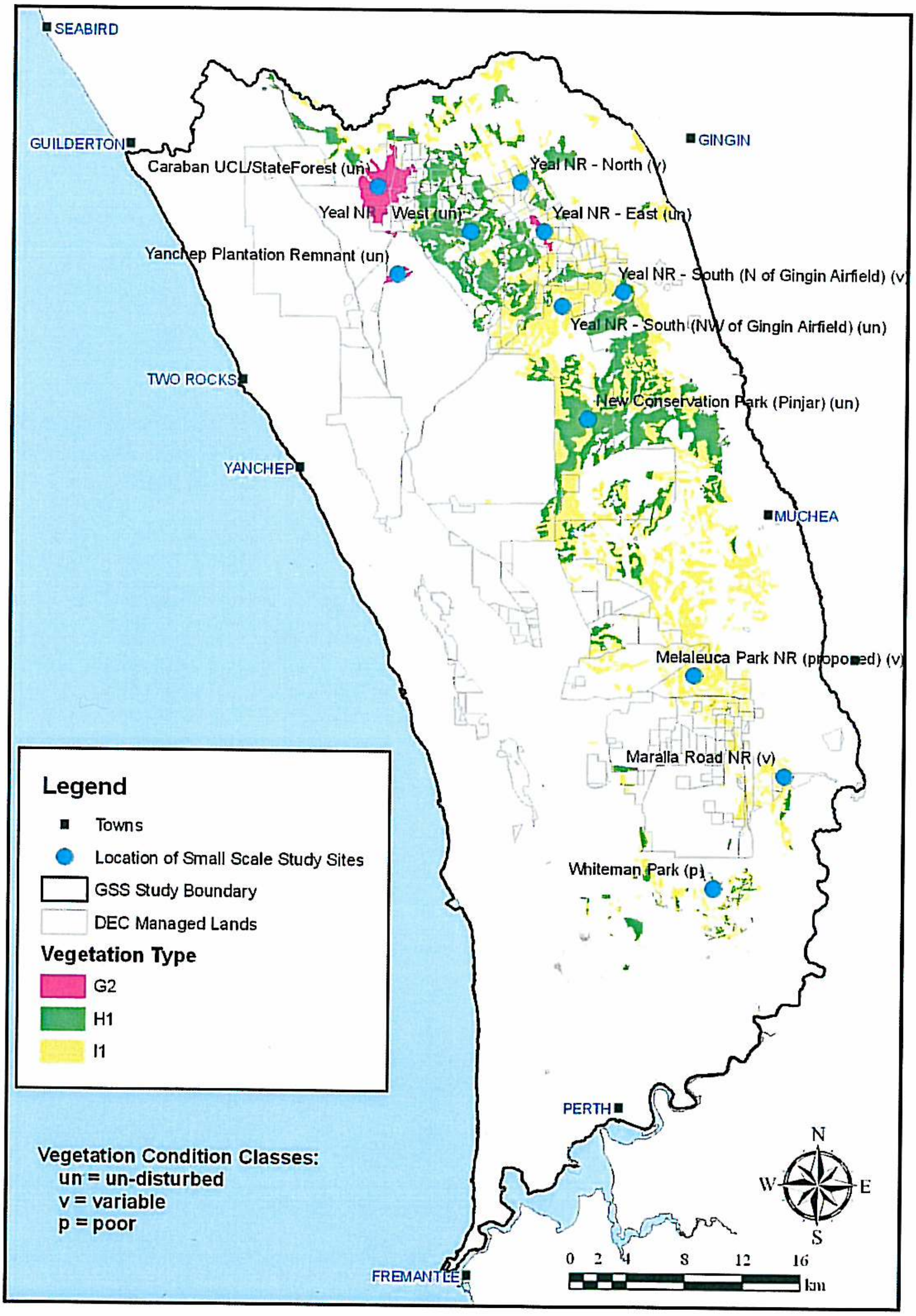


Figure 1: Location Map showing the extent of I1, H1 and G2 vegetation types on the Gnangara Mound and the location of the small scale study sites.

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).

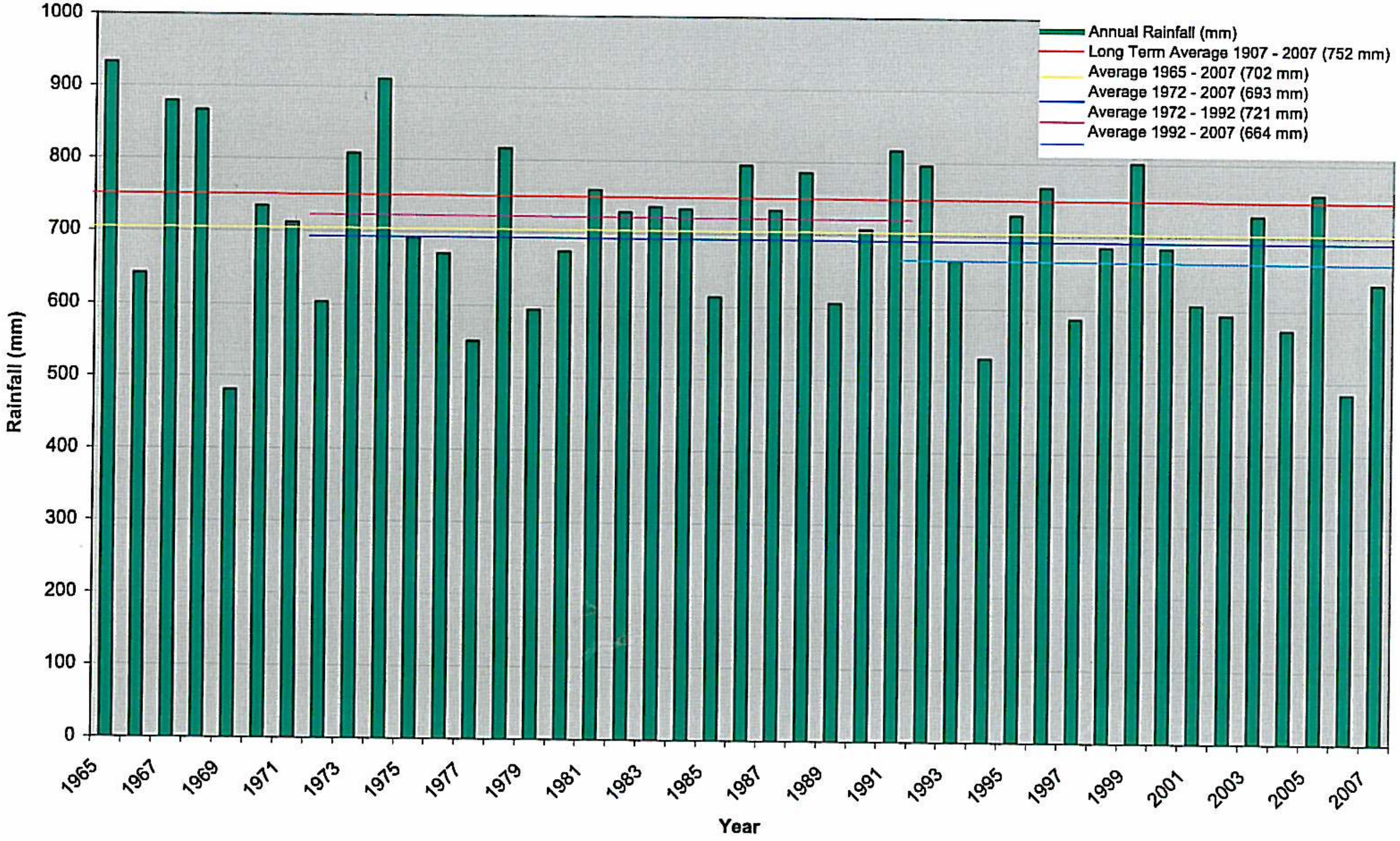


Figure 2: Mean annual rainfall for four meteorological stations across the Gnangara Mound (Allambie, Perth Airport, Muchea Tree Farm, Yanchep) for the period of 1907 – 2007. Rainfall data for each station is a combination of observations and interpolated data to fill any gaps ('patch') in the record.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

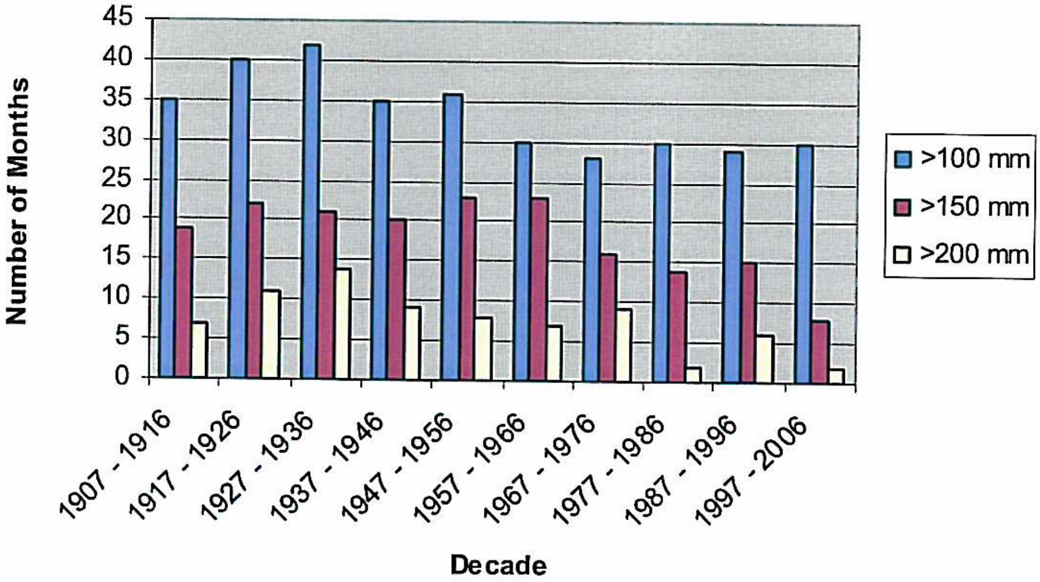


Figure 3: Frequency of wet months for the last ten decades at the Perth Airport. Rainfall data is a combination of observations and interpolated data to fill any gaps ('patch') in the record. Data source: Patched Point Dataset http://www.nrw.qld.gov.au/silo/.

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.

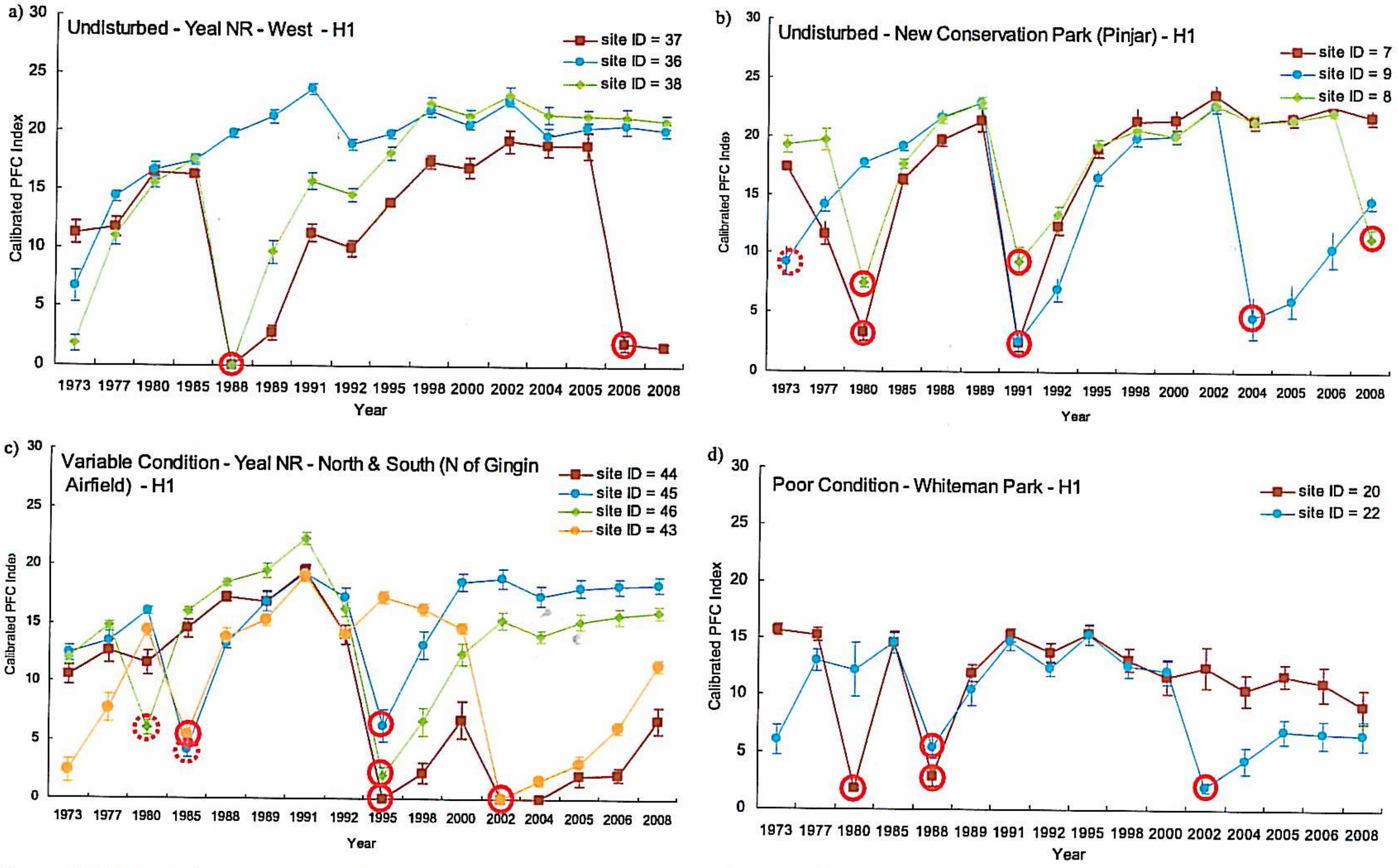
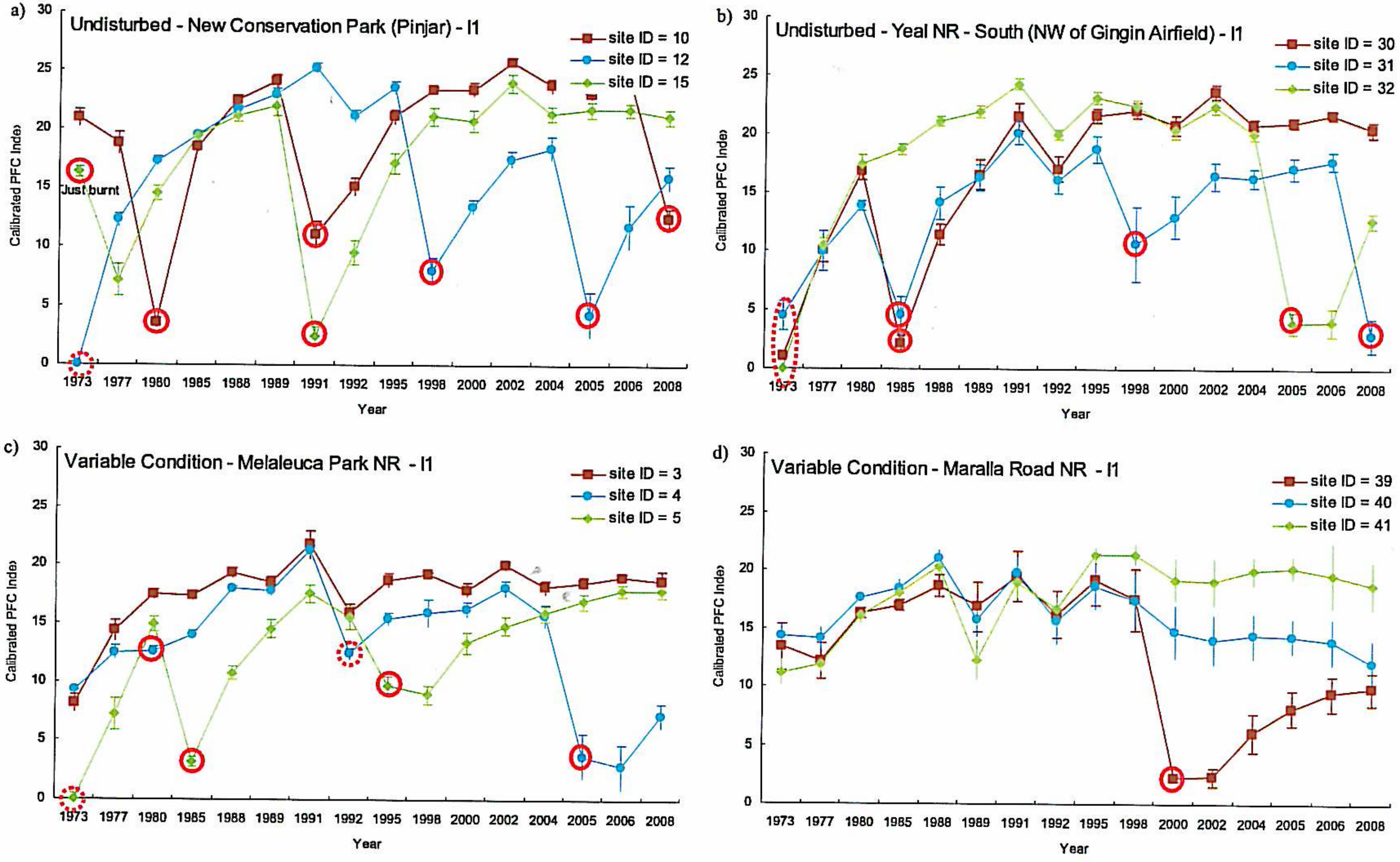


Figure 4: Mean and standard deviation of calibrated PFC Vegetation Cover Index values, over 35 years, on (a) and (b) un-disturbed, (c) variable condition and (d) poor condition small scale sites on Vegetation Type H1. Years when the site was burnt are indicated with a red circle. Dashed circles indicate 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
0
5
10
15
20
25
30
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

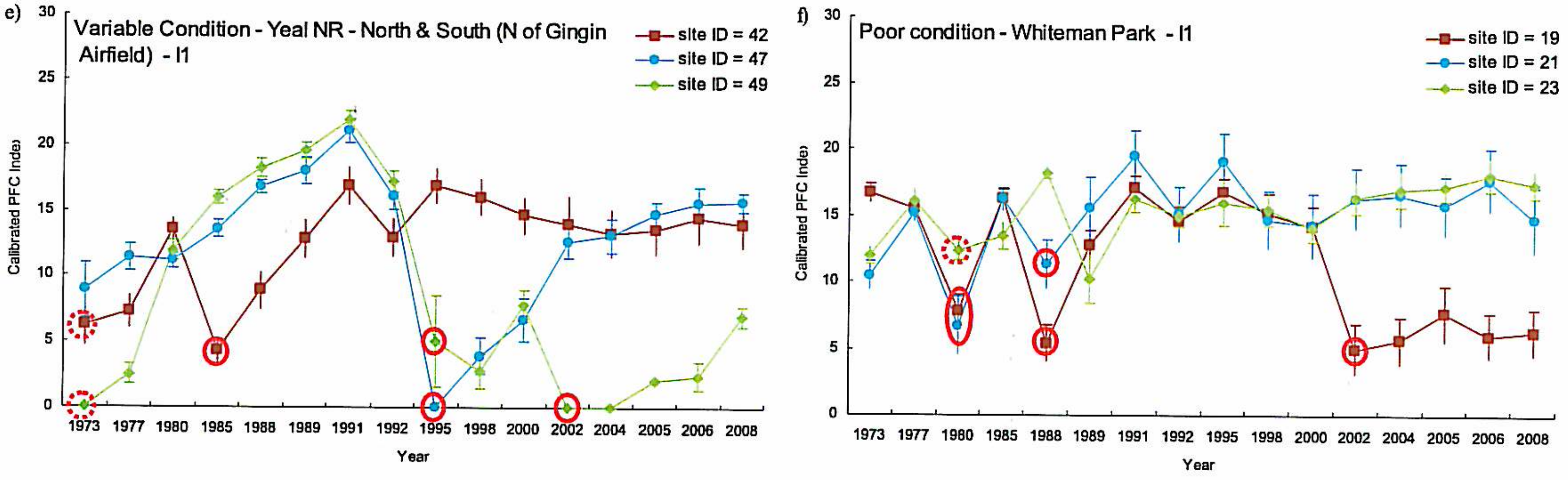


Figure 5: Mean and standard deviation of PFC Vegetation Cover Index values, over 35 years, on (a) and (b) un-disturbed, (c), (d) and (e) variable condition, and (f) poor condition small scale sites on Vegetation Type I1. Years when the site was burnt are indicated with a red circle. Dashed circles indicate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

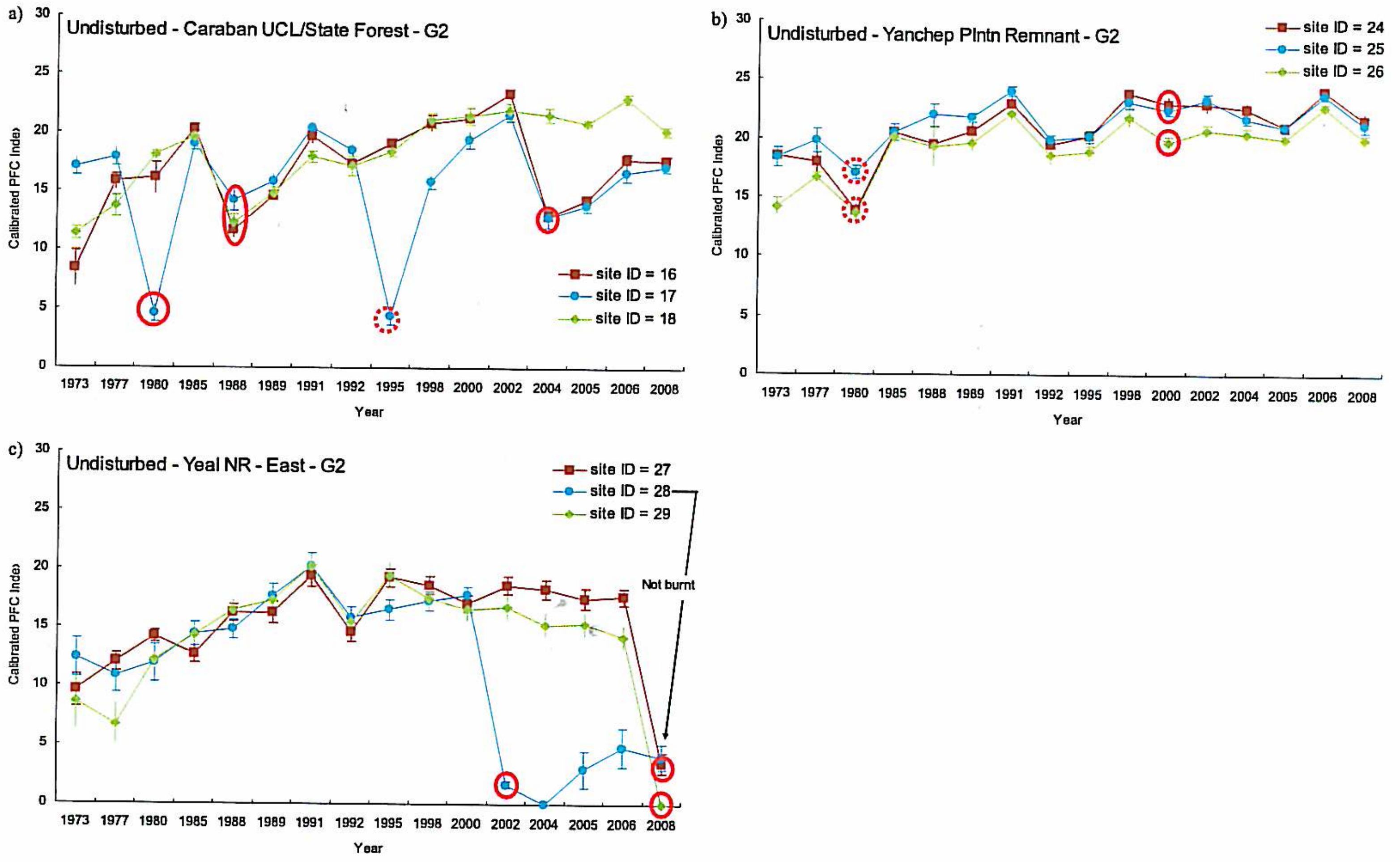


Figure 6: Mean and standard deviation of PFC Vegetation Cover Index values, over 35 years, on (a), (b) and (c) un-disturbed small scale sites on Vegetation Type G2. Years when the site was burnt are indicated with a red circle. Dashed circles indicate uncertainty of year of fire event due to the time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

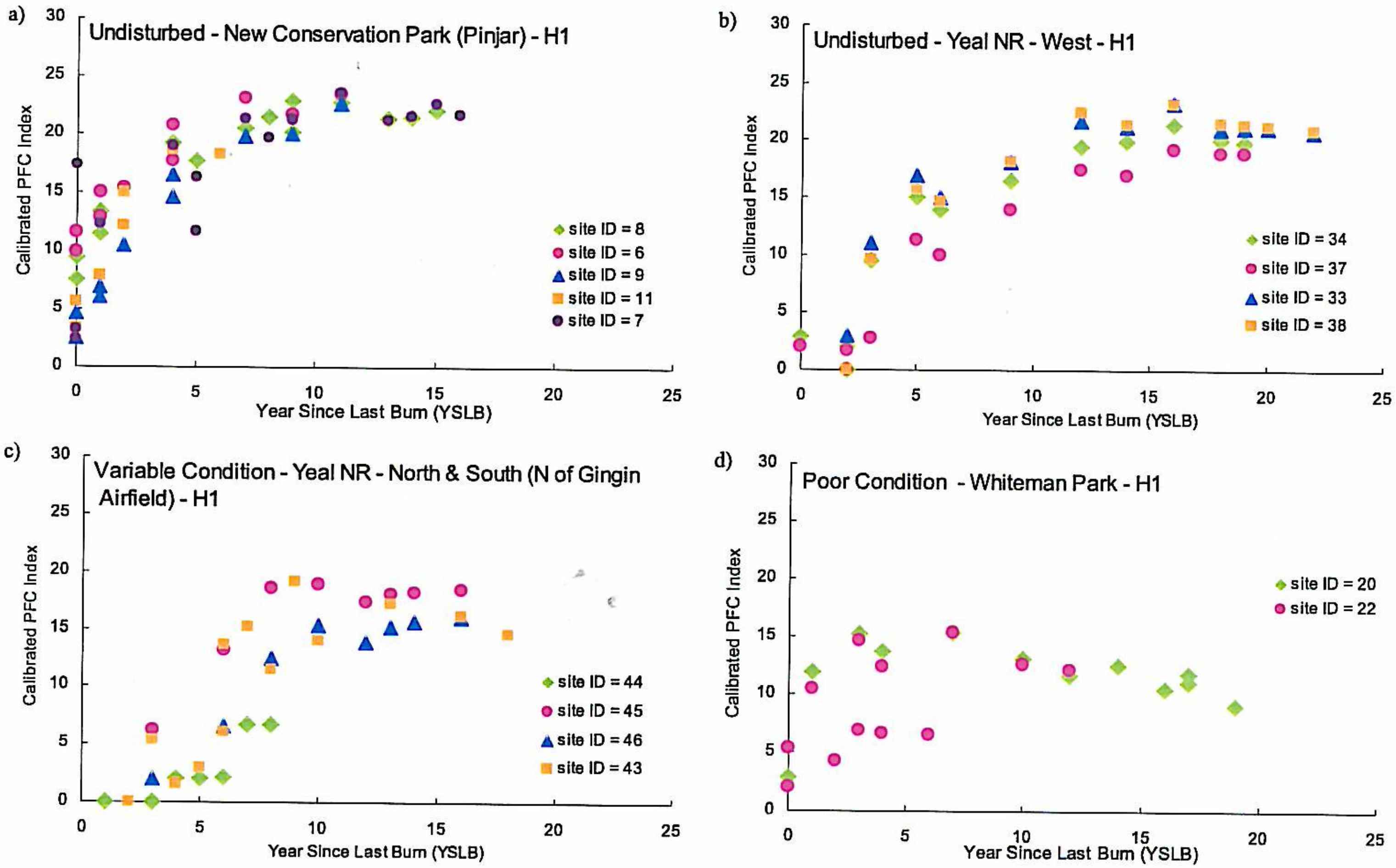
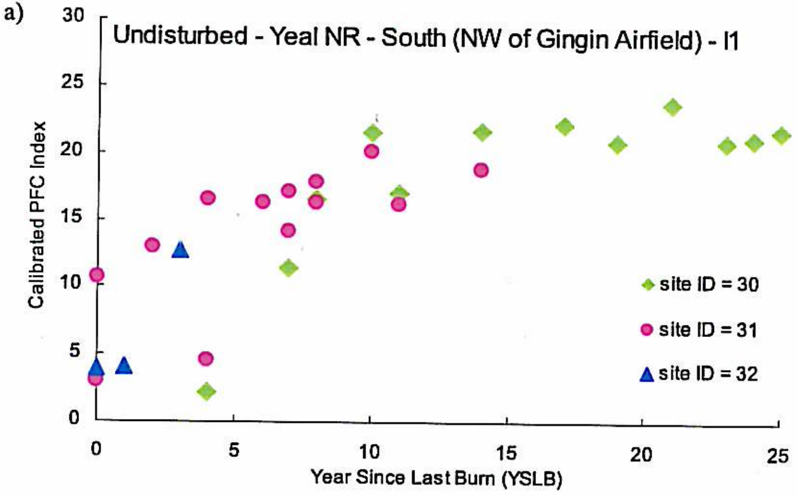
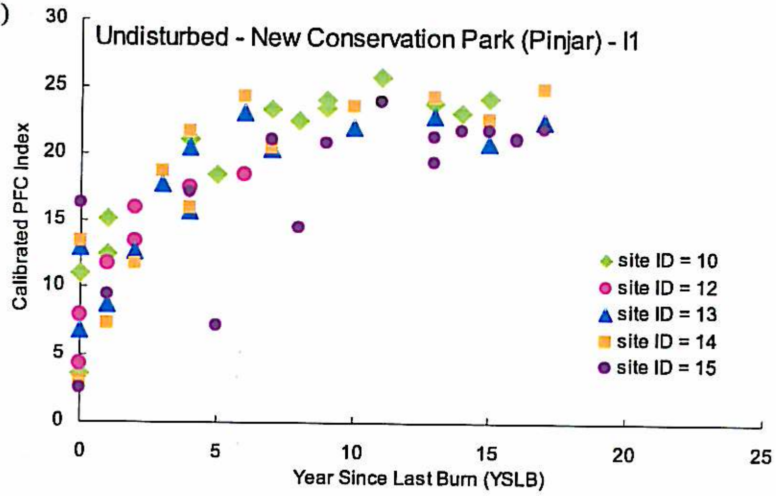


Figure 7: Mean PFC Vegetation Cover Index values in relation to year since last burn (YSLB) for (a) and (b) un-disturbed, (c) variable condition and (d) poor condition sites on vegetation type H1.

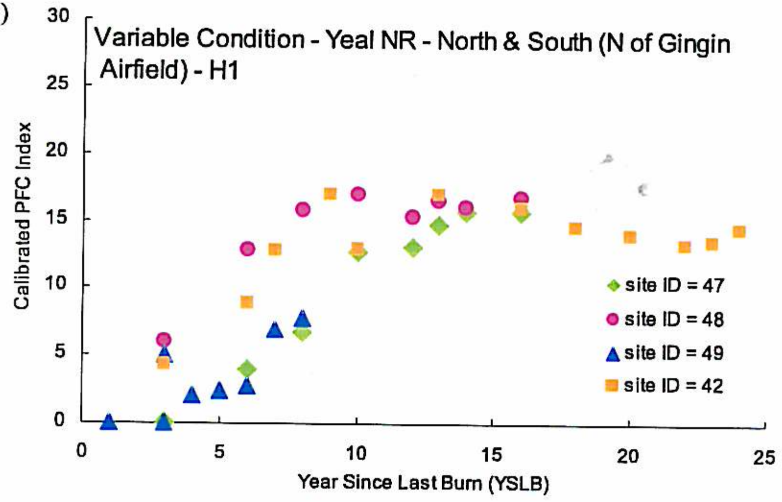
a)


Undisturbed - Yeal NR - South (NW of Gingin Airfield) - I1
Calibrated PFC Index
30
25
20
15
10
5
0
0
5
10
15
20
25
Year Since Last Burn (YSLB)
site ID = 30
site ID = 31
site ID = 32

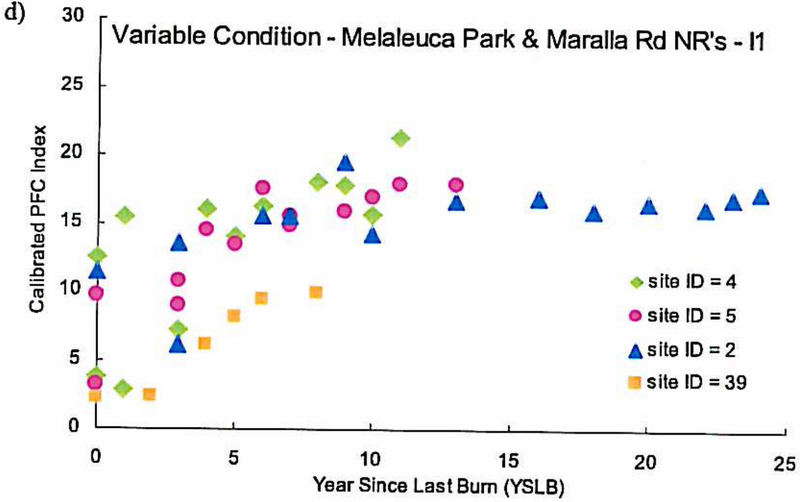
b)


Undisturbed - New Conservation Park (Pinjar) - I1
Calibrated PFC Index
30
25
20
15
10
5
0
0
5
10
15
20
25
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
30
25
20
15
10
5
0
0
5
10
15
20
25
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
30
25
20
15
10
5
0
0
5
10
15
20
25
Year Since Last Burn (YSLB)
site ID = 4
site ID = 5
site ID = 2
site ID = 39

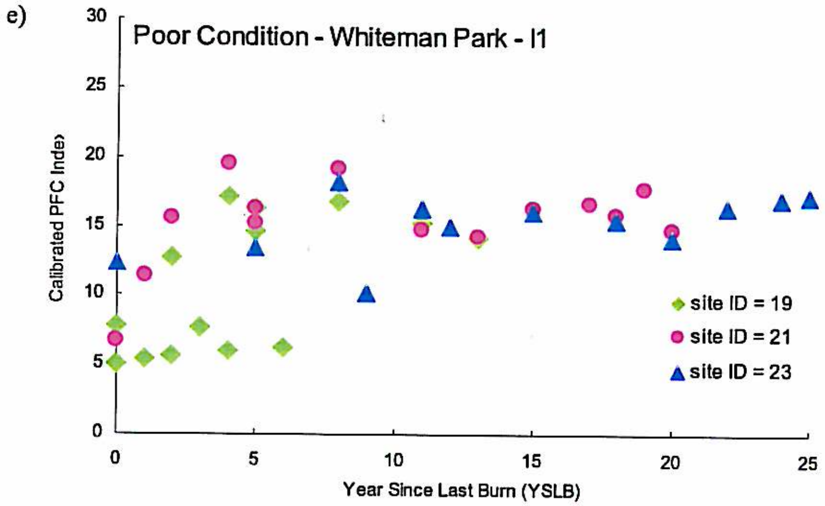


Figure 8: Mean PFC Vegetation Cover Index values in relation to year since last burn (YSLB) for (a) and (b) un-disturbed, (c) and (d) variable condition and (e) poor condition sites on vegetation type I1.

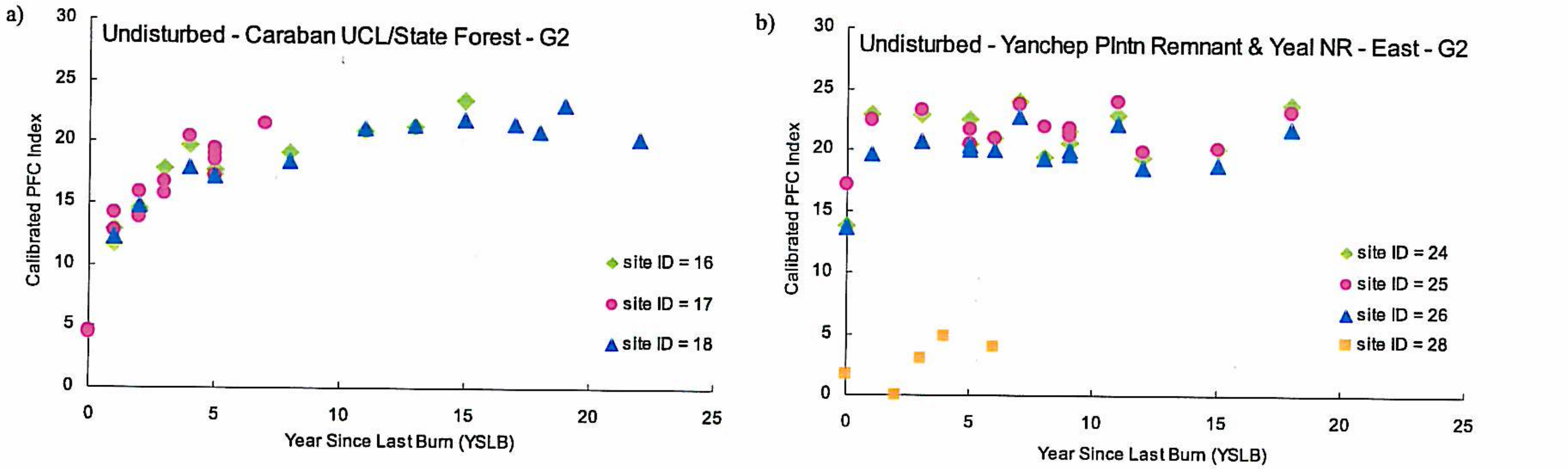


Figure 9: Mean PFC Vegetation Cover Index values in relation to year since last burn (YSLB) for (a) and (b) un-disturbed sites on vegetation type G2.

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**

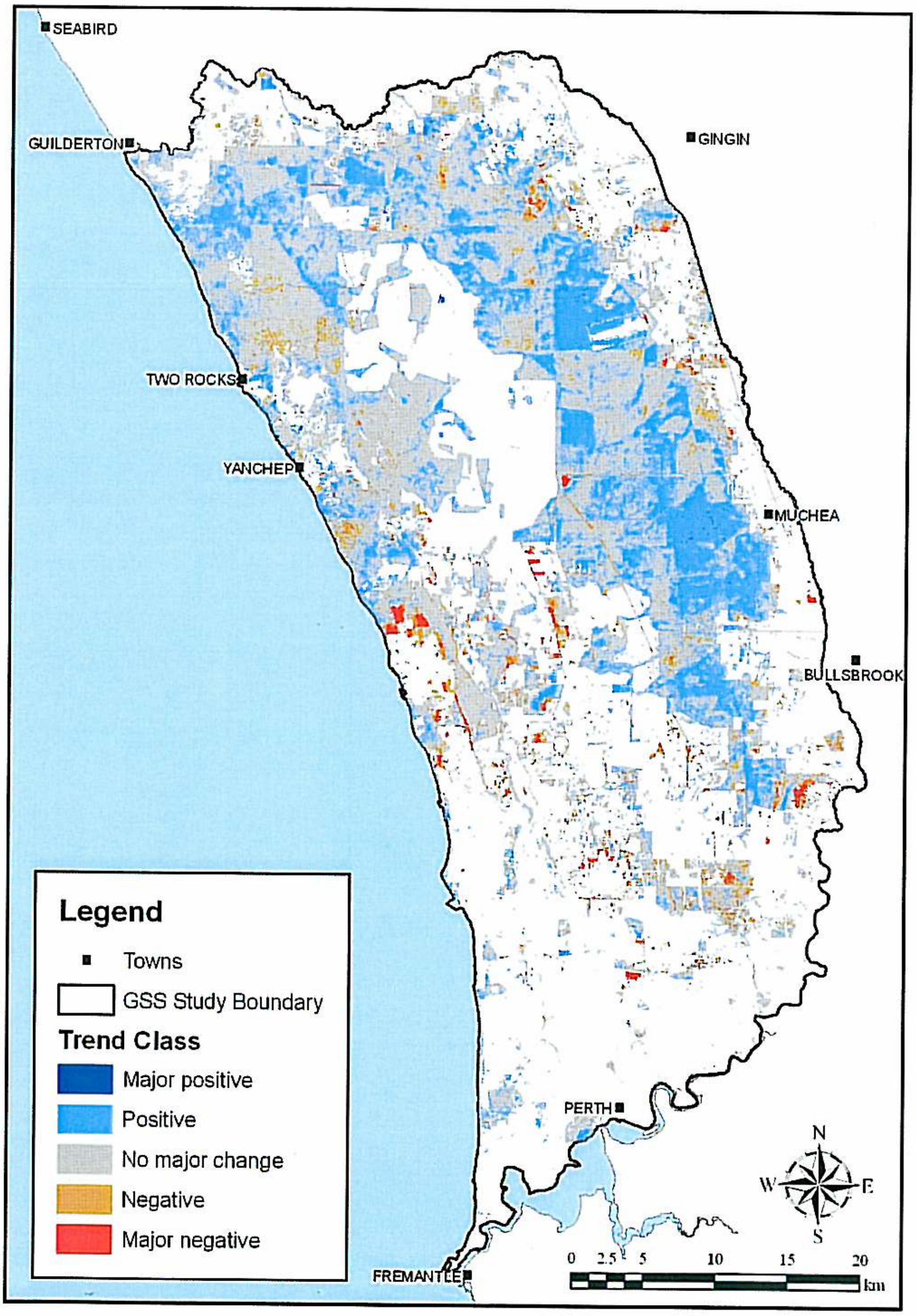


Figure 10: Landsat linear trend classes for 1973 – 2008 for the 2005 extent of remnant vegetation across the GSS study area. Codes on trend classes are major positive: large increasing trend in vegetation cover; positive: increasing trend in vegetation cover; no major change: no major change in vegetation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

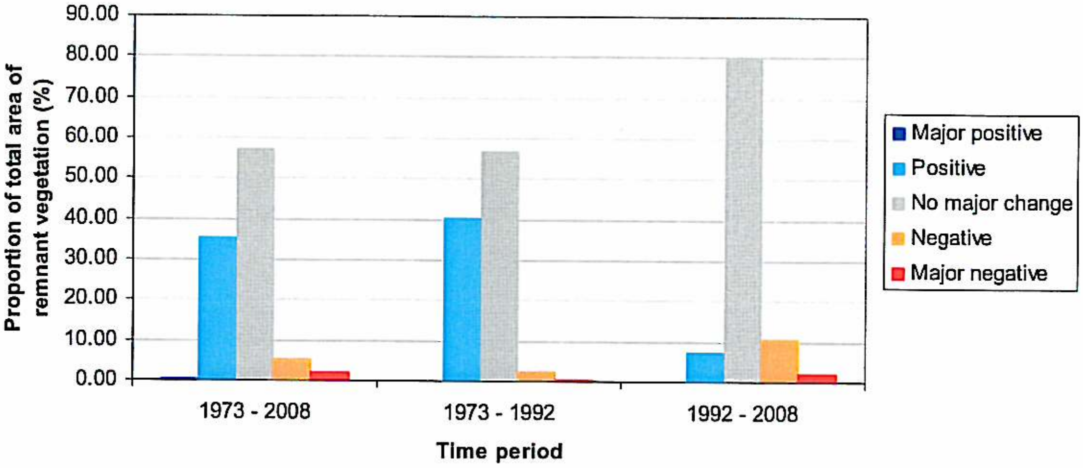


Figure 11: Proportion of total area of 2005 extent of remnant vegetation in each Linear trend class for three time periods 1973 – 2008; 1973 – 1992; 1992 – 2008.

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:

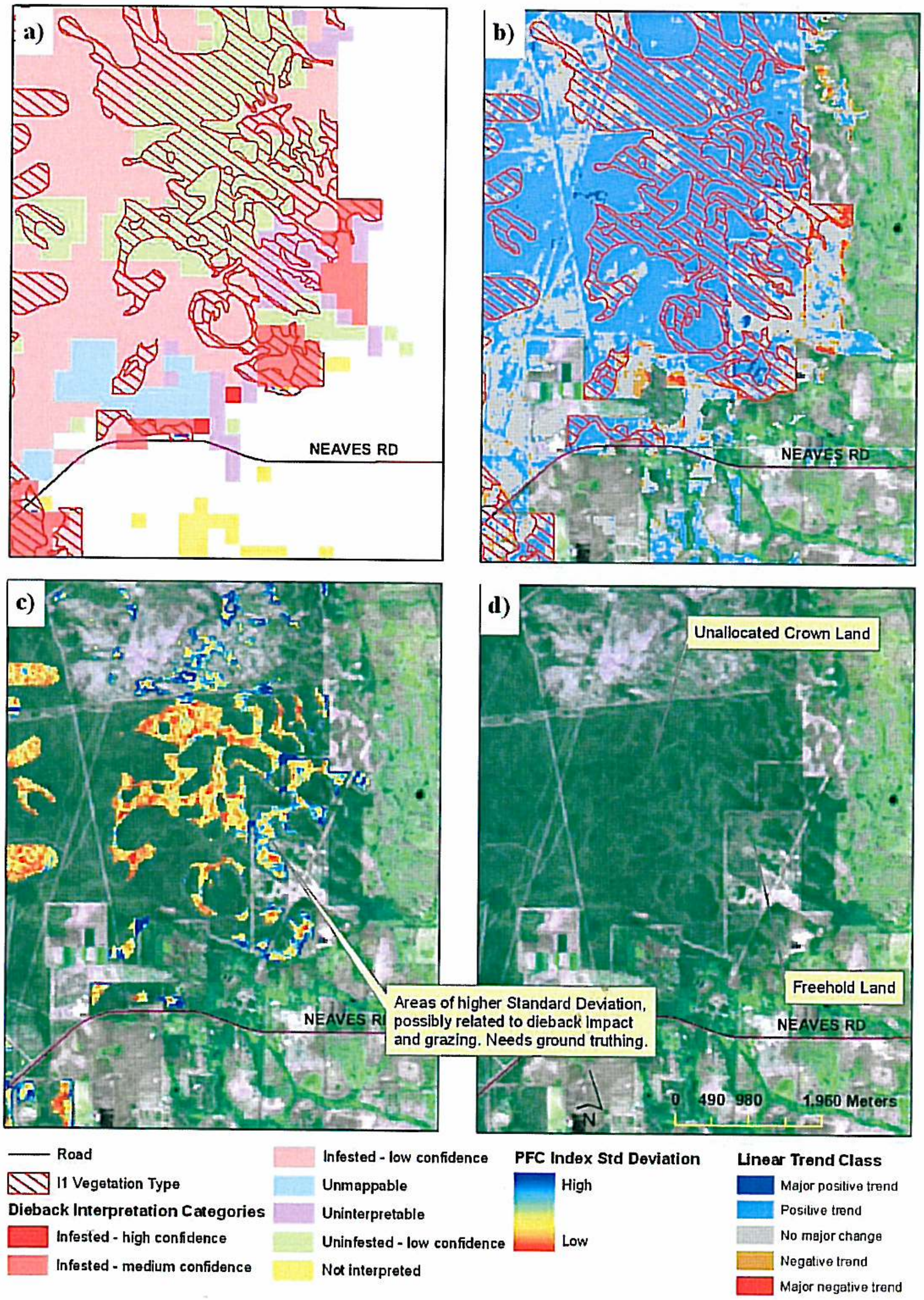
- Un-disturbed - PFC Cover Index values between 17 and 25.
- Poor condition – PFC Cover Index values between 10 and 16.

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).



Areas of higher Standard Deviation, possibly related to dieback impact and grazing. Needs ground truthing.

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 5 x 5 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

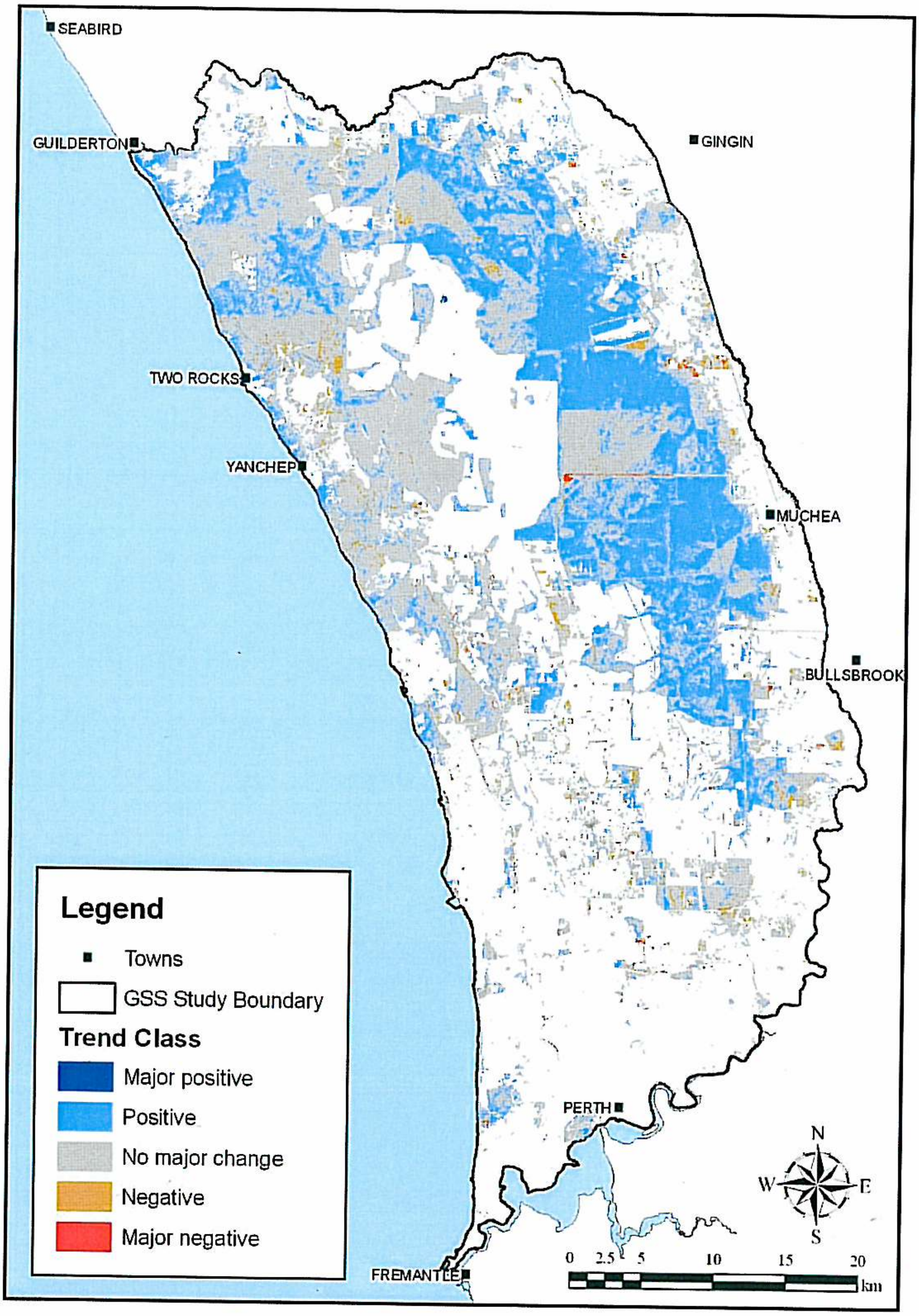
Small Scale Study Sites		Vegetation Type	Condition Class	Dieback Interpretation Category	Fire History				Maximum cover 1973 - 2008	Linear Trend Class
Site Name	ID				Verified YSLB	# of burns 1977 - 2008	1973 burn status	Maximum length of time with no burn		
New Conservation Park (Pinjar)	8	H1	Un-disturbed	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

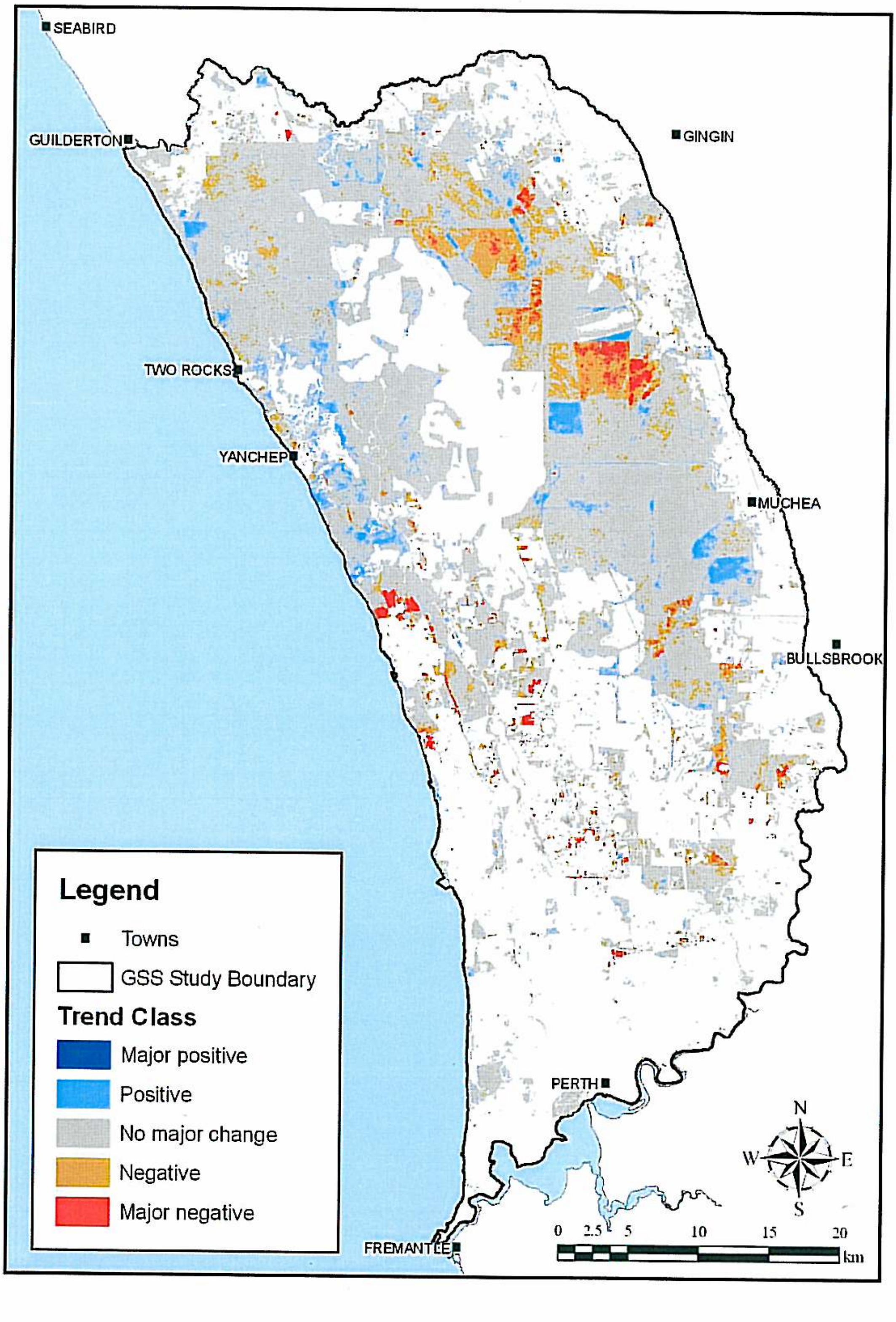
Appendix B: Landsat Linear Trend classes 1973 – 1992

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

MONITORING RIPARIAN VEGETATION WITHIN MILLSTREAM-CHICHESTER NATIONAL PARK

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Abstract

Millstream-Chichester National Park is set within the semi-arid Pilbara region of Western Australia. The national park covers about 200,000 hectares in the central west Pilbara district, including a series of freshwater springs on the Fortescue River, flowing from a calcrete aquifer and supporting dense riverine vegetation.

Knowledge of the variation in vegetation density is a basic information requirement for resource and environmental management purposes. This is acknowledged by government agencies charged with the responsibilities of land and water management. The Millstream aquifer was a major source of fresh water supply to coastal towns of the west Pilbara, and until the Harding dam was commissioned in the mid 1980's it was the only source. An understanding of the interaction of water draw-down and vegetation response to the draw-down will assist in management processes. To date only isolated mapping or knowledge of the whereabouts of any vegetation changes has occurred. This report describes the methods and findings of a project which analysed satellite remotely sensed data to locate and monitor variations within the riparian vegetation zones at Millstream.

Satellite remote sensing technologies were seen as the most appropriate means of monitoring the vegetation dynamics as it provided a consistent and un-biased look at the historical events that have impacted the vegetation. It provided the area coverage plus the spectral sensitivity to accurately discriminate density of vegetation cover.

Introduction

Multispectral remote sensing offers an alternative to that of traditional one-off aerial photography and ground survey methods of mapping. Ground based methods are not well suited to estimation of the areal extent of vegetation density variations and along with aerial photography are not easily repeated, are labour intensive, time consuming and expensive.

Satellite data from sensors with fixed, broad spectral bands can provide routine broad-scale synoptic coverage, subject to suitable weather conditions. If the multispectral data can reliably identify the vegetation cover densities then it offers an attractive complementary approach to mapping vegetation.

Previous research conducted by the Department of Conservation and Land Management (CALM), WA has demonstrated the feasibility of detecting these variations using rectified satellite imagery. Some of these results have been used to map forest occurrences using percentage foliage cover (PFC) estimates, within the Kimberley and Goldfield regions of Western Australia (Behn *et al.* 2001).

This project used similar techniques to map the vegetation cover densities. The successful application of such a technique provides a method of mapping the locations at a better resolution than is possible with current techniques. This will have a variety of benefits for many agencies interested in vegetation management and monitoring.

The primary objectives of the project were:

- Develop a common remote sensing methodology for reliable monitoring the vegetation cover (current extent), within the project area, and
- Use multiple (16 sequential dates) Landsat TM satellite images (1979 - 2003) to map the riverine vegetation variation within the project area.

Satellite Imagery

TM data provide routine broad-scale coverage of an area and is ideal for monitoring change. The ground picture element (pixel) size (25m for TM and 50m for MSS imagery) is practical for broad-area surveys and gives results appropriate for resolution with at least several trees and shrubs per pixel and several pixels per homogeneous area. The ability to monitor change also becomes possible with the ability to co-register and analyse imagery from various dates.

Thematic Mapper (TM) 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. Band six is located in the thermal infrared part of the spectrum whilst Multispectral (MSS) imagery had 4 four band, bands one and two in the visible, band three in the near-infrared and band four in the short-wave infrared.

Cloud-free Thematic Mapper images were geometrically corrected to the GDA94 datum and in MGA50 map projection, using nearest neighbour transformation. Table One and Figure One below show the date and type selected for the project.

Date	Landsat	Pixel Size (m)
14/11/79	MSS	50
25/10/81	MSS	50
20/11/83	MSS	50
16/12/84	MSS	50
17/11/85	MSS	50
04/11/86	MSS	50
09/12/87	MSS	50
28/11/89	TM	25
18/01/91	TM	25
06/02/92	TM	25
28/01/94	TM	25
02/11/97	TM	25
18/11/00	TM	25
08/01/02	TM	25
24/11/02	TM	25
12/02/03	TM	25

Table One: *Date and type of satellite imagery used for the project.*

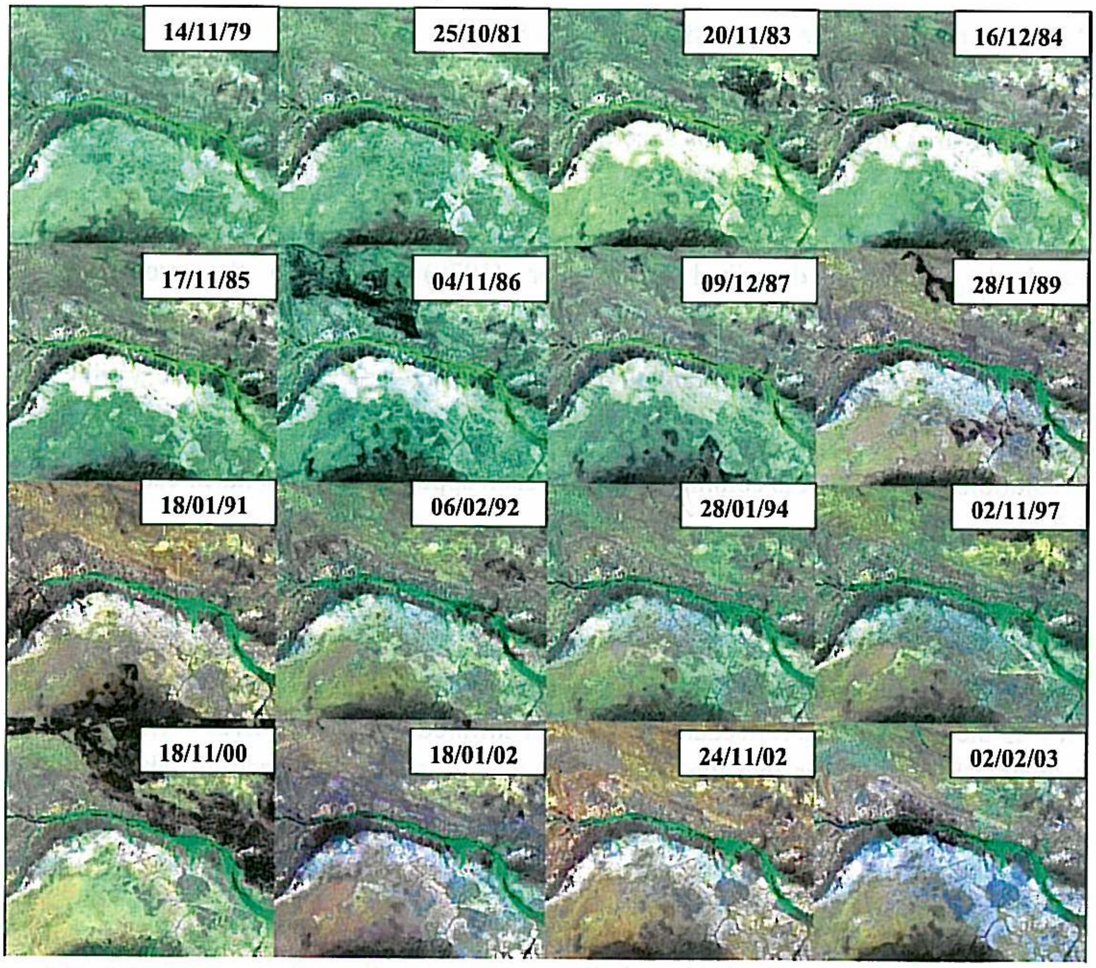

Figure One: *Historical sequence of satellite imagery covering the project area.*

Spectral Index

The reflectance, that is, spectrum displayed by any pixel representing natural vegetation is a combination of the relative spectral combinations from tree canopy, understorey, ground cover and exposed soil within the pixel. When the canopy or tree crowns are not dense, the spectral reflection from soil and vegetation can dominate the spectral influence of the trees on the pixel characteristics. The analysis of remotely sensed data involves understanding the spectral responses and variation of the numerous components, and developing techniques that explain these variations. The potential use of Landsat imagery for vegetation monitoring is attractive, provided that the relevant information can be extracted from it. In this context the project looked at the summary of vegetation indices and known spectral bands from various dates of imagery. There are several vegetation indices developed that would be well suited to this project, however as the time sequence selected included both Landsat MSS and TM imagery it was considered appropriate to use the established Normalised Difference Vegetation Index, an index transferable between both Landsat systems.

Normalised Difference Vegetation Index (NDVI)

Indices, or mathematical combinations of spectral bands, are derived to express spectral anomalies that are diagnostic of specific target materials. The most commonly used is based on normalised ratios and can very effectively measure the amount of green vegetation cover over the soil. Using the visible red waveband (VIS), which corresponds to TM band 3, and the reflected near infrared waveband (NIR), which corresponds to TM band 4, an index described by Tucker (1979) relates to the proportion of photosynthetically absorbed radiation.

This index measures the differential reflection of green vegetation in the visible and infrared portions of the spectrum and provides a basis for monitoring vegetation. Satellite imagery is well suited for this monitoring with its spectral and spatial resolutions. The NDVI is commonly used in such applications. This index can be defined as:

$$NDVI = \frac{R_{nir} - R_{vis}}{R_{nir} + R_{vis}}$$

Where R_{vis} is the land surface reflectance in the visible waveband (0.58 - 0.68 μm) and R_{nir} is the land surface reflectance in the near infrared waveband (0.725 - 1.1 μm). The principle behind this is that the visible region is a part of the spectrum where there is considerable absorption on incoming solar radiation by chlorophyll, and the near infrared is a region where spongy mesophyll leaf structure leads increased reflectance (Tucker and Sellers, 1986).

The NDVI is affected by the degree of absorption by chlorophyll in the red wavelengths, which is proportional to leaf chlorophyll density, and by the reflectance of near-infrared

radiation, which is proportional to green leaf density. Therefore, NDVI is likely to correlate well with green leaf biomass, and can be related to healthy vegetation.
The NDVI is generally related to both green biomass and leaf area index (LAI) of plants and is a very good measure of plant health and vigour. However, this relationship can vary with the structure of the vegetation type, and different relationships for major vegetation types are required to account for dry biomass (Bellairs and others, 1994). The colour and brightness of the soil also affect NDVI values.

If the NDVI is calculated from calibrated data it is repeatable between times of measurement, an important consideration within this project.

Ground Sites

The basic objective of the project was to accurately estimate the variation in vegetation within the riverine vegetation. A key factor in using satellite imagery for this purpose is to calibrate the satellite image with ground measurements. Thirty prospective field sites were selected covering the range of crown cover anticipated across the project area. Areas of non-cover were also included for comparison. The size of the prospective field sites were approximately 100m X 100m. Prospective field sites were selected on aerial photographs in transects alongside tracks and other identifiable features, with the location accurately plotted to enable data extraction from the satellite imagery. Prospective field sites were chosen to be reasonably homogeneous with respect to the degree of cover, tree composition and structure (Figure Two).

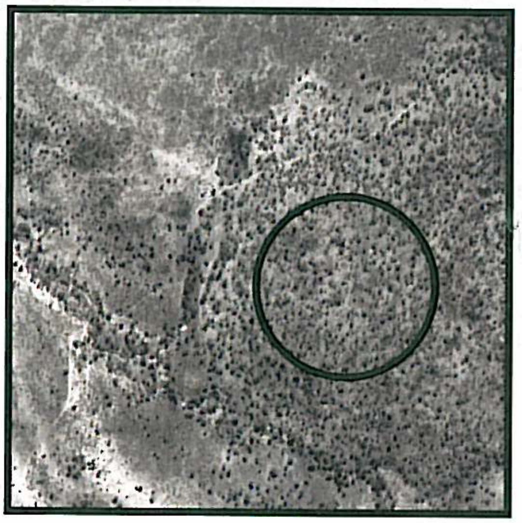

Figure Two: Enlarged section of the aerial photograph showing varying tree densities and open areas. Areas with a homogenous tree cover such as the area circled in black were targeted as prospective field sites.

Selection of the 30 ground sites was concentrated in the vicinity of Millstream within the Park and based partly on accessibility, and partly on the advice of CALM's Pilbara

Region officers (Figure Three). Factors influencing the selection were vegetation condition, type, the appearance of spectral homogeneity on the image and ground knowledge.

In an attempt to maintain consistent outcomes from field description, standard procedures were adopted. However, because of cover variations in vegetation density, structure and species, plus the vegetation change in a temporal sense there is an expected error component from the initial cover estimates using the aerial photography in comparison to the actual ground cover estimates.

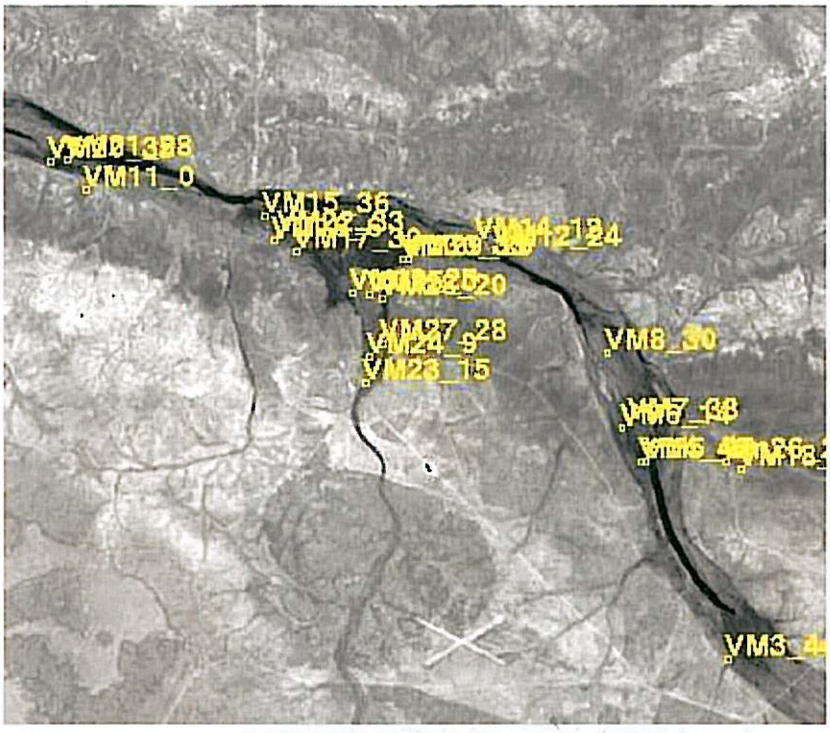

Figure Three: Location of the 30 measured training sites. Each site is labelled, for example: VM8_30, meaning the location numbers VM8 and the 30 being the cover estimate of 30%.

Ground Measurements

Ground sampling methods were devised, from which the 30 nominated sites were selected; each site was systematically sampled for ground description, observation and measurement. Details were recorded (measurements of crown cover and crown density), to determine Projected Foliage Cover (PFC) for each site. It is important to appreciate that what the Landsat TM image portrays is PFC, not the canopy cover. Whereas PFC is the projection, on the ground, of the extent of foliage on the tree, a circle describing the extent of the crown gives canopy cover. For example, a PFC of 12 percent is typically equivalent to a canopy cover of about 15 percent.

Crown Cover

Crown cover is a measure of the ground area within the vertical projection of the periphery of crowns in an area, assuming that tree crowns are opaque. In the field plots, crown cover was measured using a spherical densiometer. Fifteen steps north, south, east and west from the site centre were paced out and a densiometer reading was taken at each of these points.

Crown Density

Crown density is a measure of the ground area within the outline of a tree crown that is occupied by leaves. Crown density was estimated by standing under a tree crown and visually comparing the density of leaves within the crown outline with that in the photographic standards of 'crown type' provided by Walker and Hopkins (1990). The crown density for the field site was then taken as an average of all the estimates for that site.

Projected Foliage Cover (PFC)

PFC is the percentage of the field site occupied by the vertical projection of foliage. PFC is the product of crown cover and crown density. For example, a site with a 20% crown cover and 75% crown density is calculated as having a PFC of 15%, as illustrated in Figure Four below.

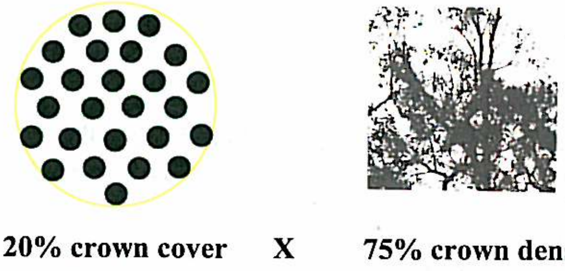

Figure Four: Projected foliage cover is the product of crown cover and crown density.

To estimate the Projected Foliage Cover (PFC) for each of the field sites across the landscape required a consistent and repeatable technique. With using the aerial photography and crown cover estimates as described above, together with standard diagrams that identify varying crown openness (McDonald *et al*, 1990) experienced ground personnel completed the visual interpretation. These values were then used in the image analysis.

Image Processing

The NDVI index was applied to the image captured 08/01/02, the image captured as close as possible to the date of ground work. The NDVI image was re-scaled to 0-255 for ease of processing. The resultant image is displayed in shades of grey (Figure Five below). Areas of black have little to no cover, while light or white areas have the greatest vegetation density. The extent of the riparian vegetation zone of dense vegetation is obvious.

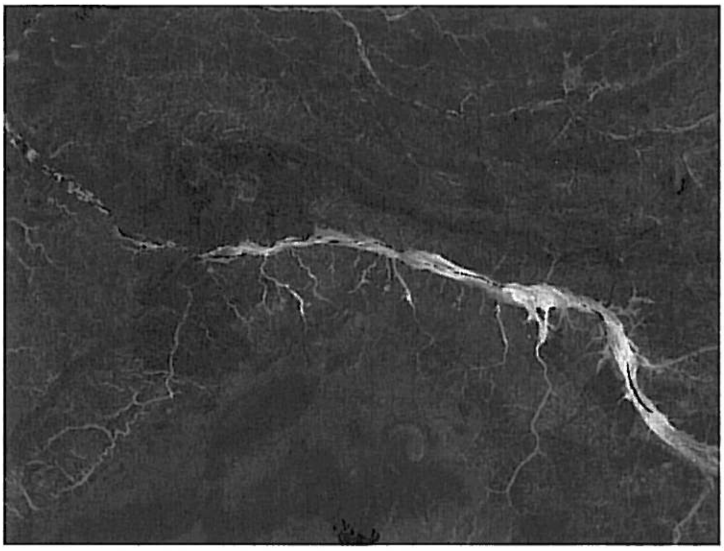

Figure Five: Re-scaled NDVI image.

The next stage was to convert the NDVI index image by establishing the relationship between it and the field measured PFC. The relationship was then used to produce a PFC image for project area.

Figure Six below shows the linear regression of the ground PFC estimates against the site mean values extracted from the NDVI image. Of the thirty original sites selected twenty three were used, the others deleted because of duplication or location error.

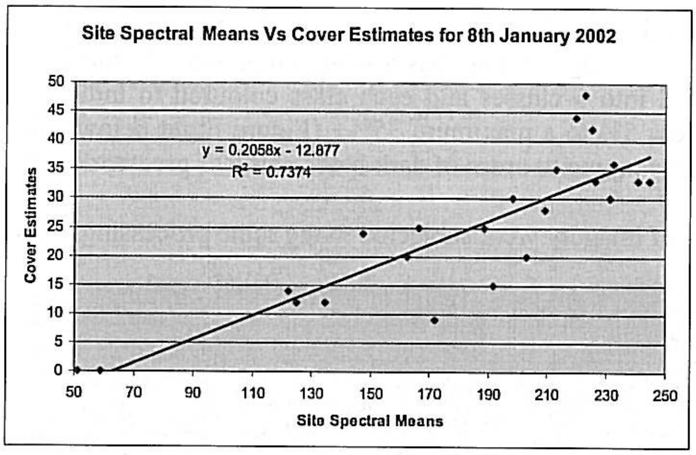

Figure Six: *Mean values of the field Cover Estimates for each site were regressed against the estimated PCC values from the NDVI image. The* R^2 *being 0.7374 and the linear equation being* $y = 0.2058x - 12.877$.

From the graph we observe that there is considerable variation in the cover estimates for ground sites of similar tree cover. The sites can vary because of a number of reasons; one which is significant is the ground responses of soils, debris and grasses. However in this case, a strong relationship exists.

The resultant linear equation (Figure Six above) NDVI * 0.2058 – 12.877 was applied to all pixels within the NDVI image to produce the PFC image (Figure Seven below).

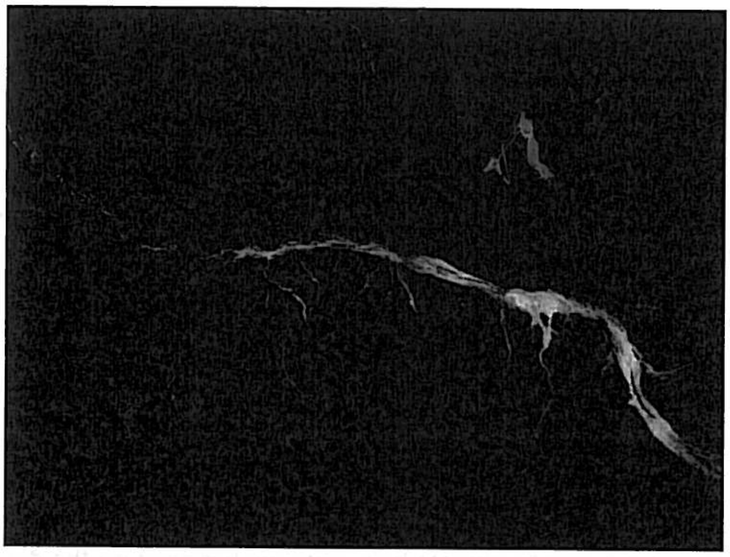

Figure Seven: *Image of projected foliage cover from remote sensing for the riparian zone. Lighter areas indicate high values of projected foliage cover.*

Light areas have relatively high values of PFC whilst the dark areas have relatively low values of PFC. The image of PFC has a value range from 0 (black) to 50 (light). This range was divided into 6 classes and each class coloured to indicate the cover density ranging from a low 5% to a maximum 35%+ (Figure Eight below). Light yellow being area of least cover ranging to areas of dark blues being of greater density.

All sixteen dates of imagery were subjected to the same processing.

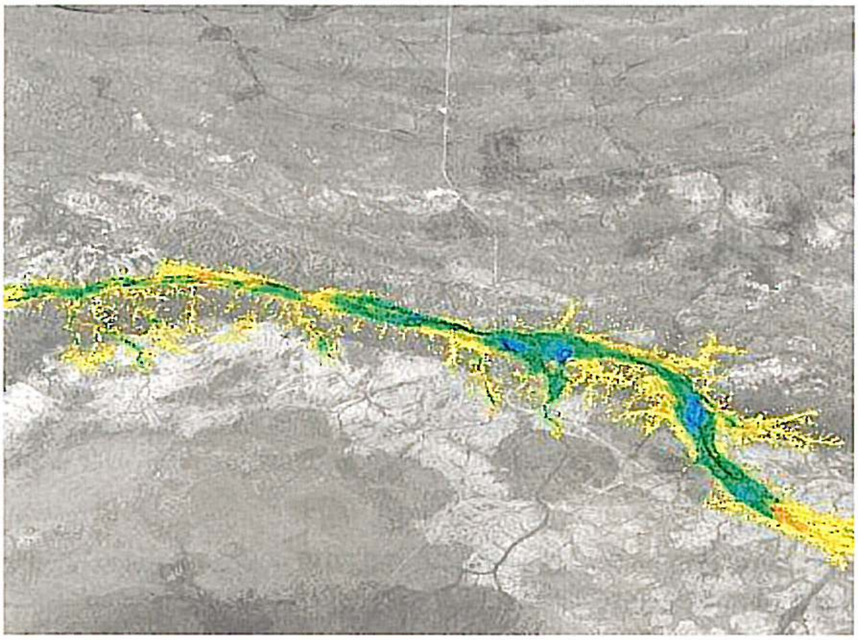

Figure Eight: Cover densities for the riparian zone for 08/01/02.

Results and Discussion

From the PFC image (Figure Eight) it is possible to produce vegetation cover density map within the riparian zone of the project area. From detailed field inspections it was confirmed that the precision of detection of the vegetation density by this methodology greatly improved upon previous knowledge and maps.

The final stage of the project was to apply the same processing all sixteen dates of the historical image sequence and determine if and where vegetation density variations had occurred.

The major difficulty in the image analysis was obtaining imagery at the appropriate time of the year as variations due to climate have obvious bearings on the data. Cloud cover and fire were other important considerations.

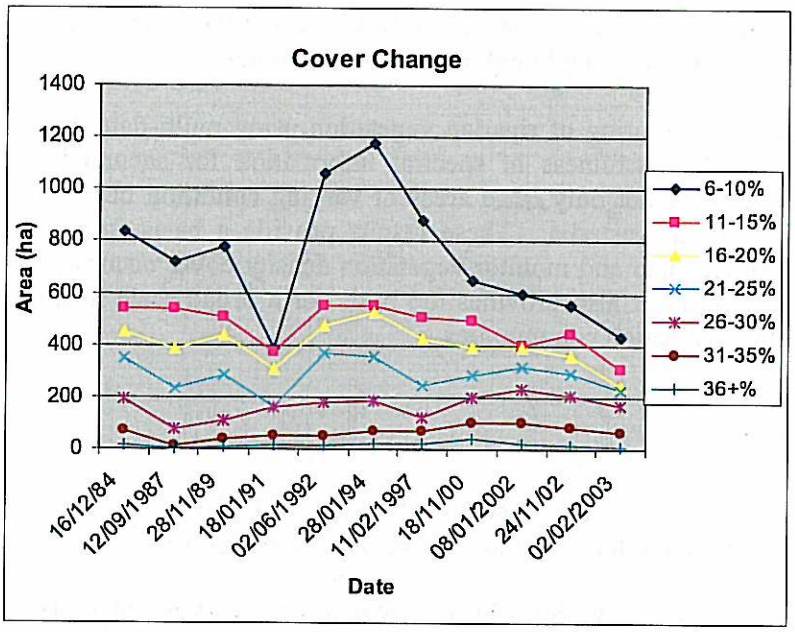

Figure Nine: *Cover Change graph indicating a overall decline in the vegetation area within the riparian zone.*

Taking a sample of the processed image dates it was possible to calculate the area of each of the density classes. The graph from Figure Nine helps summarise the results. Obviously the dense vegetation of 36+% has the least total area over the time span, this graduating out to the sparse areas of 6-10% with the most. From the graph important information can be observed:

1) The total riverine cover in 1984 (approx 800ha) is greater than in 2003 (approx 420ha).
2) Dense cover shows the least change although any change here is significant.
3) A major cover change happened at around 1991 (major wild fire), especially in areas of less than 20% cover. There was rapid recovery until 1993 followed by a gradual improvement in high density classes, and a gradual decline in low density classes.
4) There has been a general overall decline in cover from around mid 2002 due to ongoing reduction of invasive vegetation and increased drying since 2000.

The assessment of the accuracy of the processed images is limited by the amount of accurate ground information available. Validation of spectral allocation against accurate ground information must be made before the proportion of correctly labelled pixels for each class and errors of omission and commission can be calculated. Historical detailed ground information was not available for the project area. From limited field inspection, in all cases, the general distribution of cover changes as depicted on the cover images are consistent with the known information previously obtained from mapping by CALM officers. Unfortunately no hard evidence exists to properly validate the result but given the acceptance of the initial processing for 18/01/02 and the isolated knowledge of past extreme events there's a strong likelihood of good accuracy.

In summary, the monitoring of riparian vegetation using multi-date, multi-spectral TM data has shown the usefulness of spectral information for accurately discriminating vegetation cover over not only large areas of varying condition but also small discrete locations of Western Australia. These results provide a basis for the adoption of a technique to locate, map and monitor vegetation density cover occurrences within other locations of concern. It also provides the basis for a broad-scale mapping monitoring project for other vegetation communities.

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Mapping Forest Cover, Kimberley Region of Western Australia

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ABSTRACT

About half the total forest area of Australia lies north of the Tropic of Capricorn. Improved information about northern forest and woodlands is required for national level statistics, forest policy development, reserve system planning and for ongoing management by relevant State and Territory agencies.

NORFOR, an initiative of National Forest Inventory (NFI), addresses this need and the need for completion of the continental forest cover map to an acceptable standard. It involves a partnership between Western Australia, Northern Territory and Queensland in the development of a common system for processing of satellite remote sensing data to achieve a consistent product that reliably details the extent of forest cover and broad forest type across northern Australia.

For the purpose of the project three locations across northern Australia were selected to trial the agreed methodology, the Kimberley region of Western Australia, the Daly Basin of Northern Territory and the Einasleigh Uplands of Queensland.

This paper reports on the work in the Kimberley region and describes the methodology used for acquiring ground information, satellite image production and the processing techniques to produce the forest cover map. It also considers issues associated with determination of the forest/savannah boundary and the effect of fire on the reliability of mapping.

INTRODUCTION

Forest inventory in Australia is undergoing a marked change as a consequence of the adoption of a definition of forest that is in line with that used internationally. This new definition was first used in the 1997 Montreal Process First Approximation Report and subsequently in the State of the Forests Report 1998. Forest is now defined as:

"Land dominated by trees having a mature codominant height greater than 2 metres and a canopy cover greater than 20 percent."

In practice the lower limit of 20 percent canopy cover is loosely applied as the cut-off point is often difficult to define on the ground.

The main effect of this change is that the forest estate now includes extensive areas of vegetation in Australia formerly referred to as woodland. As a result, the total area of forest has increased from about 43 million ha (in the high forest zone) to an estimated 156 million ha overall. Much of this additional forest lies in the northern part of the country, where the data for forest cover and forest type are of much poorer quality than in the south.

The National Forest Inventory (NFI) is a cooperative State-Federal initiative aimed at providing improved national level data on forest resources. It funds cooperative projects in States that contribute to the national forest database. One of the issues facing the NFI is the compatibility of forest-related data between adjacent States. NORFOR is a cooperative project between Western Australia, Northern Territory and Queensland that addresses this issue by first developing a common methodology and then applying it across the whole of northern Australia, an area of some 60 million ha of forest.

The existence of reliable data for forest cover for northern Australia will enable completion of the NFI continental forest cover map to an acceptable standard. It will also greatly improve the accuracy of reporting for the Montreal Process criteria and indicators of sustainable forest management, the periodic national State of the Forests Report and carbon storage estimates for greenhouse gas accounting. All these are important contributors to policy formulation.

Satellite remote sensing was considered the only viable approach to mapping an area of such size, given the time constraints of the project, and the need to update the results on a regular basis to detect time trends. The success of remote sensing projects of this magnitude elsewhere within Australia (Woodgate 1988, Ritman, 1994, and Kuhnell, 1998) indicated the potential of the technology to provide useful results for this purpose. Landsat Thematic Mapper (TM) imagery was chosen as providing the best balance between accuracy, cost and sensitivity.

The primary objectives of the project were:

- Develop a common remote sensing methodology for reliable mapping of forest cover (current extent), structure and broad forest type, for use across northern Australia, using concurrent pilot projects across each State/Territory.

- Carry out the mapping of forest cover using this methodology in the three jurisdictions, to achieve a seamless coverage of forest and woodland over the north of Australia.

Forest structure in this project meant mapping into NFI height and density classes. The height classes are:

Low – 2 to 10 metres mature codominant height
Medium – 11 to 30 m
Tall – greater than 30 m

The density classes are:

Closed forest – canopy cover greater than 80 percent.
Open forest – canopy cover 50-80 percent
Woodlands – canopy cover approximately 20-50 percent

Broad forest types are those defined in the Montreal Process First Approximation Report 1997. The types expected to be encountered in the Kimberley region were as follows:

Rainforest vine thickets
Medium open eucalypt forests
Low open eucalypt forests
Medium eucalypt woodlands
Low eucalypt woodlands
Acacia forests and woodlands
Mangrove forests and woodlands
Unclassified forest

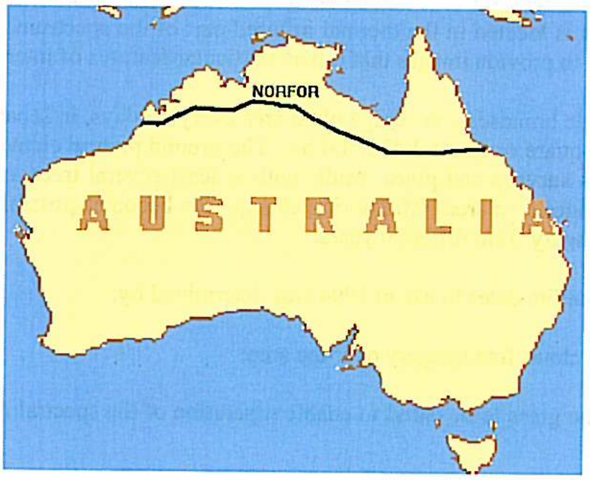
The NFI unclassified type includes forests that are of a heterogeneous mixed type, of unknown type or comprising a mixture of minor genera.

The Department of Conservation and Land Management (CALM) is responsible for the project in the Kimberley region, with the Northern Territory being covered by The Department of Lands, Planning and Environment. In Queensland the responsible agency is the Department of Natural Resources (DNR) in association with the Queensland Herbarium.

LOCATION AND EXTENT OF NORFOR

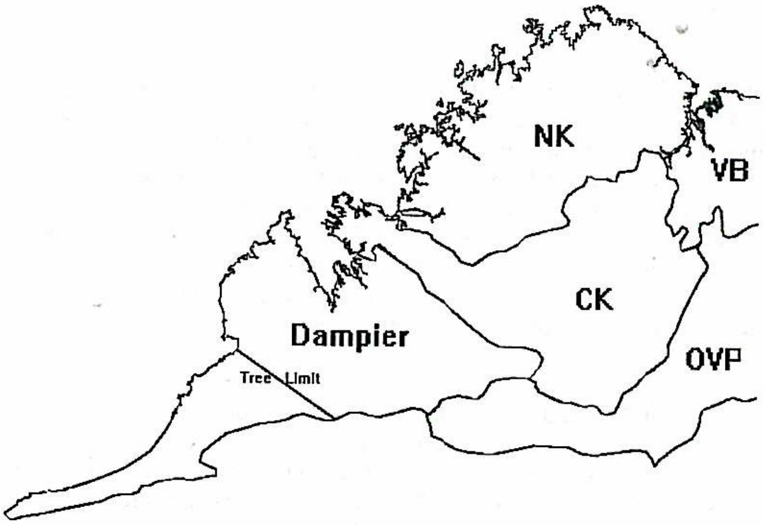
The biogeographical boundaries from the Interim Biogeographic Regionalisation of Australia (IBRA) were chosen as the basis for delineation of the area to be covered by the NORFOR project. IBRA divides Australia in to bioregions containing recognisably distinct suites of vegetation. Using IBRA maps and the NFI definition of forest, it was possible to define the IBRA regions in which forest will be found. In this way a southern boundary for the project was established (see Figure 1).

Figure 1 **Approximate location of the NORFOR project**



The approach taken by the partners in NORFOR was to test the Landsat methodology in three trial areas, one in each jurisdiction. The Kimberley region was treated as one such trial area, as it was considerably smaller than the forest areas in the NT and Queensland, yet contained a variety of vegetation types. The trial area in the NT was the Daly River IBRA and the Einasleigh Uplands IBRA in Queensland.

Figure 2 **Location of Kimberley IBRA regions.**



The Kimberley trial area comprises five IBRA regions: Dampier (DAM), North Kimberley (NK), Central Kimberley (CK), Victoria Bonaparte (VB) and Ord-Victoria Plains (OVP) (see Figure 2).

CALIBRATION OF SATELLITE IMAGE AND GROUND TRUTH

Satellite Imagery

Consultation between the partners established that all had access to 1994 Landsat Thematic Mapper (TM) data, so this was chosen as the base year for the project. Although it was known there would be some complications in interpreting the effects of subsequent fire in the region, 1994 provides a convenient baseline for a possible repeat exercise using year 2000 imagery.

Thematic Mapper 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. Band six is located in the thermal infrared part of the spectrum. The data from various bands can be combined to provide images that reflect particular features of interest on the ground.

Landsat TM data provide broadscale coverage of an area every 16 days, in separate "scenes" that cover an area about 185 km square or about 3,422,500 ha. The ground picture element (pixel) size (30m) is practical for broad-area surveys and gives results with at least several trees and shrubs per pixel and several pixels per homogeneous area. Monitoring change also becomes possible with the ability to co-register and analyse imagery from different years.

The choice of which satellite dates to use in 1994 was determined by:

(1) availability of cloud-free imagery over the area;

(2) the need for the grass to be cured to enable separation of the spectral reflectance of trees from grasses.

The dry season in the Kimberley was the obvious choice. However, the major drawback to this choice is the amount and areal extent of annual fire occurrences in the region. Since TM relies on reflectance from vegetation and soil, recently burnt areas are black, having low reflectance, and provide little vegetation information to the sensor.

Some twenty TM satellite scenes were co-registered against the ground cadastral framework and calibrated to form a seamless mosaic of the Kimberley region shown in Figure 2 above. Production of this mosaic is a critical step in establishing a base for subsequent image analysis. Without a mosaic it is not possible to ensure complete coverage of the area, or to ensure that there are no boundary inconsistencies between images.

Aerial photos

The basic objective of the project is to accurately estimate the variation in projective foliage cover (PFC) across the landscape A key factor in using satellite imagery for this purpose is to be able to reliably calibrate the satellite image with what we see on the ground. Field validation plots were established across a range of forest types and IBRAs to provide this calibration. Within each Kimberley IBRA region transects were established that best represented the variation in forest cover and forest type in the region. These transects were chosen on the basis of field knowledge of the areas concerned. Within the transects field validation plots were established, gathering data on canopy cover, tree crown opaqueness, overstorey and understorey species composition and soils. A total of 180 field validation plots was established across the Kimberley region as a whole, and marked as permanent plots for future use as monitoring sites.

It is important to appreciate that what the Landsat TM image portrays is projective foliage cover, not the canopy cover, which is the attribute used in the NFI definition of forest. They are not quite the same things. Whereas PFC is the projection, on the ground, of the extent of foliage on the tree, a circle describing the extent of the crown gives canopy cover. A PFC of 15 percent is equivalent to a canopy cover of value of about 20 percent, and the difference between the two measures is greater at higher PFC values.

A difficulty with field plots is that projective foliage cover or canopy cover cannot be measured easily, so it was decided to "calibrate" forest cover estimates by TM using aerial photographs covering the transects.

Aerial photography covers the entire Kimberley region at varying scales. From inspection of 1:40 000 or 1:50 000 black and white photos it was possible to discriminate the differing tree cover densities, to an acceptable standard. Photos that covered the identified transects and the field plots were then obtained, digitised and co-registered to the satellite image mosaic. Canopy cover was measured on aerial photographs using dot grid templates. The template assumes an opaque crown. To convert the canopy cover to foliage cover (which is what the satellite imagery responds to), ground measurements on a range of sample plots establish the degree of actual crown opaqueness

Using the digitised aerial photographs, canopy cover templates and crown type diagrams, estimates of PFC were calculated for each of the field validation plots. These values were then plotted to calculate layers or classes within the woody 'spectral cloud' category, representing differing forest densities.

The Limits to Forest Cover

Another important issue was to establish the lower limit of canopy cover for what was classified forest. In the field there are few sharp forest/non forest boundaries. The normal situation is for a gradual change from what is clearly forest to an area where there are few trees. As outlined above, the NFI lower limit of 20 percent canopy cover is interpreted flexibly in the field. However, when dealing with an automated image analysis system, as we are here, it is necessary to have training areas that describe a homogenous vegetation occurrence with respect to its cover. These areas need to be of several pixels (picture elements) in size.

A range of the field validation plots was examined in the field to establish the lower limit of canopy cover for forest, using the NFI definition. Under the conditions encountered in the Kimberley region, a projective foliage cover of 15 percent was established by a group of experienced observers as the practical boundary between what was plainly vegetation dominated by trees (forest) and what was clearly not dominated by trees (savannah). This figure was used to establish homogenous training areas of forest/non-forest for the image analysis in this project. The difference between forest and savannah is illustrated by the following three photographs, from field validation plots, which depict Kimberley forest of 10%, 15% and 20% PFC respectively.

Figure 3. Savannah with projective foliage cover of 10%.

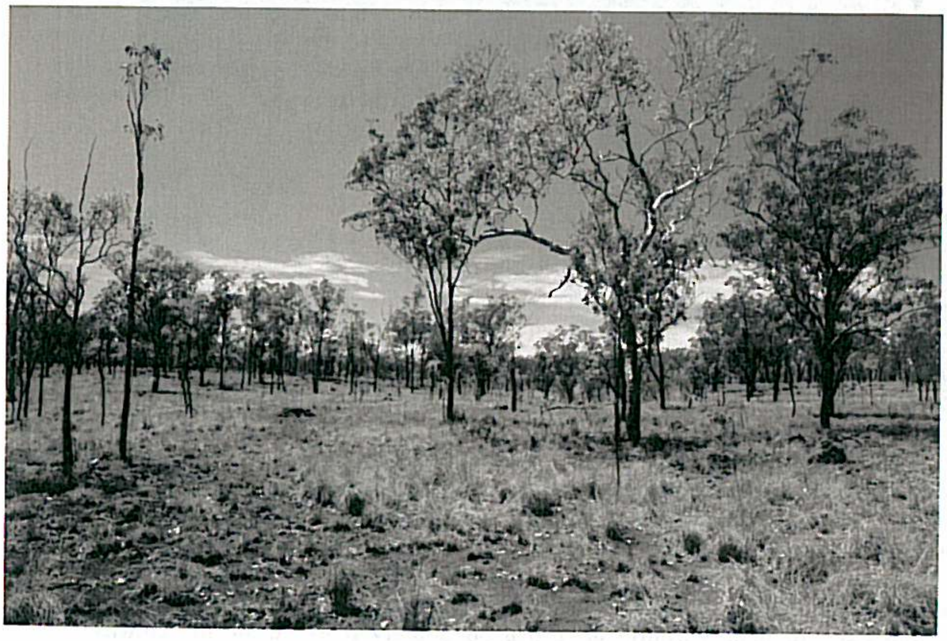


Figure 4. Forest with projective foliage cover of 15%.

Figure 5. Forest with projective foliage cover of 20%.

Despite the use of an objective definition of the savannah-forest boundary in this way, it is still possible for errors to be made in classifying an area in to forest or non-forest. Low spectral reflectance values can be due to poor crown condition as a consequence of severe late season fire or drought. There may be just as many tree stems, of similar size, in two adjacent areas but one may fail to be classified as forest due to previous crown damage that caused it to fall below 15% PFC. To minimise this problem, the Landsat imagery used for forest mapping should be timed for just after the understorey grasses have cured, but before severe drought or wildfire has had an opportunity to degrade the tree crowns.

IMAGE ANALYSIS

Spectral Information

Reflectance spectra of forest stands are the combination of reflectance spectra of trees, understorey, shadow, debris and the underlying soil. Forest reflectance spectral values depend on the proportions of these different elements in a picture element (pixel) which are visible from above.

When the tree crowns are not dense, the effect of underlying soil and vegetation can be dominant and can mask the effects of the trees. The reflectance of a forest canopy can display large differences from leaf reflectance when there is a large contrast between trees and understorey vegetation.

Inspection of preliminary TM images of the Kimberley indicated there were several distinct zones of reasonably uniform appearance. On further examination, it was found that these distinct zones closely coincided with the IBRA regions, probably reflecting the varying geological zones and suites of vegetation on which the IBRA regions are based. It seemed possible, therefore, that the statistical relationship between the spectral image and forest cover could vary between IBRA regions. To test this hypothesis, the imagery was divided so that the five IBRA regions that cover the Kimberley were processed individually.

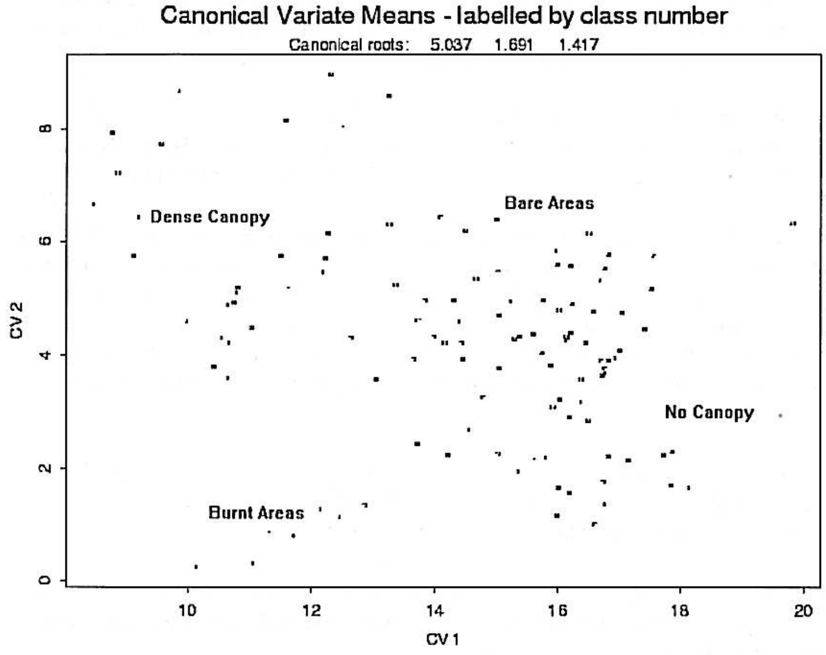
The woody vegetation density classification is based on analysis of the spectral data and the observation that forest foliage density increases with increasing greenness (a combination of TM satellite bands 3 and 4) and decreasing B5 values.

Canonical variate analysis was used to discriminate between areas of dense forest canopy and areas of no forest canopy. These areas were then contrasted against one another to establish a smoothed index that shows the dense canopy from areas of no canopy.

The crucial factor in producing spectral maps or enhancements, which reliably display areas of greater than 15-percent PFC, is that the spectral separation of the dense from the sparse tree canopy classes is large, compared to the variation within classes. If this can be established, then important band combinations, which provide the discrimination, can be identified and appropriate enhancements produced. A classification mapping approach can also be adopted and pixels can be allocated with confidence to one or other of the classes (or to none).

Canonical variate (CV) analysis (Anderson, 1958) was used to summarise the class separation between the validation plot site data. Associated computational routines allow the important discriminating spectral bands to be identified (Campbell 1984: McKay and Campbell, 1982). The CV analysis summarises the separation between sites in the multivariate (7 bands = 7 dimensions) spectral space. It discovers successive band combinations (vectors) which maximise the site separation. These vectors are referred to as canonical vectors and associated with each is a canonical root - a number that is an index of the separation between sites along that axis. The sum of the canonical roots gives a measure of the overall site separation in all dimensions.

Figure 6 **Canonical variate (CV) plot of the site data for the North Kimberley IBRA region.**



The canonical roots form a decreasing sequence. The first CV direction is the single axis that has the greatest separation. Frequently, the site separation in spectral space can be adequately summarised by the first few canonical variates, thus reducing the dimensionality of the data set while maintaining relevant information on site clustering and separation. Band reduction routines are then applied to identify simplified combinations of bands, which maintain the separation between groups of sites. The results may be used to identify useful image enhancements, or as input to the classification procedures.

Data for the North Kimberley IBRA region are presented here (Figure 6) to illustrate the process of developing a relationship between spectral reflectance and PFC and translating the relationship to a map of forest cover. The canonical variate plot shows the separation of dense tree canopy from that of sparse or no canopy. Figure 6 also demonstrates how 'dark or burnt areas' have an influence in the spectral separation of the sites.

Band reduction routines established the three satellite TM bands 3, 4 and 5 were the most significant bands that separated the sites. The sites of high density were contrasted against sites of low density to establish a smoothed band index, the established index being :-(3* band 3) + (3*band 4) – (band 5).

This index was applied to the North Kimberley IBRA region to produce an enhanced CV image. The mean values for the ground validation plot sites were extracted from this image. These mean values then had a linear regression applied against the PFC estimates obtained on the ground. The resultant linear equation was applied to the CV image creating an expected Projective Foliage Cover image over the IBRA region.

Further analyses established that there were appreciable differences in the relationship between index value and FPC between IBRA regions. Table 1 shows how these indices vary between the five Kimberley IBRAs.

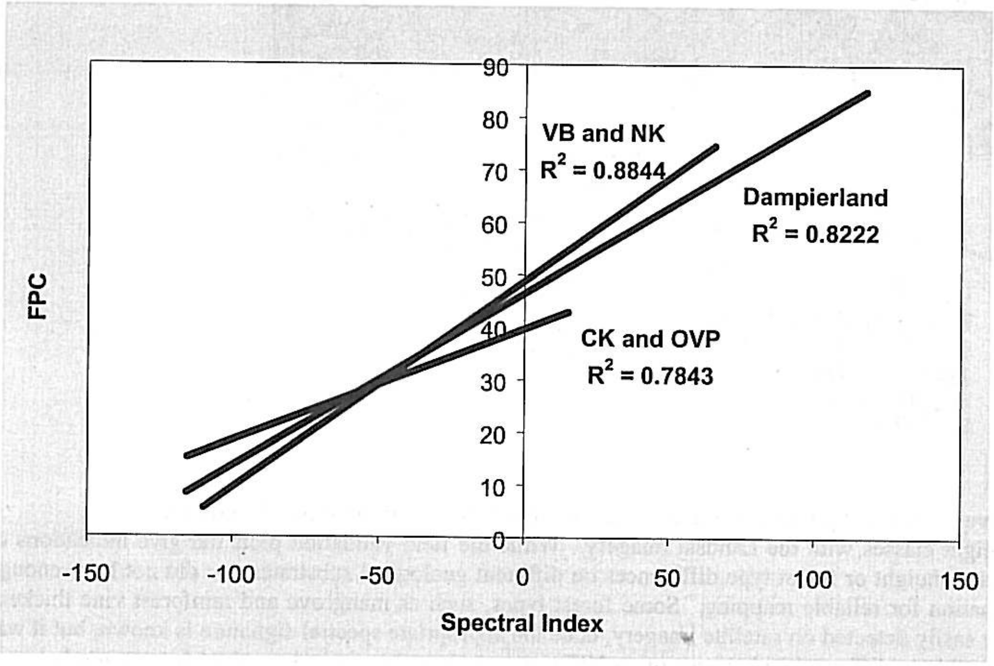
Table 1. Spectral indices for each Kimberley IBRA.

IBRA Region	Victoria-Bonaparte	North Kimberley	Central Kimberley	Dampier	Ord-Victoria Plains
Spectral Index	-(3*B3)+(3*B4)-B5	-(3*B3)+(3*B4)-B5	-(5*B3)+(5*B4)-B5	-(5*B3)+(5*B4)-B5	-(4*3)+(4*B4)-B5

Where:
B3 = Landsat TM Band 3
B4 = Landsat TM Band 4
B5 = Landsat TM Band 5

It can be seen that the five IBRAs can be grouped according to their spectral index. Victoria-Bonaparte and North Kimberley have the same index, while Central Kimberley and Ord-Victoria Plains share a different relationship and Dampier is different to both other groups.

Figure 7 FPC: Spectral index regressions for three IBRA groups in the Kimberley region.

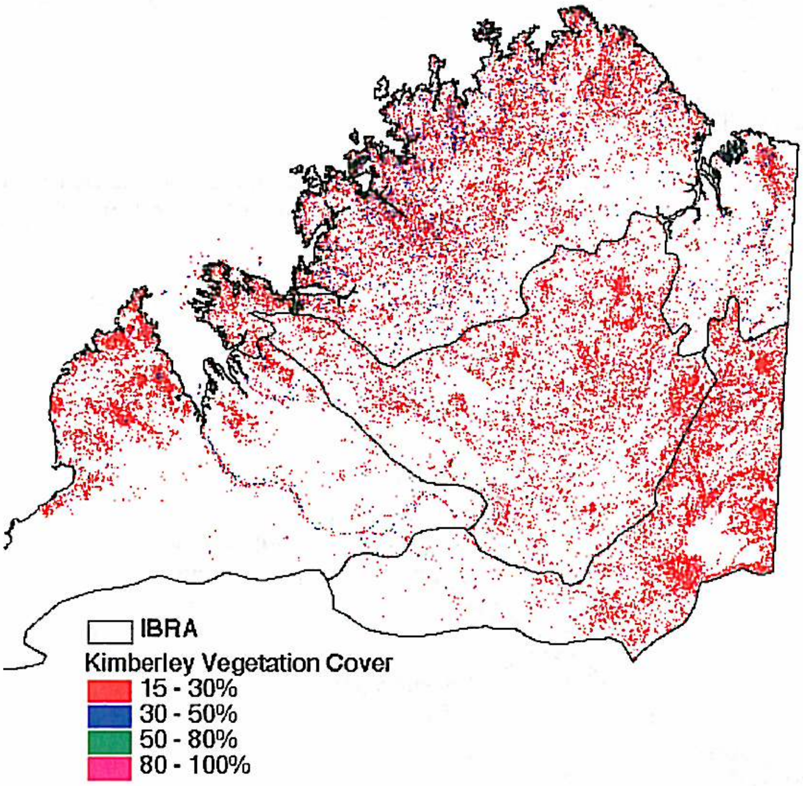


The difference between the regressions for the groups is of practical significance. Therefore it will be necessary to calibrate the index/PFC relationship for each IBRA to ensure accurate mapping of forest cover in this region.

DISCUSSION

The PFC images obtained by this procedure were combined to map areas of like forest cover density within the IBRA region. Figure 8 presents the forest cover map for the region derived in this way. Detailed field inspections confirmed that the precision of detection of forest/non forest boundaries by this methodology gave a suitable standard and that the map is a very good representation of conditions on the ground. We are therefore confident that we can map forest cover reliably and accurately in forest similar to that in the Kimberley region using the approach described in this paper. With recalibration of the spectral index:PFC relationship, the same approach can be applied across northern Australia.

Figure 8. Forest cover map for the Kimberley region



However, it was not possible to reliably discriminate between different NFI forest types nor height classes with the Landsat imagery. While the field validation plots did give indications of consistent height or forest type differences on different geological substrates, we did not have enough information for reliable mapping. Some forest types, such as mangrove and rainforest vine thickets, can be easily detected on satellite imagery, once the appropriate spectral signature is known, but it was not possible to differentiate between other NFI types, such as Acacia and eucalypt forests, nor between medium (11-30 m) and low (2-10 m) eucalypt forests. Development of an NFI forest type map for the region therefore required a different approach.

The Kimberley region is covered by 1:250,000 scale vegetation maps (Beard 1989) developed from a combination of aerial photography and ground inspection. Vegetation is classified from an ecological standpoint in to various species mixtures and structural types. In the absence of a better technique we used this vegetation map for forest type classification. The Beard vegetation types relevant to forests were examined and grouped to conform to the NFI forest types listed earlier in this paper. While this is not an ideal outcome, from the viewpoint of management, it does give us far better data on forest occurrence than before.

The final stage of the project was to use a GIS to intersect the forest cover data derived from the Landsat imagery with the NFI forest type categories (based on Beard's vegetation mapping) to establish a structure and broad forest type map.

Since the Landsat imagery permits us to classify the forest cover into density classes, we have presented the forest cover data here in four classes, rather than the three classes used by the NFI, to illustrate the flexibility possible in an all-digital environment (see Table 2).

Table 2. NFI Forest Type Area Statement for the Kimberley Region by PFC Class (ha)

NFI Forest Type	15-30%	30-50	50-80	80-100	Total
Rainforest	2108	9146	6207	240	17701
Mangrove	15220	23536	70077	14449	123282
Acacia forest	564377	11412	301	13	576102
Low eucalypt forest	173198	21034	7434	306	201972
Medium eucalypt forest	1843266	275382	27857	965	2147471
Unclassified forest	23797	6541	2573	434	33345
Totals	**2621966**	**347051**	**114449**	**16407**	**3099873**

At least half of the 15-30 percent PFC class would have been eliminated as forest if we had used a higher cut off figure of 20 percent PFC for the image analysis. Under Kimberley conditions, 15 percent PFC is the real lower limit of what is forest. Whether this is a figure generally applicable to inland and northern forest elsewhere in Australia, where satellite imagery is likely to be used to monitor vegetation cover, should be investigated.

A major problem in the image analysis is accounting for the effects of fires. Wildfire is a dominant factor influencing forest extent and composition in the Kimberley. They cover extensive areas every dry season. Late season fires, in particular, can be very damaging and may kill the overstorey (especially Acacia) over large areas, resulting in rapid changes in forest extent at a particular point in time.

Figure 9. Composite map showing all fires that occurred in the Kimberley region during 1994.

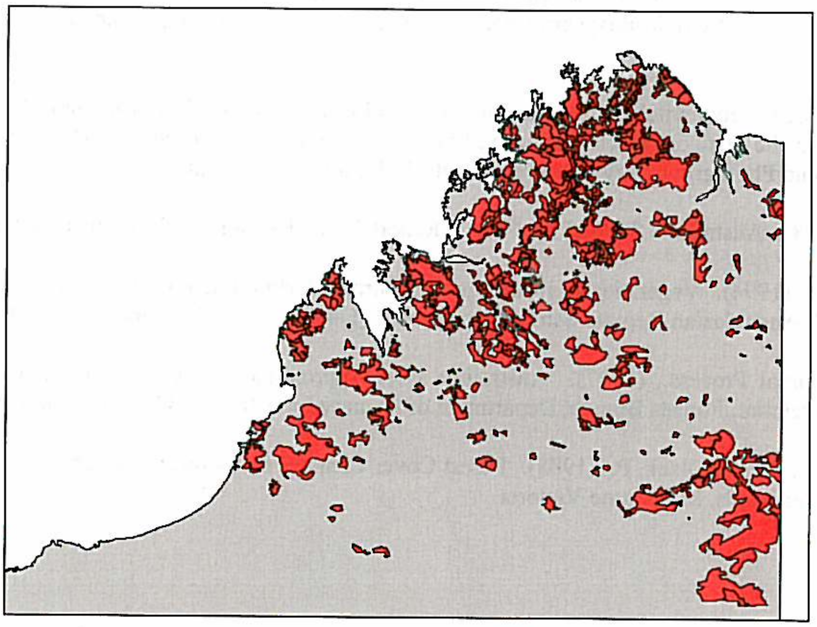


Figure 9 shows the area burnt during the 1994 fire season across the Kimberley region. The map is based on AVHRR imagery (which has a 1 km resolution) and includes both early and late season fires, so the impact of the fires is not as serious as the map suggests. Nevertheless, the map does demonstrate the significance of the fire factor in this region.

In this project we have concluded that it is too subjective a process to attempt to classify recently burnt forest, and we map it as "unclassified ". It is quite clear that we are dealing with a totally different situation from southern forests, where forest cover is relatively stable. In the north, forest cover is much more dynamic, the cover on a particular area varying over a relatively short period as a consequence of haphazard fire events.

The methodology described here provides a sound basis for rapid, accurate mapping forest cover across the more sparsely populated regions of Australia where the use of conventional aerial photography cannot be economically justified. However, our results indicated that the calibration of the PFC:spectral index relationship needs to be checked for each IBRA.

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LANDSAT MONITORING OF WOODLAND REGENERATION IN DEGRADED MULGA RANGELANDS: IMPLICATIONS FOR ARID LANDSCAPES MANAGED FOR CARBON SEQUESTRATION

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Abstract

In WA's North-eastern goldfields region, woodland regeneration at two different sites has been intensively monitored on the ground. At one site, woodland establishment and expansion has been occurring spontaneously in recent decades as a result of altered landscape processes. At the second site, engineering and plant establishment trials on degraded lands have resulted in significant woodland regeneration. These rapid changes and field observations provide an opportunity to test and demonstrate cover monitoring information from time series Landsat imagery. Landsat monitoring information provides a comprehensive picture of the regeneration and of active processes in the broader region. Field measurements on plant growth and carbon can be linked to the monitoring data, and seen in the context of observed processes in the broader landscape.

1. Introduction

Rangeland monitoring for both regulatory and scientific purposes has a long history in Australia. Detection of where and when vegetation changes have occurred is important for understanding ecological processes and management impacts in arid lands, and significant effort has been applied to the research and development of methods for rangeland monitoring using satellite imagery. Landsat imagery, because of its spatial resolution and long term archive of Australia, has been applied in many different environments. Operational methods and systems based on cover indices from time series Landsat have been successfully developed to provide monitoring data and indicators in rangelands (Bastin *et al* 1998, Karfs *et al* 2000, Wallace *et al* 2006).

For carbon accounting of forest cover changes, Landsat imagery also provides the core data for Australia's National Carbon Accounting System Land Cover Change Project (NCAS-LCCP). This system has been developed and implemented by Australia's Department of Climate Change in response to the conditions of the Kyoto Protocol. The NCAS-LCCP was developed initially for monitoring forest changes since 1972. Allowable areas of forest change detected by the monitoring system are converted to carbon estimates for the national accounts using established forest growth models. The NCAS LCCP has produced a consistent archive of processed Landsat imagery covering the continent (Furby 2002) and this archive has been made available for public use.

In rangelands, quantitative knowledge of growth rates and associated carbon fixation is rare. Since 1996, sites on Sturt Meadows station in the North-Eastern Goldfields region of WA have been intensively studied in the field to understand their carbon biosequestration potential, as part of long-term strategic research into representative bioclimatic areas by Japan Science and Technology Corporation (JST). Under its research partnership Core Research for Evolutional Science and Technology (CREST), JST has conducted extensive quantitative sampling, field experiments, revegetation trials and associated ecophysiological and atmospheric monitoring within the study area. These formed part of a wide-ranging international study into the biosequestration potential of arid and semi-arid lands, which has included studies of carbon, water and nutrient cycles (Yamada *et al* 2003). Known woodland regeneration which has occurred in the region in the period of the Landsat archive provides an opportunity to demonstrate the monitoring of these sites using established Landsat-based techniques.

2. LANDSCAPE CONTEXT AND STUDY SITES

2.1 Location

The area is located on Sturt Meadows station approximately 40km NE of the town of Leonora in Westerns Australia's Eastern Goldfields (Figure 1). It lies within in the Murchison bioregion and is climatically arid, receiving roughly 225 mm mean annual rainfall. The Leonora district is highly mineralised and has been subject to mining activity cycles, mainly for gold and nickel. The broader landscape has been used for pastoral sheep grazing since the early 20th century.

Figure 1: Location of study sites. Left: 250K topographic map with all JST study sites and Doyle's Well; Right: Landsat 2005 image red, green, blue in bands 5, 4, 2, the area of interest marked in red is 10km by 15km.

Two sites of particular interest provide the core field information of the work presented here and are described more fully below. At one site (Doyle's Well), spontaneous local reafforestation was studied to investigate the underlying mechanisms of natural processes occurring on a drainage line. At another location (Site C) slightly higher in the nearly flat alluvial landscape, the JST research project carried out large scale engineering and plant establishment works to imitate or replicate some of the conditions for woodland regeneration in evidence at Doyle's. The aim was to examine the capacity for revegetation and carbon sequestration on chronically degraded alluvial plains. A huge range of investigations was conducted and large volumes of data covering the environmental distribution and dynamics of water, carbon and nutrients have been collected and reported from the JST trials in the area (see for example Kumada *et al* 2006, Shiono *et al* 2006, Takahashi *et al* 2003, Taniguchi et al 2002, Yamada *et al* 1999, 2003). Here, the interest is in using these sites and the observed changes as validation for vegetation monitoring, and we describe only the relevant aspects of the trials.

The landscape is largely comprised of extensive nearly-flat alluvial fans which support mulga (*A. aneura*)-dominated tall shrublands and low woodlands (figure 2). Both sites are located within such systems. These colluvial-alluvial fans and plains carry overland water flow only at very irregular intervals averaging in the order of once per year. Full descriptions of the landsystems, soils and vegetation are found in Pringle, Van Vreeswyk and Gilligan 1994. Pastoral overuse has led to widespread degradation in the region, with losses of perennial plant cover and diversity, and losses of litter cover and cryptogamically-stabilised topsoils. The processes of grazing-related degradation in arid shrublands have been widely studied and documented in Australian and overseas literature. In such degraded states, infiltration of water and nutrients is reduced, and water flows are accelerated, resulting in upstream micro-terracing, sheet loss and stream bank erosion of highly dispersible soils (Pringle *et al* 2006). More locally there is accumulation of water, sediments and nutrients at some points in the landscape and at a variety of spatial scales (Ludwig and Tongway 1995, Tongway and Hindley 2000). The lack of infiltration-retention of water and nutrients, and loss of topsoil, means that rapid recovery of the original vegetation on such areas may be impossible without mechanical intervention. On some susceptible land units in the study region, degradation has led to almost complete loss of perennial cover and ongoing soil erosion on the fans and interfluves (Figure 2). Drainage lines show characteristics of recently concentrated flows with gross erosion and loss of streambank vegetation, incision, and mobilisation of fresh bedloads.

Figure 2. Left: groved mulga shrubland in healthy intact condition including strongly developed cryptogramic flora; Right: degraded alluvial fan of the same land system.

2.1 Doyle's Well

Around Doyle's Well, located in the lower parts of the landscape profiles and drainage systems, there is an isolated and dense *E. camaldulensis* woodland of apparently recent origin which is of special interest in view of its locally unparalleled vegetation biomass (Figure 3). Here, an almost closed canopy woodland with a locally dense understorey has developed over deep recent alluvial deposits of flood debris. The woodland itself supports some large individual river red gums, none of which appear to be of even nearly mature age. On the first series of air photography available for this site from ca. 1962, there is no such woodland adjacent to the well. By 2002 dominant vegetation along previous drainage lines showed decline and senescence. This was an *Acacia burkettii* community (Figure 4). It appears that, as a result of increased overland flows from the degraded upstream areas, new drainage lines have developed as flood debris accumulated and the original watercourse is effectively water-starved.

Figure 3 Left: Aerial view of woodland at Doyle's Well. Right: Young river red gum *E. camaldulensis* community at Doyle's Well with relic of a probable parent tree (behind).

Figure 4. Part of the senescent *A. burkettii* former streamline trees with encroaching *E. camaldulensis* visible in background

2.2 Site C

This major experimental site was established by JST early in 1999 on a degraded very gently sloping and slightly convex alluvial fan. Surface water engineering works were conducted to slow sheet water flow for increased infiltration and use after major rains. A surrounding bund wall was pushed up with inflow/outflow flumes for flow and water use gauging of the site. The wall encloses an area of approx 15ha. Within the site, ponding bays were constructed, each approximately 50m by 50m. Figure 5 shows a ground photo of the area prior to the trial, and an aerial view of the ponding banks in 1999. Within the bays, various plant establishment techniques were implemented including blasting of the hard pan for niche establishment and plantings of river red gum, mulga and a range of other local and regional tree species. Tree establishment was very successful (Figure 6), and growth rates and carbon stores have been regularly measured. Recent field data has measured vegetative carbon stocks of 2.4 tonnes/hectare within particular bays (J. Law, unpublished field data collected for JST). Soil carbon levels which were extremely low at the time of establishment have shown increase in recent years but remain very low (J Law, unpublished field data).

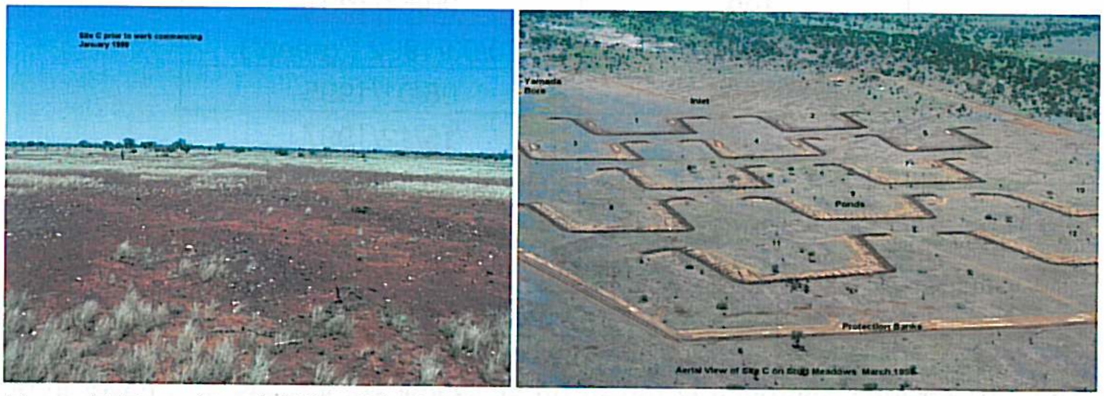

Figure 5. Experimental Site C before (left) and after surface water engineering works.

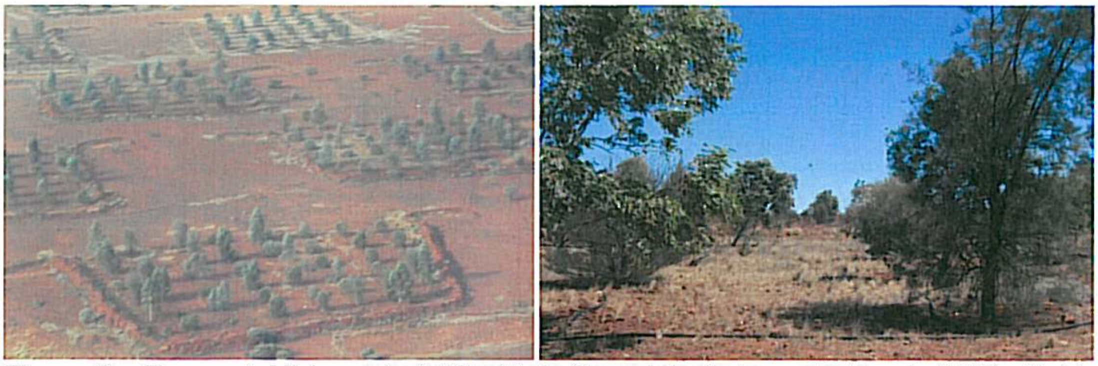

Figure 6. Tree establishment at Site C. Left: aerial photograph March 2003; Right: ground photograph March 2007 within one of the bays.

3. REMOTE SENSING MONITORING DATA AND METHODS

We have applied the index-trends approach (Wallace and Thomas 1998, Wallace *et al* 2006) to produce Landsat-based monitoring information for the area. In combination with field data, the approach is referred to as land cover change analysis (LCCA, Karfs et al 2000, 2002). Time series Landsat TM imagery from the NCAS-LCCP archive (map sheet SH51) has been used as the data source. These data are archived as mosaics of 6 spectral bands covering 1:1million map sheet areas for each time epoch. At the time of this study, nine dates of NCAS-LCCP Landsat TM imagery from map sheet SH51 covering the period 1989-2005 were available. The actual dates of the image covering the study region are listed in Table 1. The period of imagery spans the establishment of the JST trials. The 1992 image is anomalous in the sequence as it is affected by ephemeral green cover. This image date has been retained in the calculation of trends, but has not been included in the graphical plots below.

Table 1: Landsat TM scene dates (NCAS-LCCP) covering the study area.

AGO epoch	Image date for study area
1989	09/12/1989
1991	29/01/1991
1992	20/03/1992 ("green")
1995	08/01/1995
1998	15/12/1997
2000	26/10/1999
2002	20/02/2002
2004	17/01/2004
2005	24/03/2005

The index-trends approach is based on statistical summaries of a cover index derived from a time series of calibrated imagery, and temporal plots of these index values. These plots indicate when and by how much the index for those areas has changed over time. The simplest and most widely used temporal summary is the 'linear trend' (i.e. slope of cover index response over time) which is used to identify areas which have had positive, negative or stable response in the cover index over chosen time intervals.

The optimal cover index depends on the contrast of cover and bare soil that is consistent over dates of the image sequence in a particular environment. A number of cover indices have been developed and applied in different studies including PD54 and the simple visible red band (Pickup *et al* 1993, Graetz *et al* 1988). In practice, simple indices which are robust across a range of vegetation types have proved effective for monitoring in the LCCA approach. The cover index we have used here is calculated as the sum of Landsat TM bands 3 and 5. This index has been shown to provide discrimination between perennial vegetation and background over a wide range of soil and vegetation types in the southwest of Western Australia, and hence can be applied across a broad range of areas for detection of change. This index forms the basis of the vegetation monitoring products produced by the Land Monitor Project which covers the southwest agricultural area (Caccetta *et al* 2000, www.landmonitor.wa.gov.au). Note that the association of cover and index values is negative; higher values of this index are associated with increased brightness and *decreases* in cover.

Calculated trends over time can be displayed as images in various ways to highlight areas of different cover changes. In the figures below a blue, green and red composite displays the negative linear, negative quadratic and positive linear trend components respectively. As noted above a negative linear trend in the index (decreasing brightness) is associated with an *increase* in vegetation cover [shown blue in trend figures], whereas the positive linear trend (increasing brightness) identifies cover decline [shown as red]. The negative quadratic is associated with recovery late in the period preceded by decline or stability in the early years. Temporal index plots for selected areas are produced to indentify timing of changes and to quantify the index changes for those locations.

4. RESULTS

4.1 Results: Doyle's Well

The expansion of woodland at Doyle's Well can be clearly observed in the sequence of Landsat imagery (Figure 7). Displays of the trend information from the sequence provide evidence of this expansion and of decline processes in the surrounding landscape (Figure 8). The areas of new and thickening woodland are clearly detected by areas of increasing cover trend (blue), while trends indicating loss of cover are evident in formerly vegetated creeklines and areas of the surrounding landscape. The temporal plots for the selected sample areas identify the timing of the different changes at these two locations; the senescence of vegetation in the old creeklines (pink line) is indicated by the increase in brightness after 1998, in contrast to the response of the blue line where thickening has occurred. These sites had almost identical index values at the start of the sequence, but differed by more than 60 counts at the end of the period.

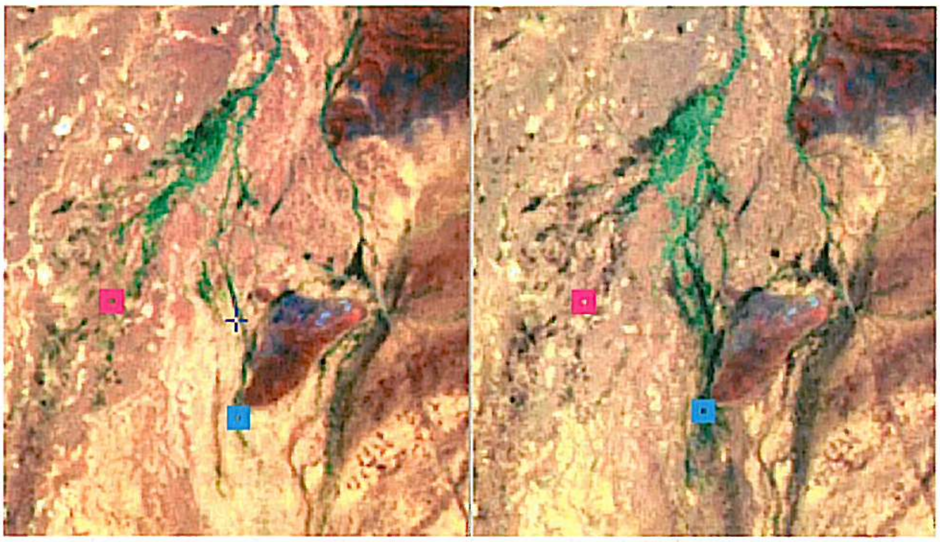

Figure 7: Landsat TM images from 1989 (left) and 2005 (right) of Doyle's Well and surrounding area (bands 542 displayed in red, green, blue). Healthy woodland areas show as green in both images. Expansion of the woodland area can be clearly seen. Area shown is 5km by 6km. Pink and blue squares identify areas for which trends are plotted in Figure 8 below.

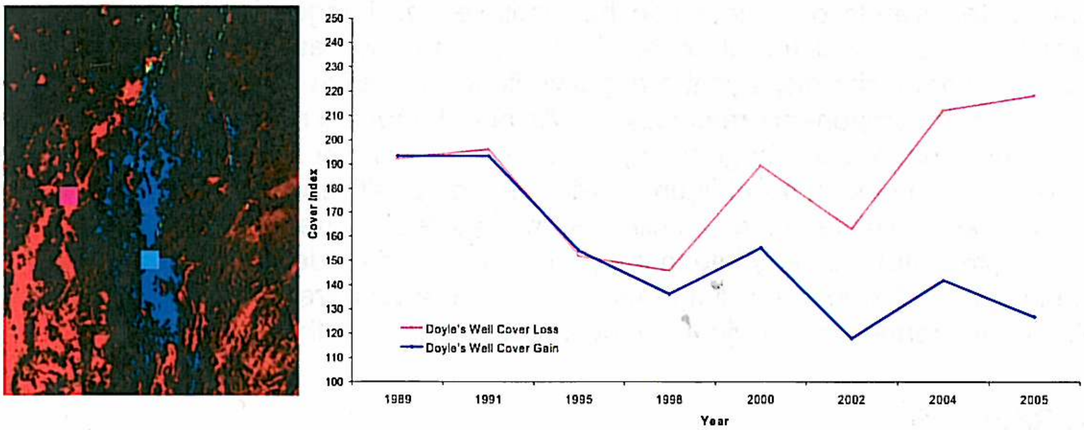

Figure 8. Left: Cover index trends image from 1989 to 2005 [same area as Figure 7]; red and blue colours in the image identify areas with linear trends associated with cover decline and increase respectively (as described above); Right: index trends plot for the two sample areas.

4.2 Results: Site C

Figure 9 below shows site C and surrounds in aerial photography and a 2005 Landsat image; individual ponding bays can be clearly seen in the photograph, while the site is only barely discernable in this Landsat display.

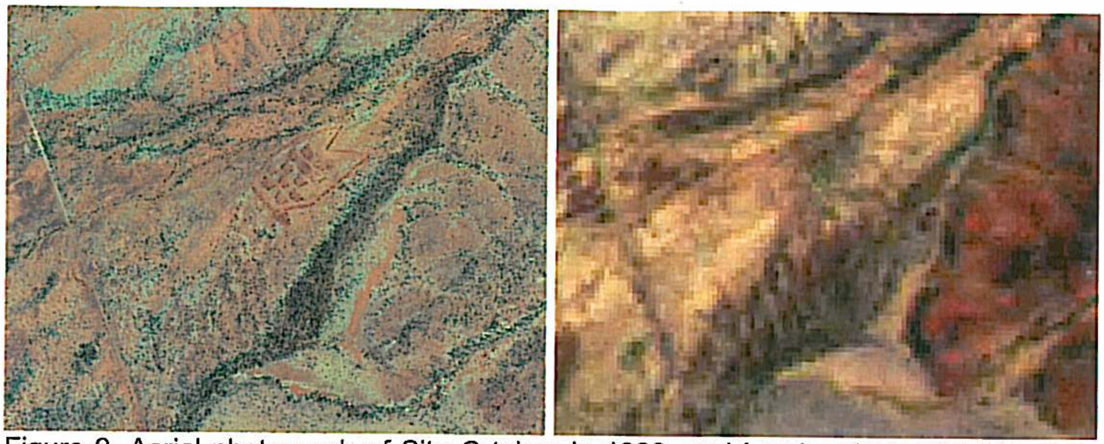

Figure 9. Aerial photograph of Site C taken in 1999, and Landsat image of the same area, March 2005. Area shown is 3km by 2km.

Figure 10 displays the linear and quadratic trends over this area for two periods to summarise changes over the whole period and in the years since the trial was established. Figure 11 shows temporal plots of the index from the selected sites; the ponded site area as a whole, two selected bays, a comparable untreated reference site outside the trial area, and a site downslope of the bund wall. The trend displays (Figure 10) clearly show evidence of cover responses within the site which contrast with the surrounding area. In the right hand image of Figure 10, individual bays appear as clear blue spots - a response which is indicative of cover increase since trial establishment. In contrast to the treated area, large parts of the surrounding landscape appear red in the long term trend image, indicating brightening of the index consistent with cover loss or loss of soil sealing cryptograms. In the trend image from the more recent period (1998-2005) many of these areas (including the reference site) appear dark, indicating that the brightening trend has levelled out over that period. The temporal plots confirm a darkening trend in the cover index in the bays after year 2000, *i.e.* subsequent to the trial establishment in 1999. They also indicate a brightening trend (cover decline) to 1998 prior to the establishment of the trial on the site and on the reference site (brown line in Figure 11). Since 2000, the index values have decreased by approximately 25 counts over the 5 years on bays. Smaller changes have occurred between bays from soil sealing and volunteer establishment. Patterns consistent with cover increase are also evident in the area downslope of the bund (Figures 10 and 11) where overland water flow has been reduced. Field visits have confirmed the establishment of volunteer perennials (*cassia spp.*) in this area. The trend plot shows evidence of cover increase at this location from 2002, somewhat lagging the response on the bays where active plant establishment was carried out.

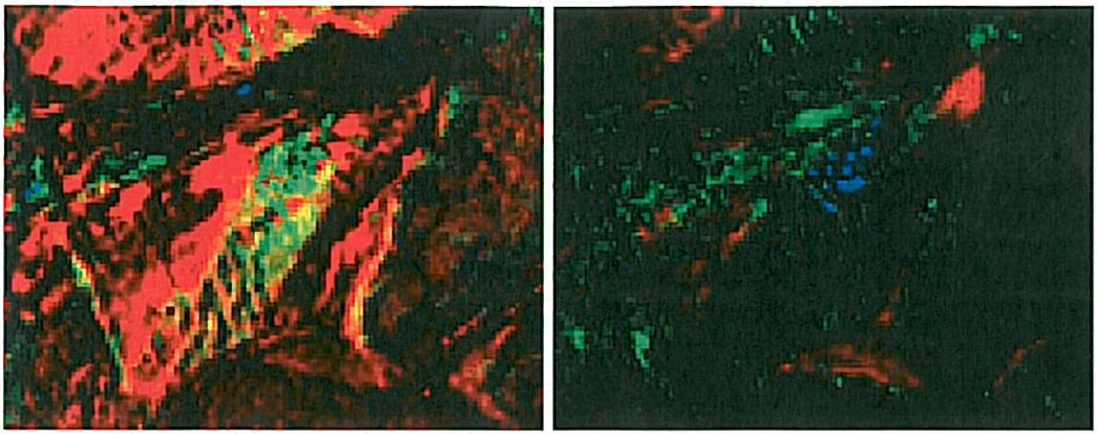

Figure 10. Trend images for the periods 1989-2005 (left) and 1998-2005 (right) for the area including Site C shown in Figure 9 above. Linear and quadratic trends displayed as described in text, Cover responses at Site C and downslope show clear contrast with wider landscape.

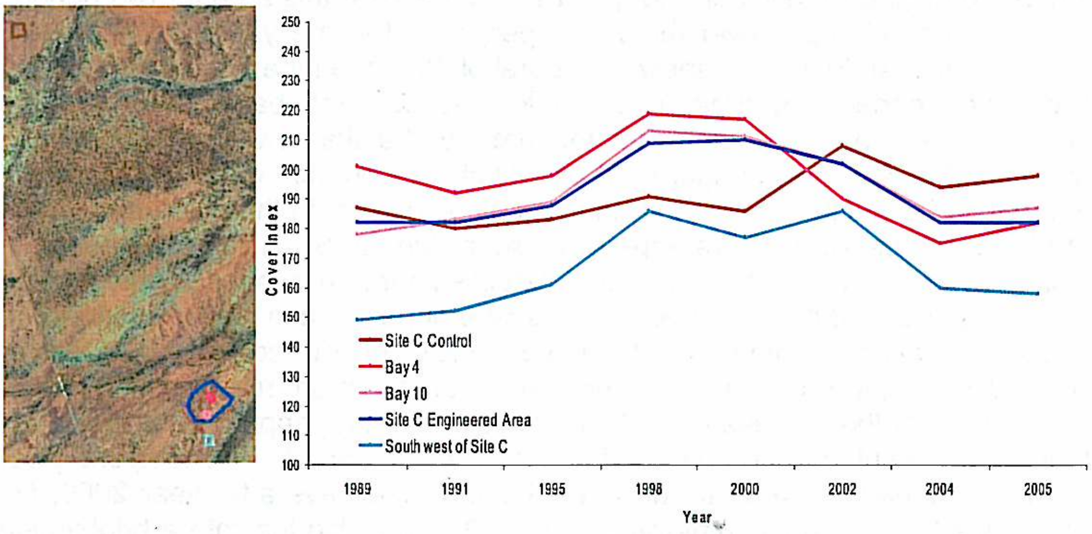

Figure 11. Temporal index plots (right) for locations in and around Site C. Left: locations for plotted lines indicated by the colours; Pink are two bays, blue the ponded area as awhole,brown area at top left is the untreated reference site, and the cyan area is downslope from Site C.

5. DISCUSSION

This study has demonstrated that a simple spectral cover index (the 'Land Monitor' index: TM band3+band5) is applicable for monitoring changes in perennial cover in the arid shrublands of the goldfields region. Trend information using this index, applied to the existing NCAS-LCCP archive, has produced results which are consistent with ground knowledge at specific sites of revegetation and volunteer plant establishment. The results demonstrate that the index is sensitive to natural and management-induced changes which are occurring in the region; major revegetation is associated with changes of 20 to 30 index counts.

Monitoring information from the trend images and temporal plots has provided direct evidence of cover changes associated with ongoing processes in the landscape surrounding the study sites, including volunteer revegetation downslope of Site C. Large portions of the surrounding catchments show evidence of overall cover decline over the period. The progression of events and timing of changes such as decline of trees in the pre-existing drainage lines at Doyle's is shown using the temporal index plots. The observed changes provide evidence that the processes described in Section 2.1 are occurring in this landscape, and identify particular locations where cover or soil surface sealing has been lost in recent years. In particular, changes upstream from Doyle's Well provide evidence of these active landscape degradation processes, which explain the woodland expansion and are consistent with field observations. Increased overland and stream flows have delivered eroded material into the drainage system. Peak flows have evidently incised and broken through pre-existing stream banks and altered the previous lower-energy drainage system. A new drainage base level appears to have been created near the upstream head of the woodland, creating a depositional zone which the *E. camaldulensis* community has been able to exploit, acting as a pioneer perennial on flood-modified sites. Information on the timing of these processes and the specific areas affected is important for understanding the system, for management and for providing context for field based assessment and monitoring sites.

In the context of carbon sequestration in this environment, the capacity to detect the timing and spatial extent of significant revegetation using Landsat time series data is demonstrated. Monitoring of such events would be one essential requirement for recognition of carbon credits. Quantification of carbon through accepted measurement or modelling protocols would also be essential. The field-measurement of carbon at these sites provides a demonstration of sequestration potential in rehabilitated sites. The WA government's rangeland regional survey program has detailed numerous areas of severely degraded alluvial plains in the mulga lands between Menzies and the Ashburton Valley. It is conceivable that carbon markets could make the repair of degraded pastoral woodlands an economically attractive proposition. While the woodland expansion at Doyle's and the revegetation at site C are clearly carbon sinks, these changes are occurring in the context of negative cover changes in the wider landscape, and are in part linked to upstream and downstream processes. In any realistic market auditing and accreditation for carbon accumulation at particular sites, changes over the surrounding catchment or sub-catchment would need to be considered.

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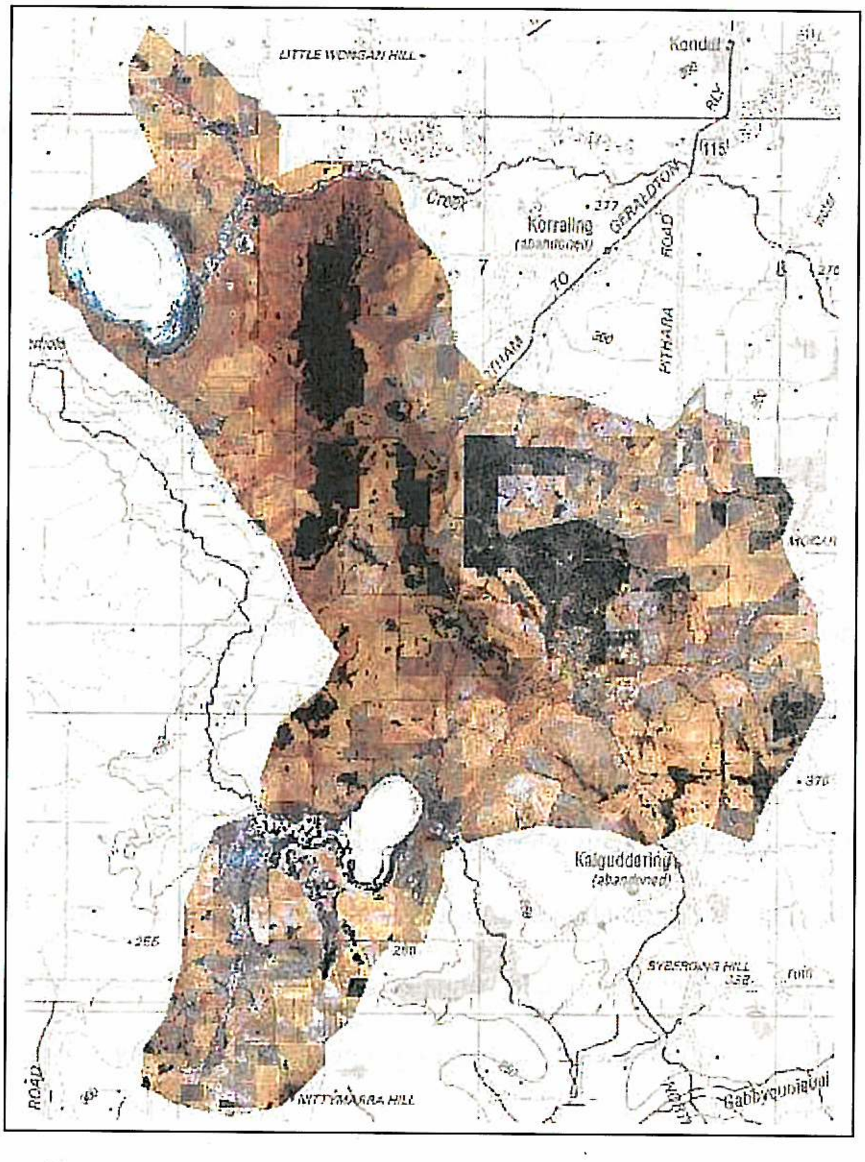
Vegetation Monitoring using Satellite Imagery

Wongan Hills Ecoscape



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April 2009

Abstract

Within this project the objective was to evaluate the effectiveness of using a time sequences of satellite imagery to locate trends in vegetation cover across a nominated location within the south-west of Western Australia. The evaluation required the implicit use of Landsat Thematic Mapper (TM) data which could be displayed to highlight anomalies in spectral responses in vegetation cover. The time sequence of the imagery was from 1990 - 2008 and had been pre-processed and calibrated to ground Percentage Cover prior to producing Trend Cover Maps from nominated epochs.

An established method was applied to the satellite imagery to detect long-term changes in woody vegetation cover and clear trends in vegetation cover densities were established from the analysis. A key factor in using satellite imagery for this purpose is to calibrate the satellite image with data obtained from field observations of crown cover and density. Additionally, stratification of the landscape greatly aids the process. The final product was ground validated for accuracy and was considered to be an effective and useful means of interrogating vegetation changes over time.

This method has the capacity to detect not just changes in vegetation cover, but to also identify areas of vegetation where there is a permanent or long-term decrease in density. The information is provided as vegetation trend maps which indicate where and when changes in vegetation have occurred. The changes at particular sites can be quantified and compared using graphical plots of the responses over time.

Context

The Wongan Hills Ecoscape lies approximately 160 km north east of Perth on the north western extent of the Avon NRM region of Western Australia. It has long been settled and is well established 'broad acre' farming centre. The first settlement in Wongan Hills dates back to the 1830's.

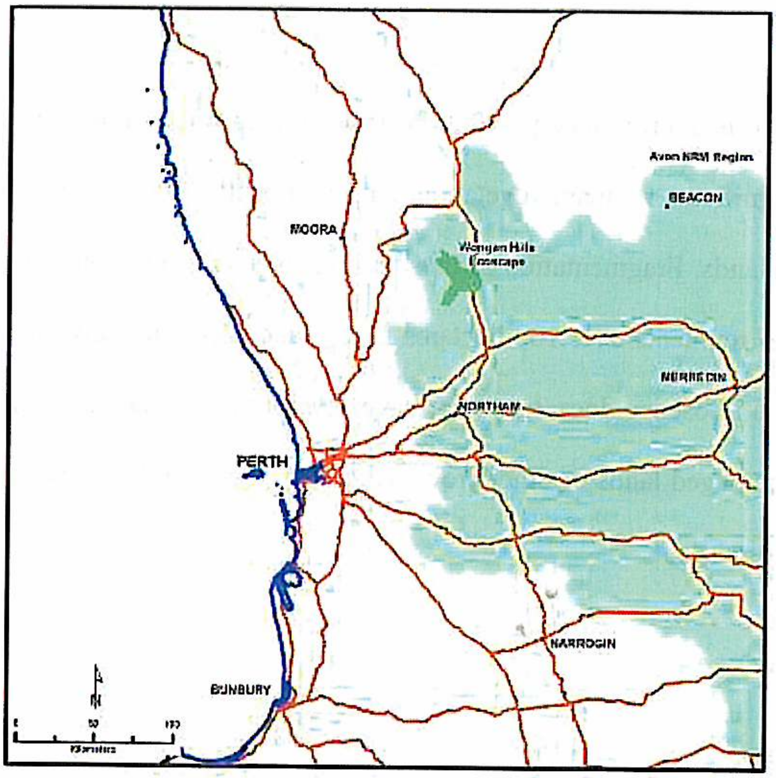


Figure 1: Location of Wongan Hills Ecoscape

The Wongan Hills region was selected as a priority Ecoscape in 2005 as part of the Avon Catchment Council's (ACC) Natural Diversity project (ND 004).The ACC defines an Ecoscape as a mosaic of ecosystems that span the topography from one ridge in the landscape to another.

To capture these Ecoscapes an iterative desktop spatial analysis (Walshe, 2006) was performed to identify regions within the wheatbelt that had a relatively high percentage (10 – 20%) of remnant vegetation, and a relatively large number (richness) of Beards-Hopkins Vegetation Associations (BHVAs). After considering other, more specific criteria, a total of 15 Ecoscapes were identified. Of these only six have received funding for projects of which three are currently funded through the ACC's NRM projects. Wongan Hills still remains as a major priority, especially within the Department of Environment and Conservation (DEC)

The Ecoscape is approximately 42000 hectares in area with around only 17% (7000 ha) being significant remnant vegetation. Approximately 3700 hectares are contained on freehold lands. Fragmentation of those remnants is an important point to consider with only 16 remnants over 100 hectares in size and approximately 200 less than 30 hectares. The Ecoscape does, however, have several large, intact remnants which are with DEC managed lands or other crown reserves. These tend to located in the upper parts of the landscape.

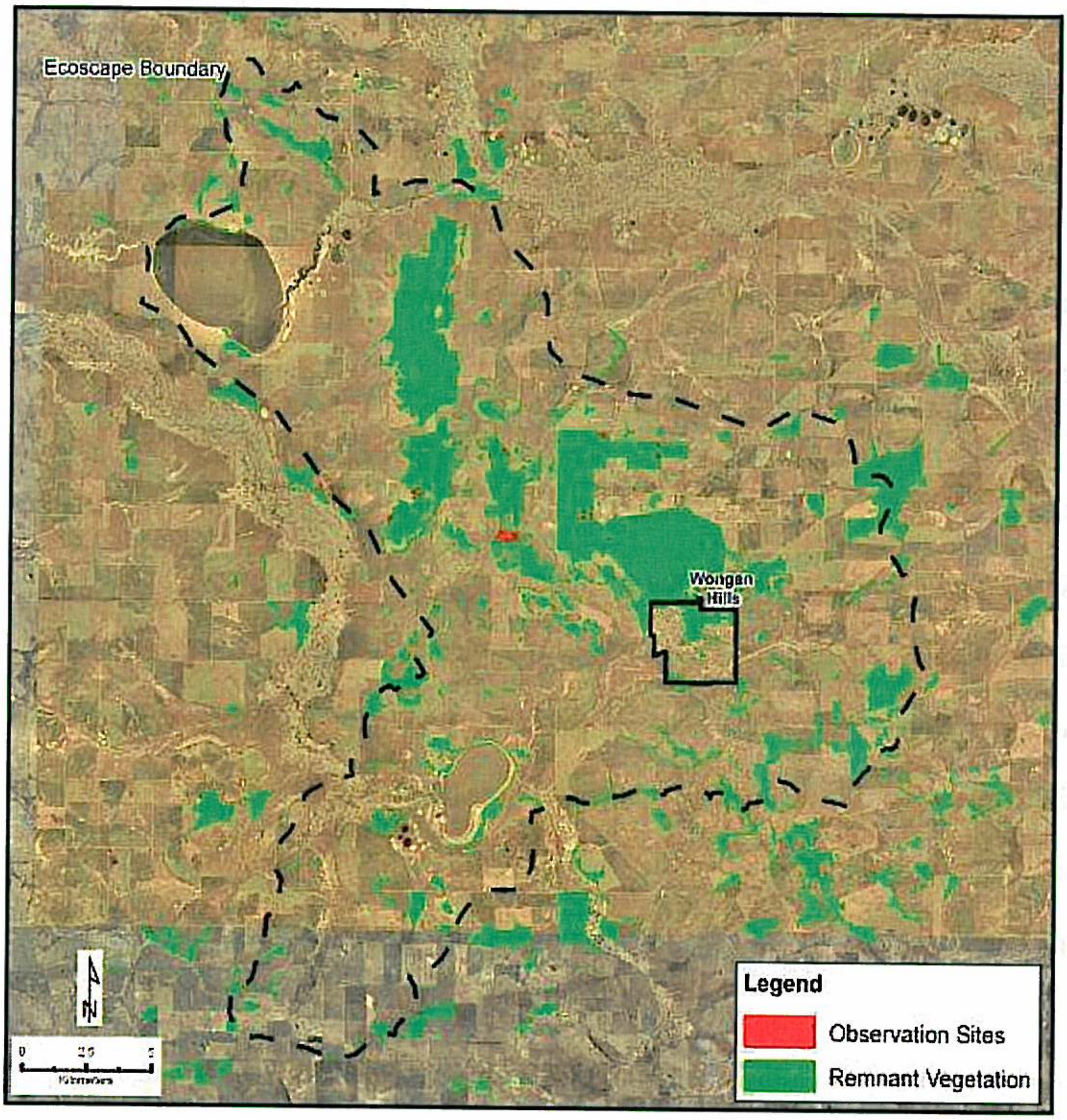


Figure 2: The spatial extent of 'baseline' remnants and the location of field sites. 268 remnants have been identified as being of significant size and condition to be included as 'baseline' remnants for the focus of the Ecoscapes project.

An important component of the Ecoscape project is to assess and monitor the health of the remnant vegetation as it will assist in determining the land management practices to be used, especially in such a fragmented landscape.

The Use of Remotely Sensed Imagery

Due to the size of the Ecoscape and the limited on-ground resources it is advantageous to use remotely sensed imagery as an appropriate means of monitoring the vegetation dynamics as it can provide an 'historical look' at vegetation trends. It provides the areal capability plus has the spectral sensitivity to accurately discriminate density of vegetation cover.

If this vegetation cover can be measured from sequences of historical Landsat satellite imagery than an alternative to the traditional one-off static mapping approach can be implemented. Ground based methods are not well suited to estimate the areal extent of vegetation density and variations, and along with aerial photography, are labour intensive, time consuming and expensive. Research has shown that satellite imagery can provide information on vegetation cover changes at a landscape scale (Wallace *et al* 2006).

Modern image processing techniques plus purpose written software packages, such as 'VegMachine', allows for the display and interrogation of the imagery for areas of interest to show and create graphical plots of the locations, timing and magnitude of the vegetation cover changes.

The outcomes are a series of coloured maps and graphs which can identify and highlight the spatial and temporal distribution of vegetation cover changes. By focussing and interrogating this information and combining expert ground knowledge of other factors influencing local vegetation cover such as hydrology, fire and salinity, rainfall, temperature and landscape patterns a fuller understanding of the dynamic biophysical environment can be created.

This application has been applied to various locations throughout DEC, including:

- Wandoo decline in Helena River Catchment, Julimar State Forest, Drummond Nature Reserve, Dryandra Woodland Reserve'
- In areas of Tuart loss on the Swan Coastal Plain,
- Within Recovery Catchments of Buntine-Marchagee and Lake Bryde, and
- Dieback investigations near Esperance, to name a few.

The information gained for these projects is used assist in future management decisions and priorities by pinpointing areas that need to be targeted, areas that are in urgent need of management and areas that require ongoing assessment.

To use the imagery to its fullest potential several preparation steps must take place so as to achieve the necessary outcomes; a modified list in order is described below:

Step 1 Rectify the imagery to standard mapping accuracies and cross calibrate each Landsat TM image so that what's black and white in one date is black and white on the next, this produces confidence when comparing changes in values of the same pixels but from different dates.

Step 2 Apply an appropriate spectral Index, (which relates to vegetation cover), to each date of imagery, creating the *Index Image*.

Step 3 From digitised aerial photos, identify and estimate sites having relatively homogeneous crown density. Select sites representing high, low and medium crown densities.

Step 4 From field inspection refine and update site cover estimates where appropriate.

Step 5 Determine the relationship between these estimates and Landsat Index Image values for each site. Once established, this relationship (linear regression) is applied to the Index Image to create the *Cover Index Image*.

Step 6 Apply this regression to each of the Index Images in the sequence creating a new time sequences of Cover Index Images.

Step 7 These Cover Images are then used to create the *Cover-Trend Images*, (images which summarise the vegetation cover variations from nominated time periods over the project area).

Step 8 Use these vegetation Cover Trend Images and the sequence of Cover Index Images as inputs into 'VegMachine'.

It's noted that a number of alternative approaches may exist within each of the above steps. For the sake of brevity, finer issues regarding assumptions and/or technical alternatives dealing with some aspects of the above process are not discussed here. The reader may follow the reference links provided or contact the authors for further details.

Overview of Landsat Imagery

The Landsat Program is a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey. Since 1972, Landsat satellites have collected information about Earth from space. The images used in this study are derived from the Landsat 5 satellite, and to a limited extent the Landsat 7 satellite. Landsat satellites orbit 705 kilometres above the Earth, and image an area every other 16 days.

Landsat satellites have taken specialised digital photographs of Earth's continents and surrounding coastal regions for over three decades, enabling people to study many aspects of our planet and to evaluate the dynamic changes caused by both natural processes and human practices. http://landsat.gsfc.nasa.gov/.

Both the Landsat 5 and Landsat 7 satellites have an onboard sensor called the Thematic Mapper (TM). The (TM) sensor has a ground picture element (pixel) size (25m) and is practical for broad-area surveys and gives results appropriate for resolution with at least several trees and shrubs per pixel and several pixels per homogeneous area. The ability to monitoring change also becomes possible with the ability to co-register and analyse imagery from various dates.

TM imagery has seven spectral 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. Band six is located in the thermal infrared part of the spectrum.

Band Number	**Wavelength (um)**	**Applications**
1	0.45 – 0.52 (Visible blue)	Coastal water mapping, differentiation of soil from vegetation.(Has poor penetration through haze)
2	0.52 – 0.60 (Visable green)	Vegetation vigour assessment also has high iron oxide reflectance.
3	0.63 – 0.69 (Visable red)	Vegetation discrimination, also has high iron oxide reflectivity
4	0.76 – 0.90 (Near infrared)	Determining biomass content and delineation of water bodies
5	1.55 – 1.75 (Middle infrared)	Vegetation and soil moisture content, differentiation of cloud from snow.
6	10.40 – 12.50 (Thermal infrared)	Vegetation heat stress analysis, soil moisture discrimination, thermal mapping. (Has limited use as a large percentage of thermal radiation in daytime is reflectance)
7	2.08 – 2.35 (middle infrared)	Discrimination of rock types and hydrothermal clay mapping.

Figure 3: Thematic Mapper Wavelengths

Important factors in producing spectral band enhancements or maps, using combinations of the above wavelengths and which reliably display vegetation, is that the spectral separation of the dense vegetation cover from sparse vegetation cover, is large compared to the vegetation variation within types of vegetation. If this can be established, then important band combinations or indices, which provide the vegetation density discrimination, can be identified (Wallace *et al.* 1994). It is after all, differences and changes in vegetation cover that is being investigated.

It is also important to note that there are many causes and interpretations of changes in reflectance that can be seen in the imagery, particularly when dealing with vegetation, and that the physical changes which result in a similar reflectance response will vary with vegetation type and background. As mentioned above, the 25m pixel can contain several trees and shrubs but also background information on soil, shadow and grasses. As the primary aim of the imagery is to provide monitoring data of the perennial vegetation, image capture dates are limited to summer dates when the grasses are in a cured state.

In Western Australia's Land Monitor project http://www.landmonitor.wa.gov.au/ a procedure to map and monitor perennial vegetation (Caccetta *et al* 2000) based on the application of indices and thresholds has been implemented and has been applied to sequences of normalised Landsat TM data over the southwest agricultural area (Furby *et al.* 2004). This Wongan Hill Ecoscape project has adopted these procedures, standards and methods for image processing.

The LandMonitor project uses (TM Band 3 plus TM Band 5)/2 with TM Band 3 being the visible red waveband and TM Band 5 being in the short-wavelength infrared (Figure 3), within their vegetation surveys. An Index image for each date of imagery (Figure 4) was made using this band combination.

Capture Date	**Landsat**	**Pixel Size (m)**
25/02/90	TM	25
30/01/92	TM	25
19/01/94	TM	25
25/01/96	TM	25
29/12/97	TM	25
13/02/00	TM	25
16/12/01	TM	25
05/02/03	TM	25
19/03/04	TM	25
02/02/05	TM	25
05/05/06	TM	25
07/01/07	TM	25
05/05/08	TM	25

Once made all dates were then combined to make a single temporal sequence file of the Index.

When using or taking measurement from the Landsat imagery, the range of values are from 0-255, and are at times confusing when trying to relate them to vegetation cover. A step here was to included re-calibrate the imagery which shows the vegetation cover as a percentage, a method shown by Behn *et al* (2001). This procedure enables better communication and reporting of the imagery for operational purposes.

Methodology Applied to Wongan Hills Landsat Imagery

In addressing **Step 1**, the cloud-free Thematic Mapper images were geometrically rectified to the GDA94 datum and in MGA50 map projection, using nearest neighbour transformation and cross calibration, and in **Step 2**, the spectral index is created using Landsat spectral bands (band 3+ band 5)/2, , references as to the research and methods employed can use found at http://www.landmonitor.wa.gov.au/.

The re-calibration of the Index images to ground-cover estimates needs to establish a relationship between measured ground foliage cover and the spectral information of the Index image. In **Step 3** we use the most current ortho-photography, in this case (2007) of the Wongan Hills region. This aerial photography assists in locating homogenous field sites with sparse, moderate and dense crown cover. The sites were chosen to give an accurate overall representation of particular ground cover densities within the study area.

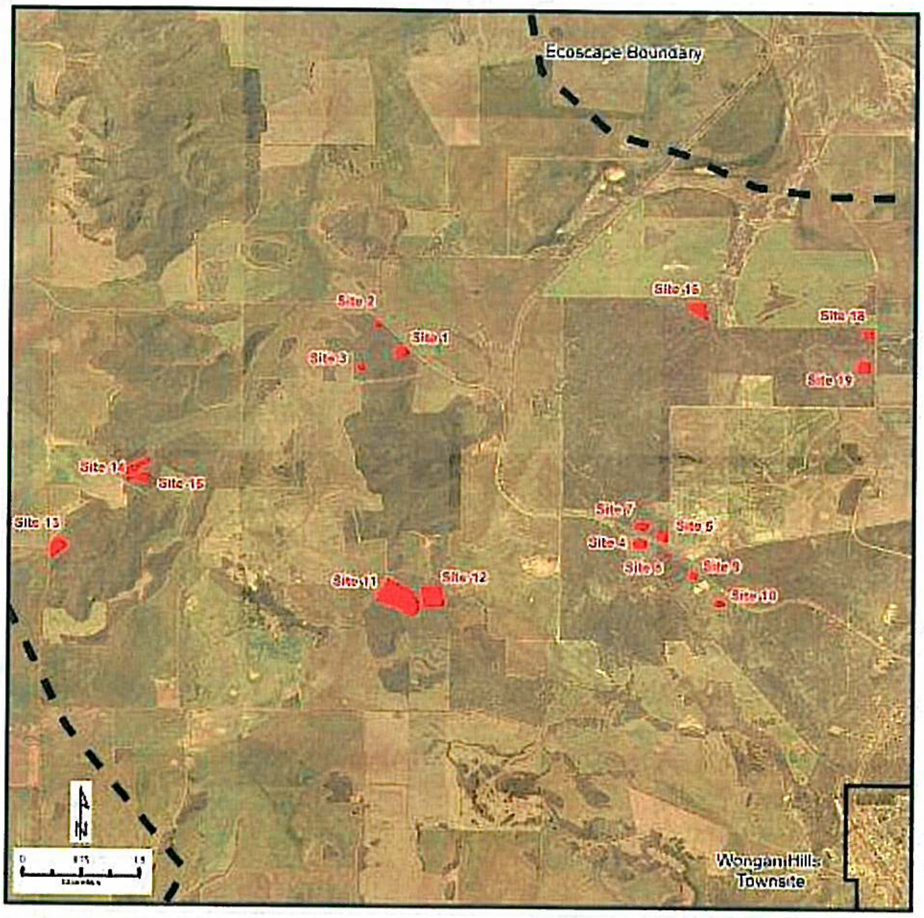


Figure 5: Location of field observation sites

Dot grid templates (Figure 6) were used to estimate the vegetation cover density within each of the sites. The template assumes an open opaque crown. Vegetation cover was also estimated from visual field inspection, **Step 4**, and was included as a double check of the desktop measurements and to account for any estimation error usually associated with vegetation cover of the mid-storey and ground, Figure 7 below.

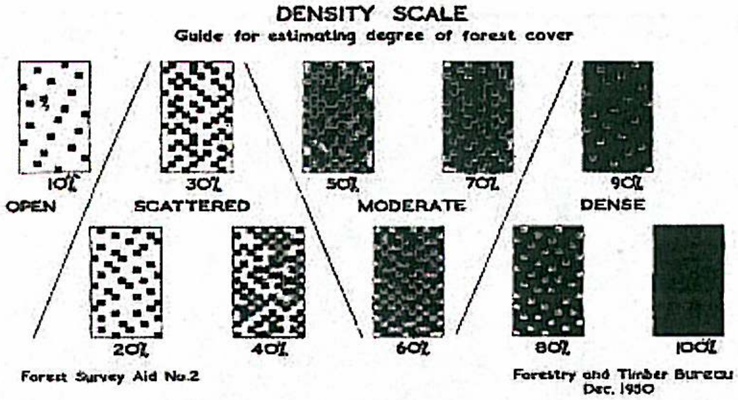


Figure 6: Crown density template (Forestry and Timber Bureau 1950)

For example, Figure 7 shows two field sites (Site 14 and15) at Wongan Hills, chosen as they represent areas of homogeneous vegetation cover. Using the density template above (Figure 6) the sites were estimated at 20% and 65% cover respectively. Field inspection later revised that estimate to 45% and 60% respectively.


(a) Ortho photo with sites
(b) Site 14, 40% cover
(c) Site 15, 60% cover

Figure 7 Field sites 14 & 15 at Wongan Hills demonstrating homogeneous vegetation cover for two varying cover sites, (a) showing their location on aerial photo (b) Site 14 (top site with yellow boundary) with a 40% estimated vegetation cover and (c) Site 15 (lower site) with 60% estimated vegetation cover.

	Vegetation Cover Estimates				
Site	Orthophoto (2007)	Field Estimates	Canopy	Mid	Ground
1	50	60	25	25	10
2	60	70	60	0	10
3	80	75	65	0	10
4	0	10	0	0	10
5	40	50	50	0	10
7	45	55	45	0	10
8	75	70	60	10	0
9	20	30	20	0	10
10	0	15	15	0	0
11	45	45	45	0	0
12	70	80	45	20	10
13	40	40	20	10	5
14	**20**	**45**	**25**	**20**	**0**
15	**65**	**60**	**45**	**0**	**15**
18	40	50	50	0	0
19	10	10	0	0	10

Figure 8: Adjusted desktop and field estimates of vegetation cover for all selected sites. Sites 14 and 15 were adjusted because of the influences of the mid-storey and ground cover.

By plotting these site values of the vegetation cover estimates against the mean spectral values of the 2007 Index image (Figure 9), a linear regression equation, **Step 5,** can be determined (Figure 10). This regression equation is then applied to the 2007 Index image to create the new Index Cover Image with values now as percentage vegetation cover measurements.

Site	Spectral Index	Field Estimate
1	65.484	60
2	63.333	70
3	57	75
4	100.172	10
5	77.043	50
7	76.72	55
8	63.286	70
9	89.833	30
10	93.938	15
11	66.695	45
12	61.971	80
13	68.804	40
14	65.64	45
15	57.763	60
18	73.25	50
19	100.524	10

Figure 9 The field site vegetation cover estimation and average spectral index from the 2007 imagery.

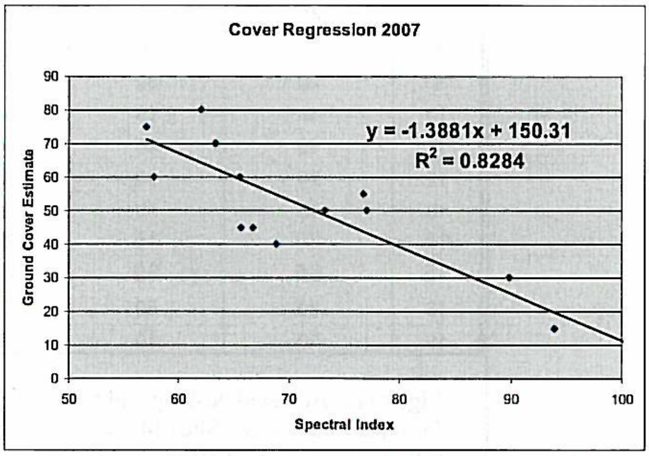


Figure 10 The linear relationship between ground cover estimates and average spectral Index

As the sequence of imagery has already been rectified and calibrated to each other, **(Step 1)**, the linear regression described above is applied to each of the image dates from 1990 – 2008 dates **Step 6**. In Figure 11 below the lighter pixels have low percentage vegetation cover values and the dark pixels high. By plotting or graphing individual or groups of pixels from each date

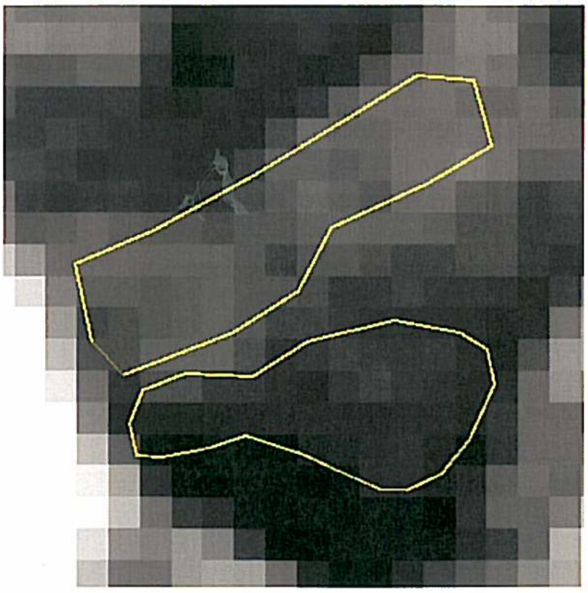
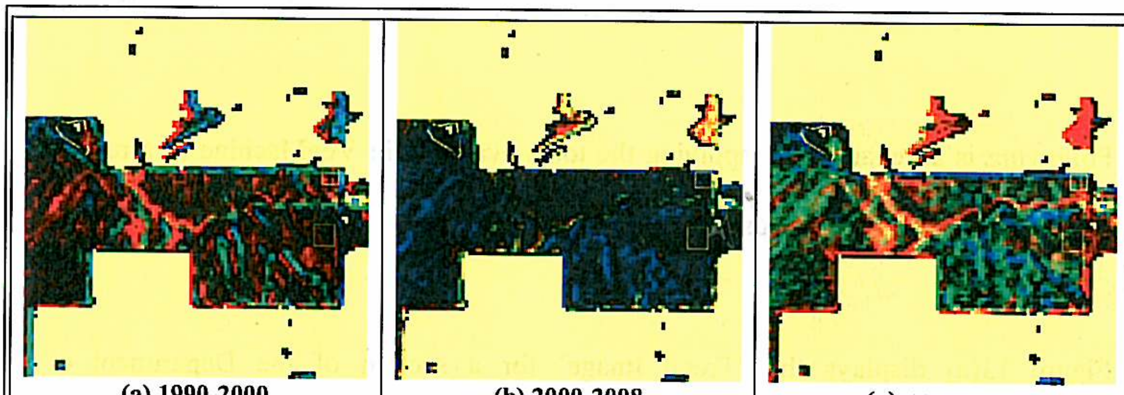


Figure 11: Cover Index Image for satellite image 2007. The regression is applied to the Index Image for each date in the sequence.

from the 18-year historical sequence of imagery, changes or trends over time can be communicated.

In **Step 7** the Trend Image is produced by determining the slope of the same pixel values (e.g. slope over time) (Wallace et. al, 1999) from each of the Cover Index images.

The Trend Image can be displayed to summarise cover trends of vegetation over time as measured by the Cover Index sequence, and in particular to highlight areas with different patterns of change. For this project simple summaries of trends over the period can be made by displaying positive and/or negative linear trends in different colours and explanations (12(a) and (b) below). Three epochs were chosen to highlight the vegetation variations, (1990-2000), (2000-2008) and ((1990-2008).



(a) 1990-2000 **(b) 2000-2008** **(c) 1990-2008**

Figure 12 Trends images covering different time periods. **Red:** There has been a reduction in vegetation cover over time, as an average, **Blue:** There has been an increase in vegetation cover over time, as an average, **Black:** Vegetation cover has remained at this level (neither, decreasing or increasing) over time, Yellow: Vegetation cover has been a reduced and has not recovered, and **Green** Vegetation cover has been lost but has since recovered to previous levels

In **Step 8** the Trend Image can be interrogated through VegMachine. As previously stated 'VegMachine' is the name of both a software package and an extension program (Karfs, *et al* 2004) and has been successfully implemented into DEC regions particularly in the SW area of the State. The VegMachine software package is designed to be an easy to use, suitable for use by field and regional staff. It can be used for display purposes and for the interrogation of the time-series of imagery. The input data is costumed prepared, and includes imagery, vectors, and monitoring products for specific regions and purposes.

Step1 to Step 8 described above, outline the development of the input data for VegMachine. By transforming the changes in vegetation cover observed from historical sequences of satellite imagery into vegetation cover density data with a familiar measured label, .products resulting from VegMachine are presented in a form that are easily understood and recognised by managers and researchers within DEC.

Following is an example of applying the tools available in VegMachine to a remnant within the Wongan Hills Ecoscape.

Figure 13(a) displays the 'Trend Image' for a section of the Department of Agriculture & Food W.A. (DAFWA) Research Station and the corresponding ortho-photo image. Three locations are selected for interrogation, based on trend colour and ground observations. The locations are shown by the vector points red, black & blue.

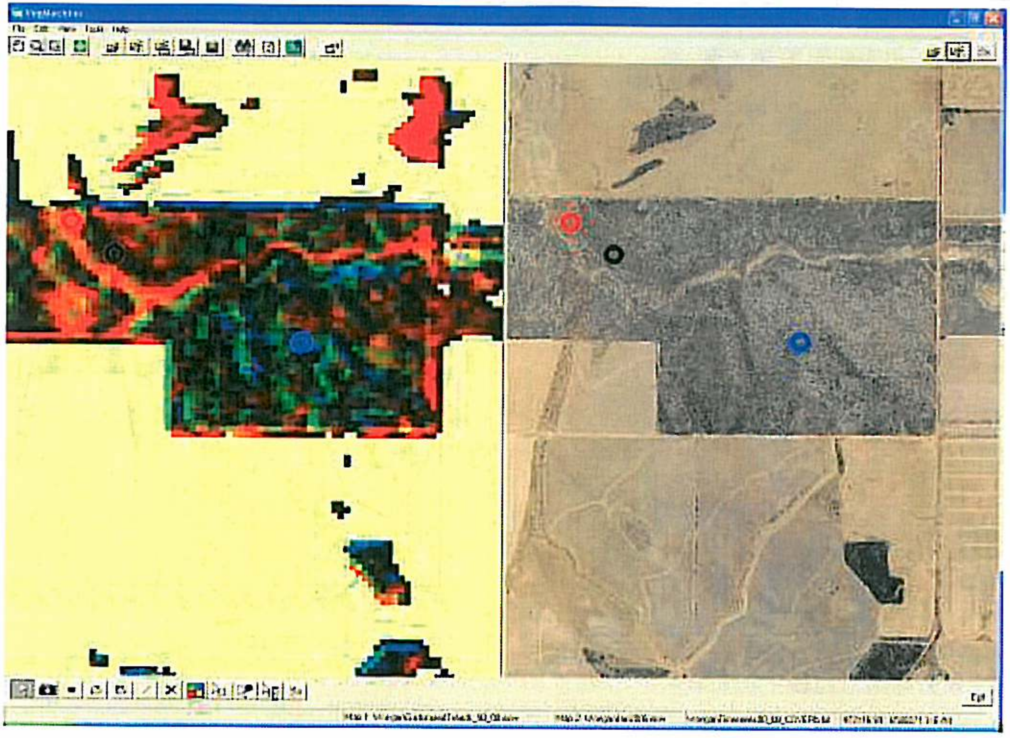


Figure 13(a) Vegetation Cover Trend for 1990-2008 with corresponding air photo as reference. Three trend varying locations are identified and shown as coloured circles in red, blue and black.

Figure 13(b) shows the time series graph for the selected locations. It can be seen that vegetation cover values vary between each location. It also shows that in a particular location the vegetation cover values vary from capture date to capture date. Even though the image colour may show a increasing, decreasing or steady trend over the selected time series there can be considerable variations during that time period as shown in the graph.

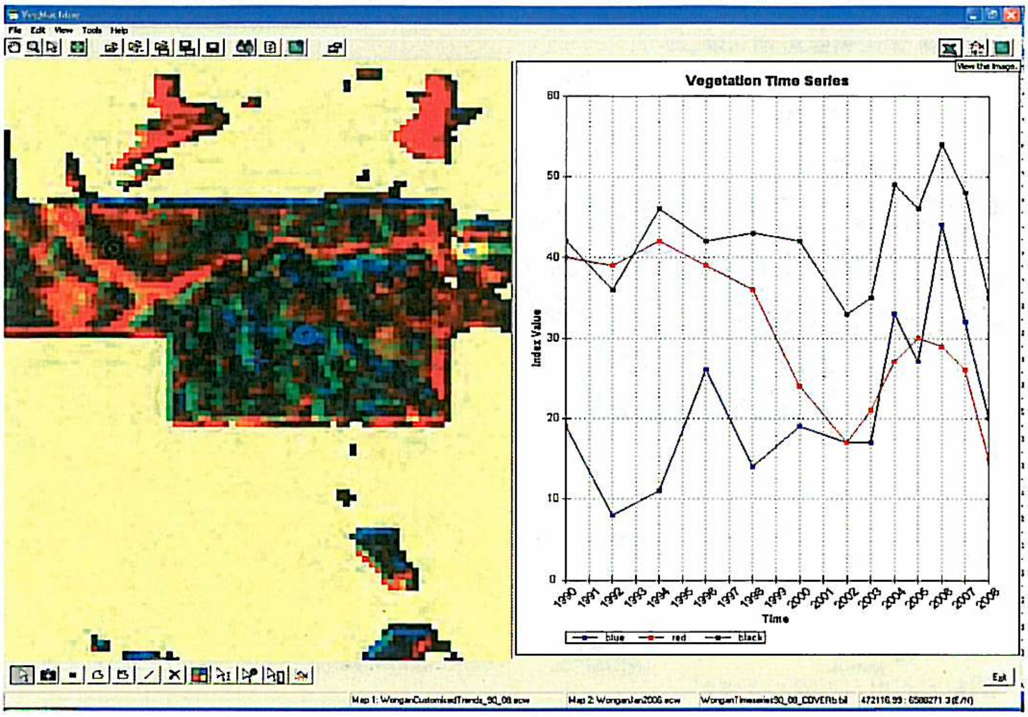


Figure 13(b) The three areas coloured red, blue and black and their corresponding temporal variations in their cover densities.

It can be seen that the vector and line colours have been manually chosen to follow the colours used in the image to illustrate times series trend. **Red:** Vegetation cover is (analysed 1998 to 2008) there has been a reduction in cover over time, **Blue:** Vegetation cover has increased in cover over time, and. **Black:** Vegetation cover is remained reasonably stable over the time period.

Interpretation of these temporal series can establish the current state of vegetation cover compared to previous years and identify periods of significant change. For example the red vector shows a significant period of decline between 1994 and 2002. Yet all three locations show an increase in vegetation cover between 2002 & 2006.

In a spatial sense, even though all three vector points are relatively close in the same remnant their position in the landscape could influence the trend. In this case the actual site of red vector is lower in the landscape and could be under hydrological threat.

The interpretation of this data can be used in conjunction with the knowledge and experiences of local stakeholders to build up a greater understanding of the biophysical history of the area.

Conclusion

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 scales particularly relevant, for which these on-ground measurements can be accurately made, and so are well placed to provide necessary and updated information for land managers.

The methodology described here provides a sound basis for rapid, accurate mapping tree cover trends across large areas where the use of conventional aerial photography cannot be economically justified.

By following the steps outlined in this document the Landsat imagery collected since 1990 has been refined from broad spectral values across the SW region to values that better suit the Wongan Hills Ecoscape. This allows for an more accurate interpretation of the time series images in the monitoring of remnant vegetation.

Relevant information on vegetation cover trends has direct links to health, condition and change and is of great interest from a variety of perspectives. 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. Sidmore *et al* (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. This 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.

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TOWARDS AN APPROACH FOR REMOTE SENSING-BASED RANGELAND CONDITION ASSESSMENT IN NORTH WESTERN AUSTRALIA

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ABSTRACT

The assessment of rangeland condition plays an integral role in ensuring the sustainability of Western Australia's (WA) pastoral leases. Current ground-based traverses provide a useful indication and summary of rangeland condition, but traversing is largely restricted to existing tracks and will not identify degraded areas out of sight of the traverse routes. Therefore, we explore remote sensing as a potential tool for providing an assessment of range condition over broader areas, thereby identifying areas of potential concern that may have been missed using standard techniques. In addition, retrospective sequences of satellite imagery were used to identify historical condition changes to provide lease inspectors with: a) a historical synopsis of the temporal dynamics in the condition of an area; and b) an early warning for areas that may be more susceptible to, or trending towards, degradation. Landsat images of a pastoral lease in the Fitzroy River catchment, west Kimberley region of WA, were selected so as to be contemporaneous to existing transect sample dates, and a soil adjusted total vegetation index (SATVI) and a stress related vegetation index (STVI-1) was applied to each. Tukey's Honestly Significant Difference (HSD) tests performed on the transect data showed that poor condition ratings significantly differed in SATVI/STVI-1 response in comparison to good condition ratings. Fair condition ratings could not be separated from those in good condition, and so were excluded. The best performing vegetation index was identified from receiver operating characteristic (ROC) analysis and reclassed into poor and good condition classes by identifying a suitable threshold from the ROC plots. Condition class trends and fluctuations were illustrated using state and transition modelling. Overall accuracy ranged from 85% to 90% based on the STVI-1 index, giving confidence in the current protocol and its

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potential future use for classifying condition and identifying historical trends at the lease-level.

INTRODUCTION

The assessment of rangeland condition is critical for ensuring the sustainability of Western Australia's pastoral leases, since this information is used by the Pastoral Lands Board of Western Australia to make decisions regarding lease conditions and the potential need for management responses. A major challenge is to ensure there is adequate sampling at the lease and paddock scale in order to make informed decisions. Unfortunately, for reasons of accessibility and cost, current ground-based sampling is routinely restricted to areas close to tracks, which represent only a small fraction of the total lease area and may also be biased in their distribution due to landscape constraints such as the need for as much access as possible during the wet weather. Consequently, areas in poor condition or trending towards poor condition that are outside of the sampling design may not be identified. Temporally-based remote sensing is a potential tool for extrapolating sample points to provide full coverage of a pastoral lease, thereby highlighting areas that are: a) currently in poor condition; b) trending towards poor condition; and c) have a history of poor condition. Similarly, it also has the potential to identify areas that are in good condition or have recovered from a previously poor state.

The application of remote sensing for rangeland condition assessment and monitoring is not new, with some of the early work in Australia dating back almost three decades (e.g. Graetz and Gentle, 1982; Graetz *et al*, 1983, 1988). This early work recognised the need for deriving methods to dichotomise the landscape into vegetative cover and bare soil, as well as the need to monitor the levels of cover and bare soil through time. A considerable body of work now exists with respect to cover monitoring in rangelands (e.g. Wallace & Thomas, 1998; Karfs *et al.*, 2000; Karfs & Wallace, 2001; Wallace *et al.*, 2004, 2006; Washington-Allen *et al.*, 2006; Curry *et al.*, 2008). As a generalisation, the primary role of this work has been to identify anomalous cover change (e.g. increases or decreases) relative to a benchmark (e.g. a mean or fitted trend line) over a considerable period of time. Maps are often derived as trend summaries, which depict, for example, whether the trend is positive or negative over time. Anomalous trends direct attention to areas that are changing differently, thereby inferring a change in condition (Wallace *et al.*, 2006).

It is not our intention in this paper to simply recreate these existing methods. Rather the intention is to develop a suite of tools that refine the choice of some of the parameters involved in these models. Firstly, there now exists a plethora of different vegetation indices, and each is designed for different purposes. Given the range of variation in soil type, colour and vegetative composition throughout the rangelands of Western Australia, we hypothesise that the choice of vegetation index is likely to vary spatially. We test two alternative vegetation indices in this paper and outline methods for choosing between them. Secondly, interpretation of cover change maps is dependent on the selection of a benchmark condition. Commonly, these have either been an initial condition at an arbitrarily chosen point in time, conditions during droughts, a measure of central tendency, percentiles or standard deviations from the long term mean (Washington-Allen *et al.*, 2006). In this research, we investigate the ability to derive a benchmark (or cut-point) at various time-periods using archived traverse data. A third modification to existing techniques was to investigate the applicability of using state and transition analysis to derive a map showing pixels that are transient from the identified benchmark and those that are static.

GENERAL DESCRIPTION OF STUDY AREA

The studied pastoral lease is situated in the Fitzroy River catchment, in the Western Kimberley Region of Western Australia. To eliminate the potential variability between land systems, the study area was restricted to a 687 km^2 portion of the lease, comprising only the Djada land system. The Djada land system is described as active flood plains with extensive back plains of brown to dark brown coloured self-mulching and cracking clays. Vegetation on the plains of the Djada land system is made up of ribbon grass (*Chrysopogon fallax*), blue grass (*Dichanthium* spp.) and Mitchell grass (*Astrebla* spp.). Tree cover is mostly restricted to zones around levees and minor channels (Speck et al., 1964).

DATASETS

Ground-based Traverses

The Department of Agriculture and Food, Western Australia (DAFWA) is the government agency responsible for collecting ground-based traverses, which are in turn used to summarise the condition and trajectory of improvement or decline of a pastoral lease. Existing tracks are used as traverse routes and an assessment is made every 1 km over an area with a nominal radius of 50 m. The criteria used to assign an area to a discrete pasture condition rating is summarised in Tab. 1. For the purpose of our study, we grouped good condition with very good condition and poor condition with very poor condition. Traverses for three temporal data-points exist in our study area, which were collected during June 2001, July 2005 and October/November 2008. These periods of collection largely ensure that only persistent (perennial) vegetation cover is assessed.

Tab. 1: Criteria used to assign a quadrat to a condition rating (adapted from Cotching, 2005).

Rating	**Condition Indicators**
Very Good	Cover and composition of shrubs, perennial herbs and grasses is near optimal, free of obvious reductions in palatable species or increases in unpalatable species liable to reduce production potential.
Good	Perennials present include all or most of the palatable species expected; some less palatable or unpalatable species may have increases, but total perennial cover is not very different from the optimal.
Fair	Moderate loses of palatable perennials and/or increases in unpalatable shrubs or grasses, but most palatable species still present; foliar cover is less than sites rated as good or very good unless unpalatable species have increases.
Poor	Conspicuous loses of palatable perennials; foliar cover is either decreased through a general loss of perennials or increased by invasion of unpalatable species.
Very Poor	Few palatable perennials remain; cover is either greatly reduced, with much bare soil, arising from loss of desirables, or has become dominated by a proliferation of unpalatable species.

Landsat Imagery and Pre-processing

Three cloud-free Landsat TM images were acquired for this study to be as close to the existing traverse dates as possible. Image dates were: 29 July 2001; 16 July 2005 and 13 November 2008. All imagery was calibrated using the absolute atmospheric correction procedures of Chavez (1996).

METHODOLOGY

Vegetation Indices

Three issues need to be considered when choosing an appropriate vegetation index in the arid and semi-arid rangelands of Western Australia. Firstly, perennial vegetation types in these regions do not reflect highly in the infra-red portion of the spectrum (Graetz & Gentle, 1982; Graetz *et al*, 1983). This is generally due to the sparsity of vegetation and such vegetation having a low leaf area index in these areas (O'Neill, 1996). Secondly, acquiring imagery in the dry season means that grasses and some shrubs are usually in a stage of senescence. As a result of these two factors, commonly used vegetation indices that are based on the differences between the red and near infra-red (NIR) bands (e.g. the Normalised Difference Vegetation Index, Simple Vegetation Index) are rarely capable of quantifying vegetation cover in these areas. These vegetation indices are best suited to quantifying healthy green and actively photosynthesising vegetation. Thirdly, due to the general sparsity of vegetation growing within a 30 m^2 Landsat pixel, average reflectance values are greatly influenced by background soil reflectance (Heute, 1988).

The choice of vegetation index for use in this study was, therefore, based on those that were able to: a) mitigate soil background reflectance; and/or b) quantify senescent vegetation. Vegetation indices that are capable of quantifying senescent vegetation often capitalise on the differences between the red band and the short-wave infra-red (SWIR) portion of the spectrum. This is because the SWIR band is sensitive to water content and thus as vegetation dries, the SWIR band reflectance increases. Such vegetation indices include the summation of band 3 (red) to band 5 (SWIR) (e.g. Curry *et al.*, 2008), the Soil Adjusted Total Vegetation Index (SATVI) (Marsett *et al.*, 2006) and the Stress-related Vegetation Index 1 (STVI-1) (Thenkabail *et al.*, 1994). Several methods exist that attempt to minimise the effects of soil background reflectance, including the addition of a soil correction factor, as used by the Soil Adjusted Vegetation Index (SAVI) (Huete, 1988). A second technique is to calculate the perpendicular distance from a soil line obtained through linear regression of bare soil sample reflectance values from two bands (typically, but not restricted to, the red and NIR bands). The Perpendicular Distance 54 (PD54) developed by Pickup *et al.* (1993) uses this technique and derives the soil line from band 4 (green) and band 5 (red) of the Landsat Multispectral Scanner (MSS), which can also be related to band 2 (green) and band 3 (red) of Landsat Thematic Mapper (TM) imagery.

In this study we chose to test the performance of the SATVI, because it attempts to correct for soil background reflectance using a soil correction factor and quantifies both green and senescent vegetation. A second index, the STVI-1 was also tested as it was designed for stressed (senescent) vegetation and has been shown to work well in the semi-arid to arid rangelands of Australia (e.g. O'Neill, 1996; Jafari *et al.*, 2007). Equations for the SATVI (Marsett *et al.*, 2006) and STVI-1 (Thenkabail *et al.*, 1994) are given below:

$$SATVI = \frac{\rho band5 - \rho band3}{\rho band5 + \rho band3 + L}(1 + L) - \frac{\rho band7}{2} \tag{1}$$

$$STVI - 1 = \frac{\rho band5 \times \rho band3}{\rho band4} \tag{2}$$

where ρ is the reflectance in band 3 (red), band 4 (NIR), band 5 (SWIR1) or band 7 (SWIR2) of Landsat TM imagery and L is a soil correction factor.

The soil correction factor (L in Equation 1) lies between 0 and 1, with 0 being full vegetation cover and 1 being no vegetation. Following Duncan *et al.* (1993) SATVI was computed using three different correction factors (0.25, 0.5 and 1). Low SATVI values suggest bare soil and high values represent higher levels of vegetative cover. In contrast, low STVI-1 values represent higher levels of vegetative cover, with higher values characterising the response of bare soil.

Statistical Separation of Condition Ratings

One-way Analysis of Variance (ANOVA) tests, followed by Tukey's Honestly Significant Difference (HSD) test (Walpole & Myers, 1993), were used to identify if the condition ratings could be separated using the abovementioned vegetation indices. This test compares the means of every condition to the means of every other condition in turn, and identifies where the difference between two means is greater than the standard error would be expected to allow. Only the condition ratings that could be separated were used in further analysis.

Choosing between Vegetation Indices: ROC Analysis

Receiver Operating Characteristic (ROC) analysis is often used to choose between alternative models and is used here to identify the best performing vegetation index in our study area. Firstly, traverse points were converted into a binary state: good = 1, the absence of good (poor) = 0 and the value of the vegetation index were then extracted at each of these points and sorted in ascending order. A set of cut-points (*C*) were defined from these values as half the distance between each successive pair. At each cut-point the True Positive Rate (TPR) and False Positive Rate (FPR; see below) is calculated based on one of two decision rules depending on the vegetation index used. For the SATVI, a traverse point that is known to be in good condition is a true positive if it is greater than or equal to *C*. Similarly, a traverse point in poor condition is considered a false positive if the traverse point is greater than or equal to *C*. For the STVI-1, a traverse point is a true positive if a point known to be in good condition is less than or equal to *C*, and a false positive if it is known to be in poor condition and is less than or equal to *C*.

A ROC plot is constructed by plotting the TPR (y-axis) against the FPR (x-axis) at each cut-point. The TPR and FPR are computed using the following formulae (Fielding & Bell, 1997):

$$TPR = \frac{nTP_i}{nGP} \tag{3}$$

$$FPR = \frac{nFP_i}{nPP} \tag{4}$$

where nTP_i is the number of true positives at cut-point i, nGP is the total number of good traverse points, nFP_i is the number of false positives at cut-point i and nPP is the total number of poor traverse points.

The ROC plot can be used to generate a summary statistic known as the Area Under the Curve (AUC). The value of AUC is between 0.5 and 1. If the value is 0.5, the classification is no better than that obtained by chance, while a score of 1 indicates no overlap in the distribution of good and poor condition scores as determined by the vegetation index; i.e., a perfect discrimination between the two conditions (Fielding & Bell, 1997; Ayalew & Yamagishi, 2005). The AUC makes comparison between vegetation indices relatively straightforward; the best model will minimise false negatives and false positives and therefore have the highest AUC (Zweig & Campbell, 1993). The AUC is calculated using the trapezoidal rule (Pontius & Schneider, 2001):

$$AUC = \sum_{i=1}^{n} [x_{i+1} - x_i] \times [(y_i + (y_{i+1} - y_i))/2] \tag{5}$$

where n is the number of cut-points, x_i is the false positive rate at i, x_{i+1} is the false positive rate at threshold $i+1$, y_i is true positive rate at threshold i, and y_{i+1} is the true positive rate at threshold $i+1$.

Identifying the Optimal Cut-Point

A perfect classification is at the left uppermost corner (0,1) of the ROC plot. At this point there are no false positives or false negatives (Liu *et al.*, 2005; Lobo *et al.*, 2008). Typically, this point is rarely achieved; however, the cut-point closest to this perfect classification is deemed to be the optimal threshold for dichotomising between two classes (i.e., good and poor condition). Optimal cut-points were identified for each year of traverse data and used to create binary layers of good and poor condition. These three layers were then used as input into the state and transition model.

State and Transition Modelling

State and transition modelling has typically been used in ecology to describe the successional processes of vegetation communities (c.f. Westoby *et al.*, 1989; Bowman *et al.*, 2001; Stringham *et al.*, 2003). The main appeal of state and transition modelling is to highlight areas that are resistant to external conditions, those that are transient, and those that are able to recover after disturbances (Stringham *et al.*, 2003). We considered these concepts portable for retrospective condition assessment monitoring.

In our model, a state may be either a pixel in good condition or a pixel in poor condition as defined from the optimal cut-point found. Transitions are caused when a pixel shifts across the optimal cut-point in a subsequent time period. Eight permutations are possible using the three transect dates as shown in Fig. 1. A state change from good condition into poor condition may suggest, for instance, that an area has been over grazed. Transitions from a poor state into a good state may suggest the area has been better managed (e.g. stocking rates below maximum carrying capacity or wholesale de-stocking). Ideally, with correct management, areas identified to be in good condition should not transition into poor condition and areas in poor condition should show improvement by transitioning into the good condition class. Areas consistently in poor condition or transitioning into the poor condition class are those requiring the greatest amount of ground-based investigation.

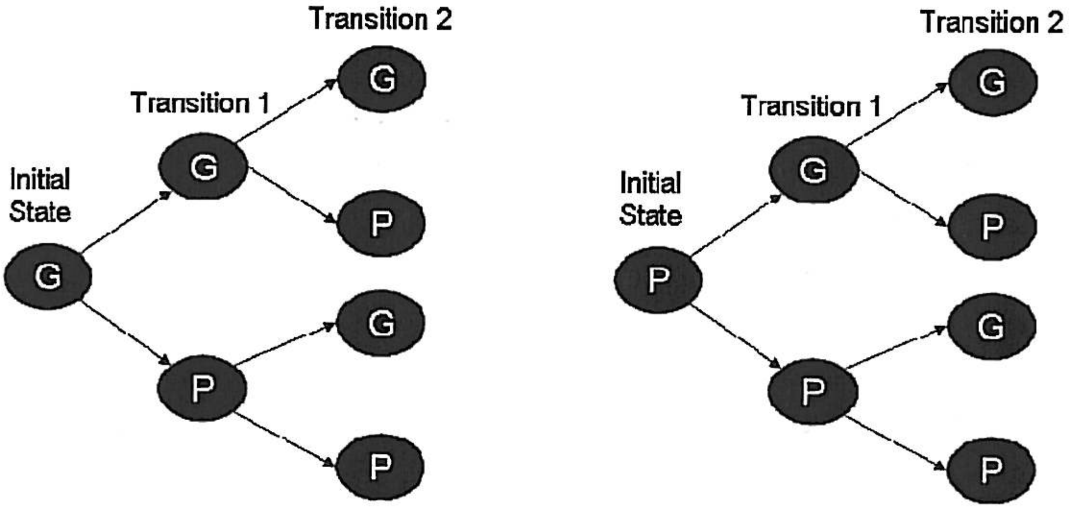

Fig. 1: Possible initial states (at 2001) and transitions through time (Transition 1 = 2005, Transition 2 = 2008) based on the three temporal data points used. "P" = poor condition, "G" = good condition.

RESULTS AND DISCUSSION

Statistical Separation of Condition Ratings

Tukey's HSD tests determined that for all vegetation indices trialled, at the alpha = 0.05 level of significance, poor condition ratings could be separated from good condition ratings, fair condition ratings could be separated from poor condition ratings, but fair condition ratings could not be separated from good condition ratings. Because fair condition ratings were not significantly different to good condition ratings (i.e., the impact of a decline from good condition to fair condition is less than that of a decline from fair condition to poor condition) we chose to exclude the fair condition class from further analyses.

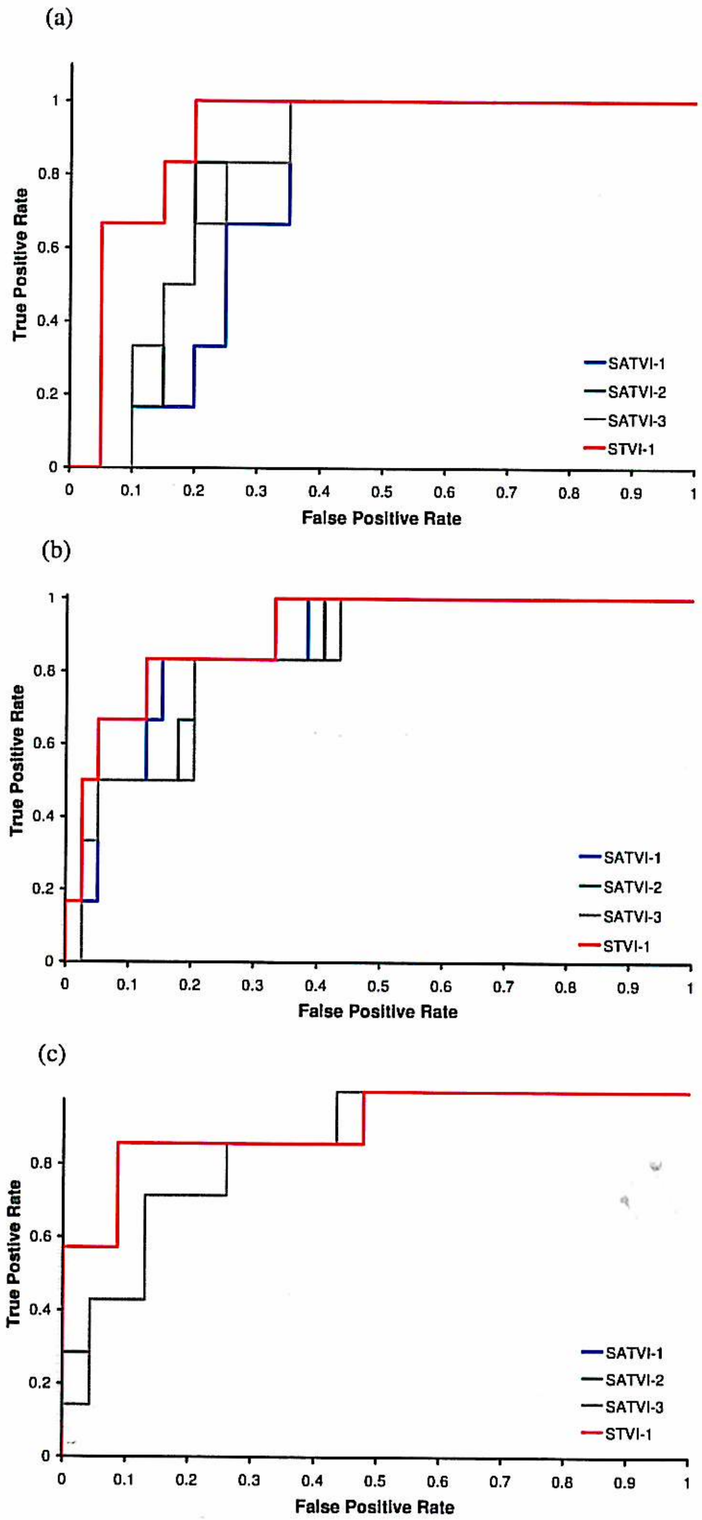

Fig. 2: ROC plots of the different vegetation indices trialled based on Landsat imagery for: a) 2001; b) 2005; and c) 2008. Note: Soil correction factor equals 0.25, 0.5, and 1 for SATVI-1, SATVI-2 and SATVI-3, respectively. ROC plots are obscured where the coordinates of the curves are identical.

Choosing between Vegetation Indices: ROC Analysis

ROC plots for the STVI-1 and the SATVI (with three different soil correction factors) are shown in Fig. 2. Fig. 2 illustrates that the STVI-1 index is the best performing index for all years in this study area, which can be identified by the fact that the true positive rate rises more rapidly than the other indices. The best performing SATVI index, based on variation of the soil correction factor, changed through time (particularly from 2001 to 2005 (Tab. 2)), which may suggest there is no correction factor of general applicability in this study area. The AUC of each of the curves is shown in Tab. 2 confirming the STVI-1 to be the best index out of those trialled.

Identifying the Optimal Cut-Point

Tab. 2 summarises the optimal cut-points found for each of the vegetation indices along with the TPR, FPR and the overall accuracy. As mentioned above, in each case the STVI-1 index provided the greatest discrimination and, therefore, was the only one used in the state and transition model (see below). As higher values are associated with lower levels of cover with this index, pixels in good condition for the 2001 STVI-1 image were all pixels ≤ 0.113, and pixels in poor condition were all those > 0.113. This was also done for the 2005 (e.g. good condition ≤ 0.259) and 2008 (e.g. good condition ≤ 0.275) STVI-1 images. Tab. 2 also shows that the optimal cut-point from the STVI-1 changed markedly between years, particularly between 2001 and 2005. A possible explanation for these changes is variable levels of rainfall prior to each image acquisition, rather than an improvement in condition, although this has yet to be studied. However, it does serve to highlight the importance of temporal traverse points for calibrating the difference between good and poor pixels at each point in time.

Tab. 2: Statistics used to choose between vegetation indices (AUC) and the accuracy of the optimal cut-points used for dichotomising between good and poor condition as found from the traverse data points for each year of data.

Year	Vegetation Index	AUC	Optimal Cut-Point	TPR	FPR	Overall Accuracy (%)
2001	SATVI-1	0.750	0.147	1	0.35	73.08
	SATVI-2	0.808	0.129	0.83	0.20	80.77
	SATVI-3	0.808	0.101	0.83	0.25	76.92
	STVI-1	0.908	0.113	1	0.20	84.62
2005	SATVI-1	0.872	0.170	0.83	0.15	82.22
	SATVI-2	0.855	0.140	0.83	0.20	80.00
	SATVI-3	0.842	0.118	0.83	0.20	80.00
	STVI-1	0.906	0.259	0.83	0.13	86.67
2008	SATVI-1	0.851	0.078	0.86	0.26	76.67
	SATVI-2	0.851	0.058	0.86	0.26	76.67
	SATVI-3	0.851	0.037	0.86	0.26	76.67
	STVI-1	0.907	0.275	0.86	0.09	90.00

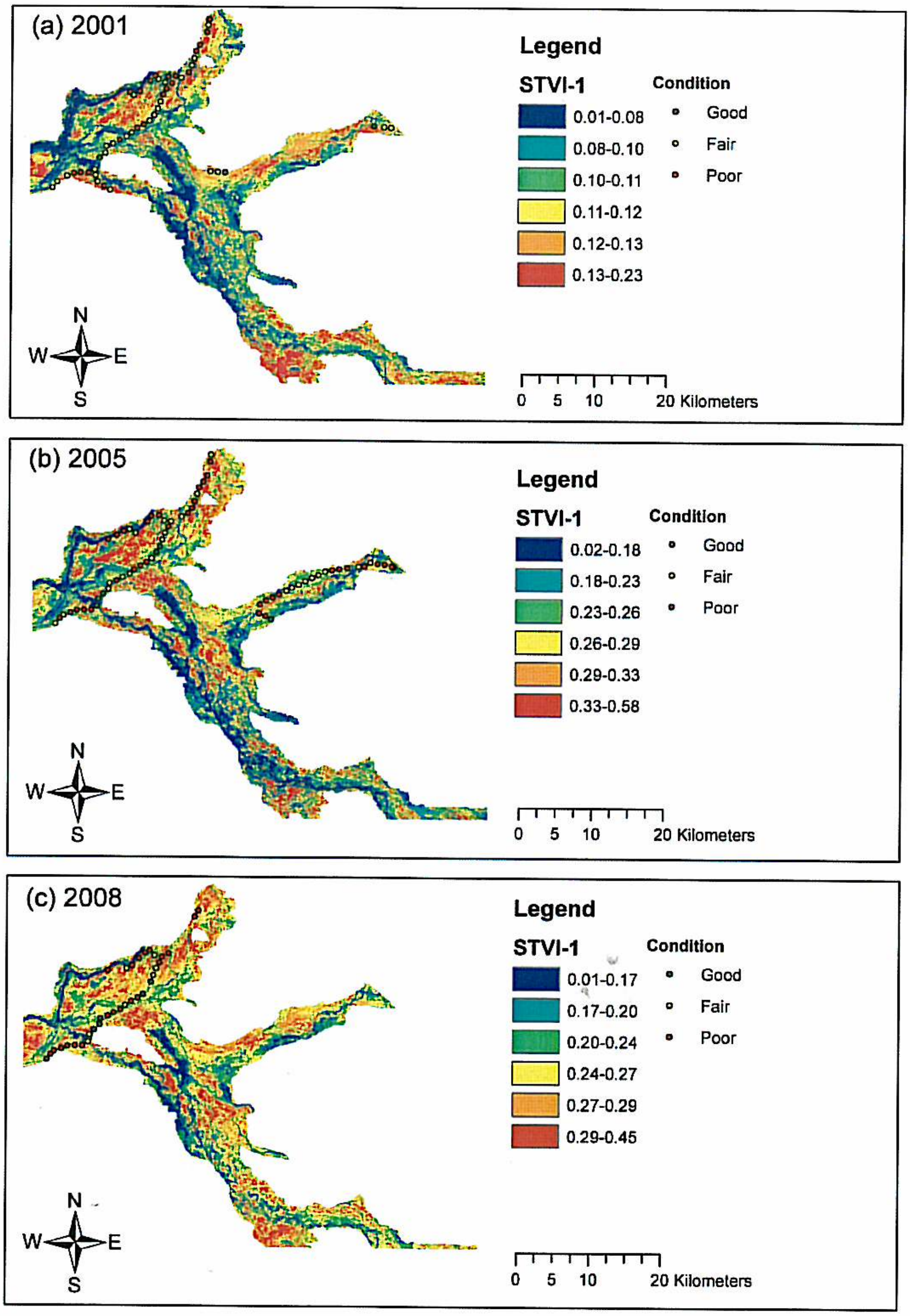

Fig. 3: STVI-1 images of the study area for: a) 2001; b) 2005 and c) 2008. Images were classified into sextiles to aid comparison. Lower values represent higher levels of cover. Condition points (i.e., good, fair and poor) are from ground traverse.

Fig. 3 shows the three STVI-1 images of the study area. Due to the large changes in the range of STVI-1 values between years, each image was classified separately. To facilitate comparison, and thus identify spatio-temporal changes, the images were classified into sextiles, which allocates the same number of pixels to each of the six classes. Fig. 3 also shows the distribution of the traverse points and their relationship with cover levels.

State and Transition Modelling

Fig. 4 displays the state and transition model over this area from 2001 to 2008 and illustrates the pixels that are static (i.e., class P|P|P and G|G|G|) and those that are transient or fluctuating through time (i.e., all other classes). Pixels constantly classed as poor condition throughout the time period studied (i.e., class P|P|P) and those fluctuating (e.g. P|G|P, G|P|G) or declining (e.g. G|P|P, G|P|P) require closer examination, and if necessary, remediation. Examination of classes recently transitioning into the good class (e.g. P|P|G) should also ensue to identify if this is indeed the case.

The inset maps of Fig. 4 clearly show evidence of cover responses that are dissimilar to surrounding areas. The inset map in the bottom left shows a pronounced fence-line effect with large areas in poor condition (brown pixels) and pockets of land that has transitioned into the poor condition class (orange and yellow pixels). These pixels are in stark contrast to the southern side of the fence, which are judged to have remained in good condition. However, it is unknown at what point in time these areas became degraded. This would require a retrospective study that predates the existing traverse records. The inset map in the bottom right shows areas in poor condition around the watering points used as a water source for stock. These areas are commonly expected to be more degraded due to stock spending a disproportionate amount of time around these watering points, relative to the rest of the paddock.

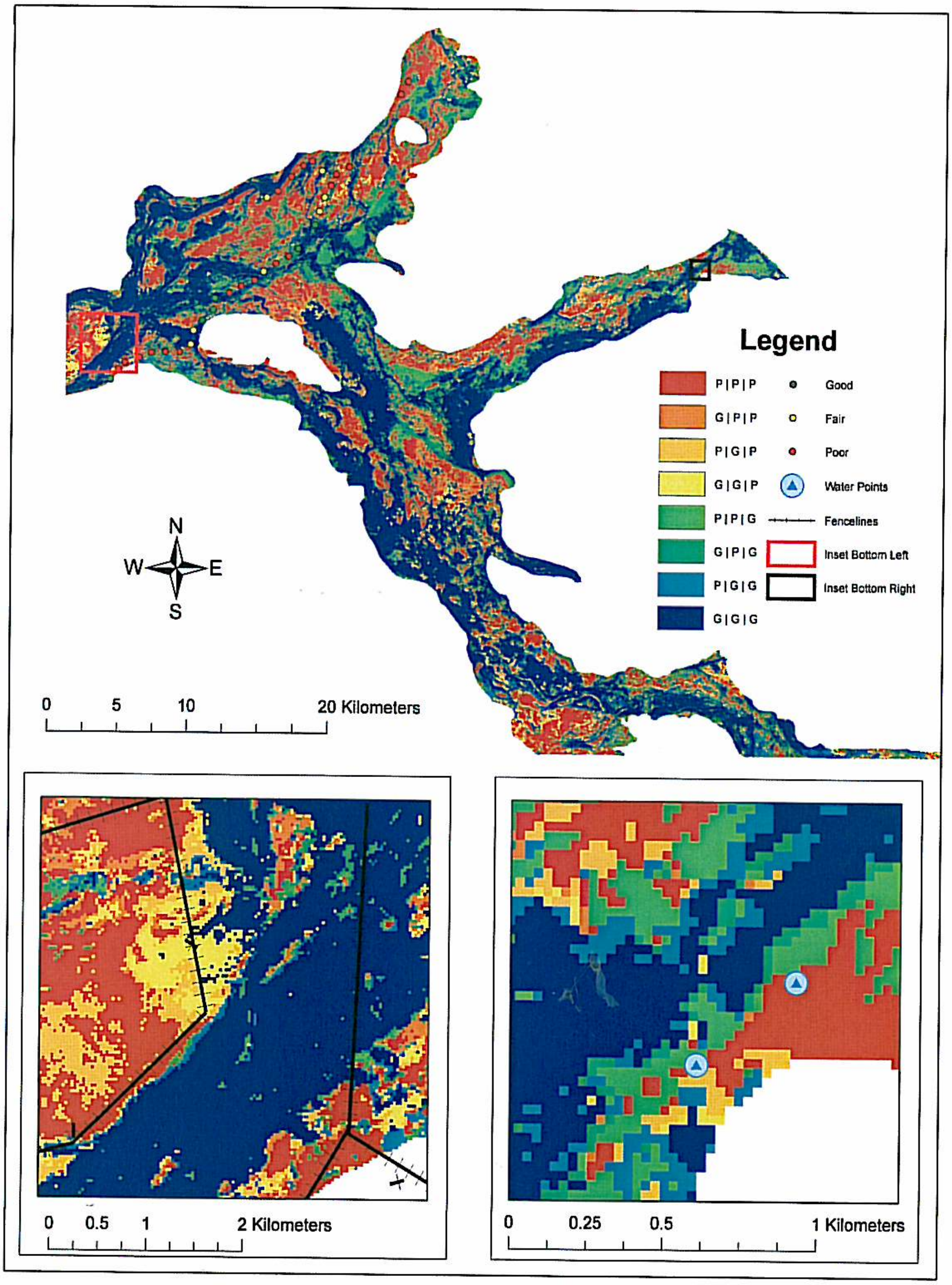

Fig. 4: State and transition model of the study area for the years of: 2001, 2005 and 2008. Inset maps depict a pronounced fence-line effect (bottom left) and degraded areas around watering points used for stock drinking (bottom right). Traverse points shown are from the 2008 field season. NB: In legend, P = poor condition; G = good condition.

CONCLUSIONS AND FURTHER WORK

This study has demonstrated that the vegetation indices applied to the Landsat imagery are capable of distinguishing between the good and poor condition ratings obtained from ground-based traverse. In particular, based on the vegetation indices trialled, the STVI-1 index appears to be the most appropriate for the land system (Djada) under study. However, the ranges of the STVI-1 appear to change substantially between the 2001 and the 2005 imagery, which means that a single cut-point (or benchmark) could not be applied through time. This highlights the need for temporal series of traverse points to calibrate the model. However, acquiring traverse data is an expensive exercise and therefore further work is required to identify techniques that have less reliance on such data.

The state and transition model was able to identify what appear to be management-induced changes such as fence-line effects and degraded areas around water sources and also identify areas recovering or declining and thus appears to be an effective tool for directing lease inspectors to areas of interest and of potential concern. Map accuracy, based on the traverse data, was sufficiently high (e.g. overall accuracies ranged from 85 to 90%) to give confidence in the current methods and their potential future use. However, additional sampling away from existing traverse points would be beneficial to test the accuracy of the state and transition model independent of the samples used to construct it. Alternatively, validation procedures for small datasets, such as cross-validation (e.g. Robinson & Metternicht, 2006), could be used for assessing the accuracy of the techniques used. Additional ground-based sampling to identify the reasons why pixels are transient, or why they are static, would assist in confirming the applicability of the techniques implemented. Further research into extending these concepts to longer periods of the Landsat archive and to include future imagery is also needed.

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