Mapping of Forest Cover in the Midwest, Goldfields and South Coast Regions of Western Australia

Sustainable Forest Management Series

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NFI

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Cover photograph: Typical Greater Goldfields Mallee Woodland.
(Taken by DEC)

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Table of Contents

1. Summary

This study aimed to map the forest cover of the Midwest, Goldfields and South Coast regions of Western Australia using satellite imagery and available vegetation type mapping to produce a map and digital information of extant forest cover in the region.

The methodology involved a number of steps:

- Rectification and cross calibration of the Landsat TM data to form a base mosaic;
- Identification of field sites using a stratification based on the Interim Biogeographic Regionalisation of Australia, and use of aerial photography to identify more than 300 prospective field sites;
- Assessment of crown and site attributes in the field at 211 field sites;
- Analysis of the Landsat TM image using canonical variate analysis to develop an index of projected foliage cover from remote sensing, and the conversion of this to projected foliage cover from remote sensing based on the relationship between the index of projected foliage cover from remote sensing and projected foliage cover measured in the field;
- Establishment of the thresholds of projected foliage cover for woodland forest (20 per cent crown cover) and open forest (50 per cent crown cover);
- Preparation of a draft map of forest cover;
- Validation of the draft map of forest cover using field validation sites;
- Adjustment of the thresholds of projected foliage cover to allow preparation of a final map of forest cover; and
- Attributions of the final map of forest cover to forest formations.

The study also examined the sensitivity of estimated forest cover to the threshold of projected foliage cover and the minimum area requirement to qualify as forest.

As with earlier studies using satellite remote sensing to map forest cover, canonical variate analysis showed much stronger spectral separation in relation to projected foliage cover than to crown cover. Indices of projected foliage cover from remote sensing were developed for the three strata in the study area, based on Landsat TM Bands 3, 4 and 5. Correlation between the index of projected foliage cover from remote sensing and projected foliage cover measured in the field for each strata explained between 9 and 11 per cent of the variability, and allowed the index of projected foliage cover from remote sensing to be converted to projected foliage cover from remote sensing.

The relationships between projected foliage cover measured in the field (PFC-F), crown cover and projected foliage cover from remote sensing (PFC_RS) were established (r2 was 0.7289). For the Coolgardie strata, these relationships indicated a projected foliage cover of between 9 and 13 per cent equated to a crown cover of 20 per cent (the woodland forest threshold). This range was evaluated by producing a map of forest cover for each test threshold and comparing this to information from the field sites and patterns of crown cover apparent on aerial photographs. For the Coolgardie strata, a projected foliage cover of 11 per cent was adopted as equating to 20 per cent crown cover, and a draft map of forest cover was prepared.

The accuracy and reliability of the draft map of forest cover was tested using ten Validation Areas with about 30 validation sites in each area. Overall accuracy for the study area was 76 per cent. Error was primarily associated with non-forest sites being mapped as forest. The mapped forest has an overall accuracy of 62 per cent. In contrast, the average accuracy of mapped non-forest was 96 per cent. The commission errors for the draft map of forest cover were often associated with a dense understorey less than 2 metres in height or vigorous regrowth after bushfire.

Based on these results, the projected foliage cover threshold was adjusted from 11 to 13 per cent for the Coolgardie strata, and a final map of forest cover was prepared. A minimum area requirement was not

applied to the preparation of the final map of forest cover, which consequently identifies patches of forest as small as 0.0625 hectare, being a single Landsat TM pixel.

Attribution to forest formations

This study estimated the area of forest in the study area to be 7,436,000 hectares, which is some 78 per cent less than the map of forest cover used for the 1998 State of the Forest Report. The total size of the entire study areas is 36,559, 599 hectares. The dominant forest formations are Eucalypt Medium Woodland Forest (4,035,000 hectares), Eucalypt Low Woodland Forest (1,604,000 hectares), Other Medium Woodland Forest (810,000 hectares), Mixed Species Low Woodland Forest (460,000 hectares) and Acacia Low Woodland Forest (406,000 hectares). There is a difference in the number of hectares of forest used in the SOFR 1998 and that which the Goldfor area covered due to variations in the criteria determining forest classification.

Estimated forest cover in the study area was very sensitive to the threshold of projected foliage cover that equates to the 20 per cent crown cover threshold that defines forest. Using a 15 per cent projected foliage cover as the threshold resulted in an estimated forest cover of less than half that estimated with a 9 per cent projected foliage cover as the threshold.

The sensitivity analysis also showed that a minimum area requirement to qualify as forest has a large impact on the estimated area of forest in the study area. The sample area with the most scattered distribution of small patches of forest was most sensitive, and a 4 hectare minimum area requirement resulted in an estimate of forest cover 29 per cent less than for a 0.0625 hectare area requirement. The sample area with the most complete and consolidated area of forest was least sensitive, with a 2 per cent difference for estimated forest cover for a 4 hectare minimum area requirement compared to a 0.0625 hectare minimum area requirement.

The final map of forest cover has a number of limitations to it that need to be recognised:

- A minimum area requirement was not used and patches of forest as small as 0.0625 hectares, being a single Landsat TM pixel, are identified as forest. Application of a minimum area requirement would reduce the estimated area of forest;
- Fire is a natural part of the environment of the study area has impacted the structure and density of the vegetation. Many fire scars of areas below the forest threshold in a landscape generally above the forest threshold were observed from the satellite imagery. The final map of forest cover therefore represents an underestimate of areas with "*mature or **potentially** mature stand height exceeding 2 metres and with existing or **potential** crown cover of overstorey strata about equal to or greater than 20 per cent".*
- The estimated area of forest cover in this study area is very sensitive to the threshold value of foliage projected cover used to equate to the 20 per cent crown cover that defines forest. This means that much of the vegetation in the study area is close to the forest threshold and probably moves above and below the threshold in response to stand age, disturbance events such as fire, and climatic effects such as above or below average rainfall sequences. The final map of forest cover therefore represents the extant area of forest at a particular point in time, and is an underestimate of areas with a "***potential** crown cover of overstorey strata about equal to or greater than 20 per cent".*
- The attribution of forest cover to forest formations is relatively coarse, being based on a number of assumptions.

Further research and development could improve the map of forest cover for the study area by:

- Using multi-temporal Landsat TM data i.e. data from several dates, to account for the effects of fire scares and vegetation dynamics and therefore provide an estimate of forest cover that better matches the definition of forest in terms of " *mature or **potentially** mature stand height exceeding two metres and with existing or **potential** crown cover of overstorey strata about equal to or greater than 20 per cent";*
- Using more field sites and greater stratification of the study area to improve accuracy and reliability;
- Using the Memoirs of Beard to improve the attribution of forest formations.

2. Introduction

Community expectations regarding the management of forests, and other resources, have evolved rapidly over the last 30 years. In the past, forests were largely recognised and valued for the wood they produced, whereas modern forest management recognises that forests provide a wide range of values.

In terms of the international agenda, the Brundtland Report (1987) enunciated the concept of ecologically sustainable development with international agreement to the principle that *'the ability of humanity to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs*'. The Rio Earth Summit in 1992 developed the concept of ecologically sustainable development further, and in relation to forests, added a focus on a broad range of forest values. In 1993, a group of countries including Australia met to develop a common understanding of the values for which forests should be managed and indicators of how well forests are being managed for these values, otherwise known as criteria and indicators of sustainable forest management. This process became branded as the Montreal Process. Similar sustainable forest management initiatives also began for other groupings of countries.

The Montreal Process recognises that forests are managed to: conserve biodiversity; maintain productive capacity; maintain ecosystem health and vitality; conserve soil and water resources; maintain global carbon cycles; and enhance social and economic benefits to the community. The concept of sustainable forest management also recognises that the criteria and indicators apply to all types and tenures of forest; publicly owned, privately owned, native forests and plantations; and covers the full range of forest uses; wood production, conservation, water production and protection, areas subject to mining or grazing, as well as unmanaged forests.

Indicators have been developed which address each of the criteria for sustainable forest management. However, to be able to report against these indicators first requires a good understanding of the location of all forest areas.

The definition of forest that is now accepted in Australia is:

"an area incorporating all living and non-living components, that is dominated by trees having usually a single stem and a mature or potentially mature stand height exceeding two metres and with existing or potential crown cover of overstorey strata about equal to or greater than 20 per cent."

This definition of forest is biologically based and is in line with that used by the United Nations Food and Agriculture Organisation (FAO). Previously, the classification of vegetation associations defined as forest was influenced by the quality of potential timber resources in such areas, with the term 'forest' largely applied to areas where harvesting for wood products was economic. The main effect of this change is that the forest estate now includes extensive areas of woodland. As a result, the total area of forest has increased from about 43 million hectares (in the high forest zone) to an estimated 156 million hectares overall (NFI 1998).

The Montreal Process First Approximation Report (MPIG 1997) and the State of the Forests Report (NFI 1998) included maps and statistics of Australia's forests in relation to the currently agreed definition. However, the quality of information on which these maps and statistics were based is variable across the nation.

In Western Australia, the maps and statistics are based on relatively high quality information for forests of the lower south-west. Conversely, information for the forests of the Kimberley and the Midwest, Goldfields and South Coast regions has been of relatively low quality for the purpose of identifying forests that meet the agreed current definition, being based on the vegetation survey of Western Australia undertaken by John Beard (Beard and Webb 1974). Beard's work was undertaken mainly through the 1960s and 1970s; however the vegetation classification system did not use a 20 per cent crown cover threshold, a 50 per cent crown cover threshold, or a 2 metre height threshold in the delineation of the various vegetation associations. Consequently, the maps of forest cover outside of the lower south-west that are derived from Beard's work can only be considered an approximation.

Behn *et al*. (2001) have subsequently mapped the forest cover of the Kimberley region using satellite imagery and available vegetation type mapping (Beard 1979) to produce a map and digital information of forest cover in the region.

The project described in the report aimed to use a similar methodology to that used by Behn et al. (2001) to map the forest cover over the Midwest, Goldfields and South Coast regions of Western Australia.

The method, with its reliance on satellite remote sensing, was considered a viable approach to mapping an area of such size. Time constraints of the project and the desire to be able update the results on a periodic basis to detect time trends that would fill in gaps and errors in data also added weight to using satellite remote sensing. The success of other remote sensing projects of this magnitude elsewhere within Australia (Woodgate 1988, Ritman 1994 and Kuhnell 1998) has shown 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 objectives of the project were to:

- Apply a satellite remote sensing methodology to produce a seamless map of current extent of forest cover for the Midwest, Goldfields and South Coast regions of Western Australia; and
- Use existing vegetation mapping to categorise the forest cover into forest structure and forest formation.

To achieve the objective of a seamless map of current extent of forest cover it was necessary to:

- Establish the relationship between an index of projected foliage cover from remote sensing (PFCI-RS) and PFC measured in the field (PFC-F), to provide projected foliage cover from remote sensing (PFC-RS). Note that PFC measured in the field is the product of crown cover and crown density; and
- Establish the 20 per cent crown cover threshold (the non-forest/woodland forest threshold) for the projected foliage cover from remote sensing (PFC-RS). This used the relationships between the PFC measured in the field (PFC-F), crown cover and projected foliage cover from remote sensing (PFC-RS). A similar process was used for the 50 per cent crown cover threshold to determine the difference between woodland forest and open forest threshold.

3. Study Area

The extent of the study area was based on the previously best available information of forest cover (Figure 1) as mapped for the State of the Forest Report (NFI 1998). The boundary of the study area covers conventional 1:250,000 map sheets (Figure 2) covering a total area of approximately 292,000 square kilometres and extending from Shark Bay in the north-west to the Nullarbor Plain in the southeast (Figure 2), a distance of some 1,300 kilometres. Mostly in the Eremaean Botanical province, the study area covers parts of the following Interim Biogeographic Regions of Australia (IBRA) (Thackway *et al.* 1995): Avon-Wheatbelt; Carnarvon; Coolgardie; Esperance Sandplains; Geraldton Sandplains; Mallee; Nullarbor; Great Victoria Desert; and Yalgoo.

The general climate of the study area is described as arid to semi-arid warm Mediterranean (Beard, 1979). The area is largely in a natural state with agricultural and feral animal grazing being the most widespread threatening processes (Thackway *et al.*1995). Other processes of disturbance include mining, fire and tourism. Diverse *Eucalyptus* woodlands with areas of sandplain heath dominate the majority of the study area, grading into mallee heathlands in the south and scrub heath in the north. Topographically, land surfaces are generally undulations and associated with occluded drainage patterns.

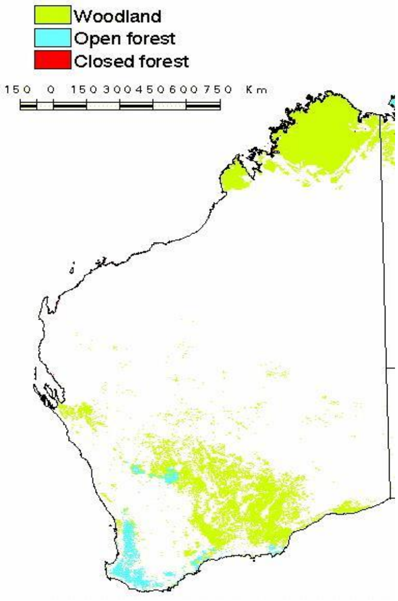


Figure 1 **Approximate location of forest cover within Western Australia, based on the State of the Forest Report (NFI 1998), and used to define the study area for this project.**

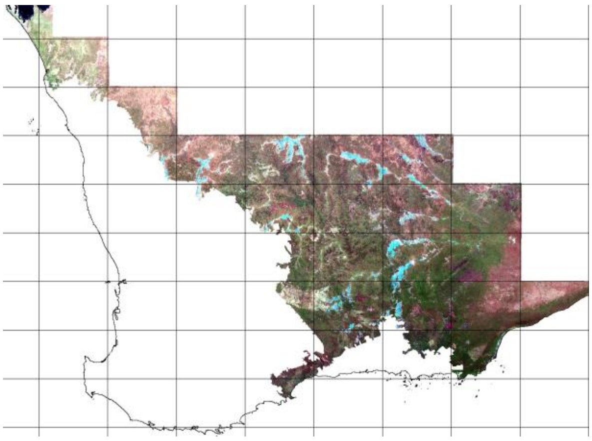


Figure 2 **The area extent of the study area depicting the Landsat TM mosaic with the conventional 1:250 000 grid superimposed.**

4. Satellite Remote Sensing

Landsat TM imagery can provide routine broadscale coverage of an area and is ideal for mapping and monitoring (Pickup *et al.* 1993). The ground picture element (pixel) size (30 m x 30 m) 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. Monitoring change also becomes possible with the ability to co-register and analyse imagery from various dates. Landsat TM records measurements in the visible and infrared region of the electromagnetic spectrum.

The nature and distribution of different vegetation associations in the Australian environment create reflectance values and patterns in remotely sensed data that are quite different from those in other parts of the world. The differences are due to the structure of the plant communities, the density of plant foliage, the unique morphological characteristics of the leaves, distribution patterns of vegetation and the spectral characteristics of the soil background (O'Neill *et al.* 1990).

Landsat TM imagery has seven Bands (Table 1) Bands 1, 2 and 3 in the visible parts of the spectrum, Band 4 in the near infrared, Band 6 in the thermal range and Bands 5 and 7 in the short-wave infrared portions of the spectrum. Band 6, the thermal band was not used although it was recorded when the imagery was initially captured. The data from these bands can be combined to provide images that reflect particular features of interest on the ground.

Landsat TM data provide broad scale coverage of an area every 16 days, in separate scenes that cover an area about 185 square kilometres or about 3,422,500 hectares. The pixel size (30 x 30) for all channels, except the thermal (60 x 60), is practical for broad-area surveys and gives results with at least several trees and shrubs per pixel and usually several pixels per homogeneous area.

Table 1 Approximate location of forest cover within Western Australia, based on the State of the Forest Report (NFI 1998), and used to define the study area for this project.

Band no	Spectral range (Microns)	EM region	Generalised application details	Ground resolution
1	0.45 - 0.52	Visible Blue	Coastal water mapping, differentiation of vegetation from soils.	30x30 m
2	0.52 - 0.60	Visible Green	Assessment of vegetation colour.	30x30 m
3	0.63 - 0.69	Visible Red	Chlorophyll absorption for vegetation and soil differentiation.	30x30 m
4	0.76 - 0.90	Near Infrared	Biomass surveys, vegetation survey and delineation of water bodies.	30x30 m
5	1.55 - 1.75	Shortwave Infrared	Vegetation and soil moisture measurements.	30x30 m
6	10.40- 12.50	Thermal Infrared	Thermal mapping, soil moisture studies and plant heat stress measurement	60x60 m
7	2.08 - 2.35	Short-wave Infrared	Soil and clay mapping, useful for some vegetation types.	30x30 m
Other Characteristics: Swath width:185 km; Repeat coverage interval:16 days (233 orbits) and Altitude:705 km				

Due to the predominantly open canopy and sparse vegetation that is generally characteristic of the region the thermal bands of the TM imagery were not used. Behn (1992) found minimal site discrimination by including this information in like vegetation classifications procedures.

5. Vegetation Classification

Details of the digital vegetation data, in particular the forest formation and type are defined in the National Vegetation Information System (NVIS) framework dataset (Cofinas *et al.* 1999). This dataset is compiled from amalgamated primary native vegetation data that best describes the NFI forest formations (Table 2) from within the region.

The project aimed to classify forest cover into the National Forest Inventory forest formation categories relevant to the study area (Table 2). The forest formations of the National Forest Inventory are based on forest structure (Table 3) combined with the dominant over-storey composition.

Table 2 Forest formations recognised by the National Forest Inventory and associated codes relevant to the study area.

NFI code	Forest formation (64 classes - Genus-height-cover)
1	Acacia Low Woodland Forest
7	Banksia Low Woodland Forest
14	Casuarina Low Woodland Forest
26	Eucalypt Low Woodland Forest
27	Eucalypt Medium Woodland Forest
29	Eucalypt Low Open Forest
30	Eucalypt Medium Open Forest
45	Mixed Species Low Woodland Forest
48	Mixed Species Low Open Forest
52	Other Medium Woodland Forest
55	Other Medium Open Forest

Table 3 Classification of forest structure as defined by the National Forest Inventory (NFI) forest formation classification and the NFI codes.

<table>
<tr><th colspan="4">Forest structure</th></tr>
<tr><th rowspan="3">Height (m)</th><th>Woodland Forest</th><th>Open Forest</th><th>Closed Forest</th></tr>
<tr><th colspan="3">Crown Cover (%)</th></tr>
<tr><td>20-50</td><td>51-80</td><td>81-100</td></tr>
<tr><td>Tall >30</td><td>Tall Woodland Forest (T2)</td><td>Tall Open Forest (T3)</td><td>Tall Closed Forest (T4)</td></tr>
<tr><td>Medium 11-30</td><td>Medium Woodland Forest (M2)</td><td>Medium Open Forest (M3)</td><td>Nedium Closed Forest (M4)</td></tr>
<tr><td>Low 2-10</td><td>Low Woodland Forest (L2)</td><td>Low Open Forest (L3)</td><td>Low Closed Forest (L4)</td></tr>
</table>

Non-forest formations include vegetation compositions that are of a heterogeneous mixed type, or unknown type or comprising a mixture of minor genera (NFI, 1998). (They will also include areas with little to no tree cover.)

6. Methods

The project was undertaken in a number of stages described below.

6.1. Rectification and cross calibration of the Landsat TM data to form a base mosaic

Satellite imagery that covered the study area was acquired on the dates detailed in (Table 4) below. The imagery was captured mainly within the summer months of January and February 1996 and 1998, a period that was cloud free and with cured grasses (Duncan *et al.* 1993, Kuhnell *et al.* 1998).

Table 4 Landsat satellite path, row and acquisition date of imagery used for this project.

Path	Row	Date of capture
107	80-82	12/02/1998
108	80-82	19/02/1998
108	83	17/03/1996
109	80-82	25/01/1998
109	83	05/02/1996
110	80-81	17/02/1998
110	82-84	12/02/1996
111	80-81	08/02/1998
111	82	03/02/1996
113	79	06/02/1998
114	78	07/01/1996
114	79	07/01/1996

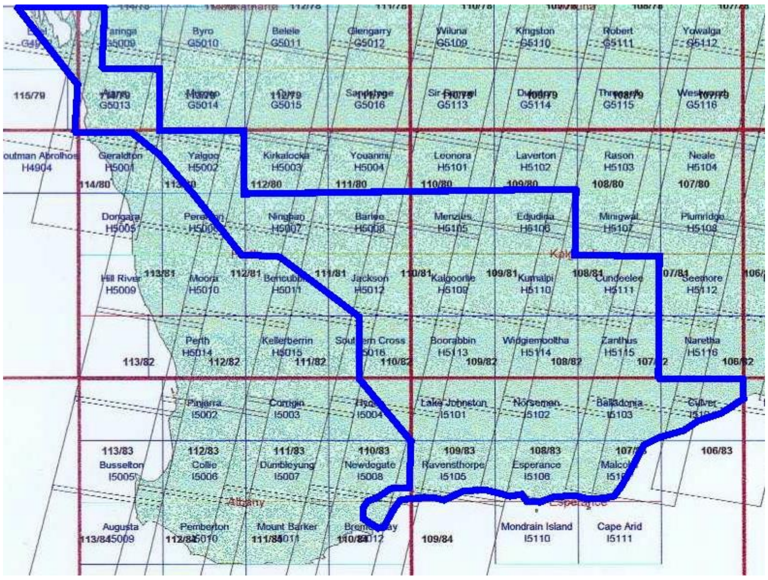


Figure 3 Study area showing the boundary in blue with the satellite path/coverage superimposed.

Twenty-two TM satellite scenes were co-registered against the ground cadastral framework and calibrated (Furby *et al.* 2000) to form a total mosaic of the project area shown in (Figure 3) above. Production of this mosaic was 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 or scale inconsistencies between images.

The data were rectified to latitude/longitude coordinate space as outlined in Table 5.

Table 5 Rectification information used for the project.

Projection Category	Projection Unit
Datum:	WGS84
Projection:	Geodetic
Coordinate:	Latitude Longitude
Unit:	Degrees
Cell Type:	Unsigned8BitInteger
Null Cell:	0
Pixel Size:	0.00025 Degrees (25 m)

The spatial accuracy has a root mean square (RMS) error of less then 0.0005 degrees or 50 metres to map control (1:100 000 topographic maps).

6.2. Identification of Field Sites

6.2.1. Stratification of the study area using the Interim Biogeographic Regionalisation of Australia (IBRA)

The Interim Biogeographic Regionalisation of Australia (IBRA) (Thackway *et al.* 1995) was chosen as the basis for delineation of regions within the study area to use for the purpose of stratification.

IBRA divides Australia into regions, which reflect the environmental determinants for broad patterns in landscape, ecosystem and species diversity. It seemed possible; therefore, that the statistical relationship between the spectral image and crown cover and foliage projected cover could vary between IBRAs and this is supported by earlier work in the Kimberley region of Western Australia (Behn *et al*. 2001). The original intent was to stratify the area using each of the IBRAs present in the study area. However, limited field data was able to be collected for a number of IBRAs due to the time and cost constraints on the project, the relatively small areas of some IBRAs within the study area, relatively small areas of forest in some IBRAs, or a limited range in forest density in some IBRAs. For example, the Geraldton Sandplains IBRA and Yalgoo IBRA had few field sites with crown cover greater than the 20 per cent, so these IBRA were combined with others to form one of the strata used for analysis. Consequently, the study area was divided into three strata based on one or more IBRAs. The strata were deliberately extended so as to overlap into one another with the Geraldton-Murchison strata including the northern part of Coolgardie strata and the Greater Mallee strata including the southern part of the Coolgardie strata (Figure 4). The process enabled common site data, with crown cover greater than the 20 per cent, to be used for the analysis of which separate strata.

The three strata and their component IBRAs were:

- Geraldton-Yalgoo and Greater Murchison strata composed of those parts of the Geraldton Sandplains, Carnarvon, Yalgoo, Avon Wheatbelt and Murchison IBRAs within the study area, as well as the northern part of the Coolgardie IBRA;
- Coolgardie strata composed of those parts of the Coolgardie and Great Victoria Desert IBRAs within the study area, and the north-western part of the Nullarbor IBRA within the study area; and
- Greater Mallee strata composed of those parts of the Mallee and Esperance Sandplains IBRA within the study area, as well as the southern part of the Coolgardie IBRA and the south-eastern part of the Nullarbor IBRA within the study area.

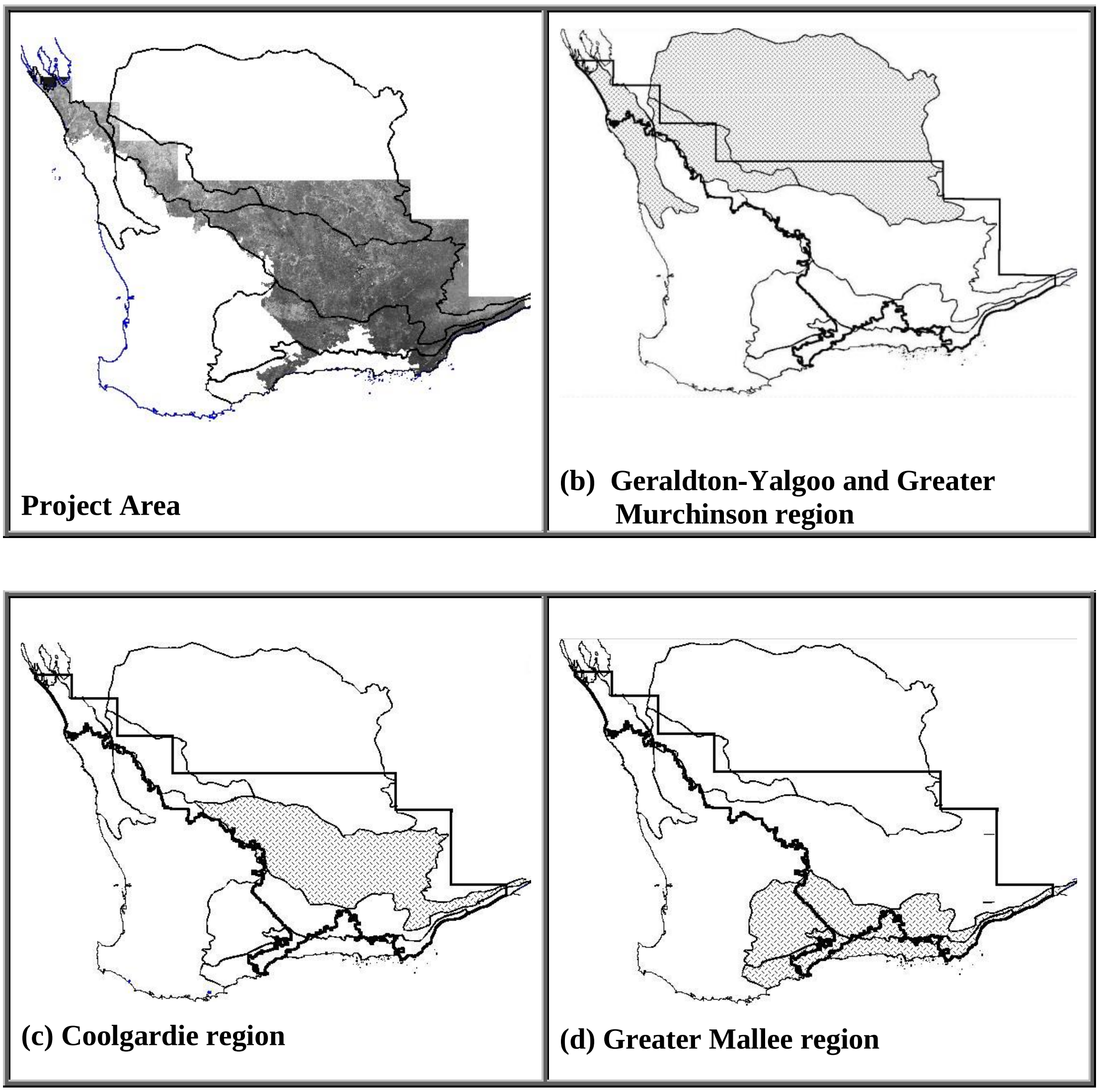


Figure 4 Image (a) shows the Project area in grey and the IBRA regions as black line work. Image (b) highlights in grey the extent of the Geraldton-Yalgoo and Greater Murchison strata, while images (c) and (d) show the Coolgardie and Greater Mallee strata respectively.

6.2.2. Aerial photography

Aerial photography covers the entire project area at varying scales. From inspection of 1:40 000 or 1:50 000 scale black and white photos it was possible to discriminate between areas representative of the differing tree cover densities. This approach was used to identify prospective field sites, generally located along transects associated with access routes (roads and tracks). Photos that covered the prospective field sites were then obtained digitised and co-registered to the satellite image mosaic. Crown cover for the prospective field sites was estimated on aerial photographs using dot grid templates. The template assumes an 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 measured in the field to check the estimates from the aerial photographs. Where there was a difference between crown cover estimates from aerial photographs and field measurements, the field measurements were used.

There were 67 black and white aerial photos digitally scanned for the project (Figure 5). Each of the photos was scanned at 400 dots per square inch (dpi) resolution giving an average size of 35 megabyte per photo frame.

Due to the location and areal size of the project the choice of aerial photography was limited, in some cases, to only one photographic run. The dates of the photography were also varied, at times 20 years old. Adding to the problem was variations in the acquisition time of the photography both seasonally and time of the day. As mentioned previously, the satellite imagery was captured in the summers of 1996 and 1998 with an overpass time of 9:30am. All these problems caused some degree of manual interpretation errors with initial crown cover estimates.

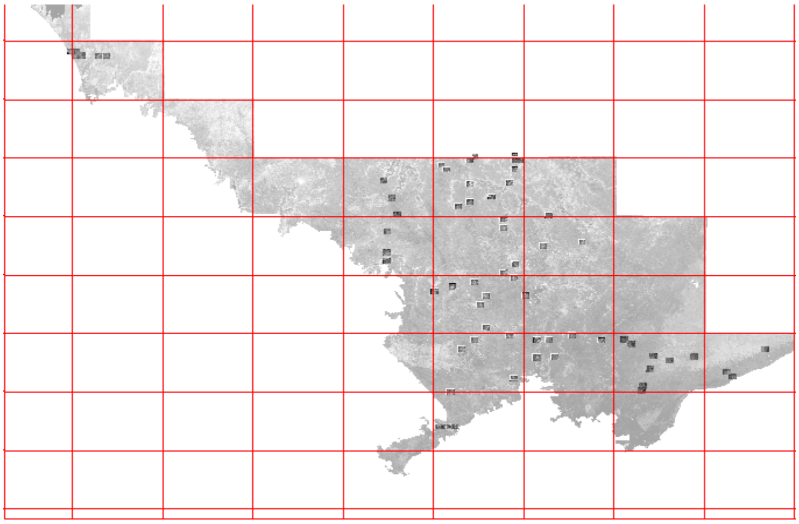


Figure 5 The study area showing the aerial photography coverage (small darker areas) from which the field sites were selected.

6.2.3. Field sites

The basic objective of the project was to accurately estimate the variation in crown cover across the landscape. A key factor in using satellite imagery for this purpose is to calibrate the satellite image with ground measurements. Three hundred and twenty four prospective field sites were selected covering the range of crown cover anticipated across the study area. Areas of bare ground and areas of non-forest (less then a 20 per cent crown cover) were also included for comparison. The size of the prospective field sites ranged from approximately 90 m x 90 m to 400 m x 400 m, as a result of variable homogeneity in visible attributes on the aerial photography. Prospective field sites were selected on aerial photographs in transects alongside tracks and other identifiable features, with the location accurately plotted to enable accurate data extraction from the satellite imagery (Figure 6). Prospective field sites were chosen to be reasonably homogeneous with respect to the degree of crown cover, tree composition and structure (Figure 7).

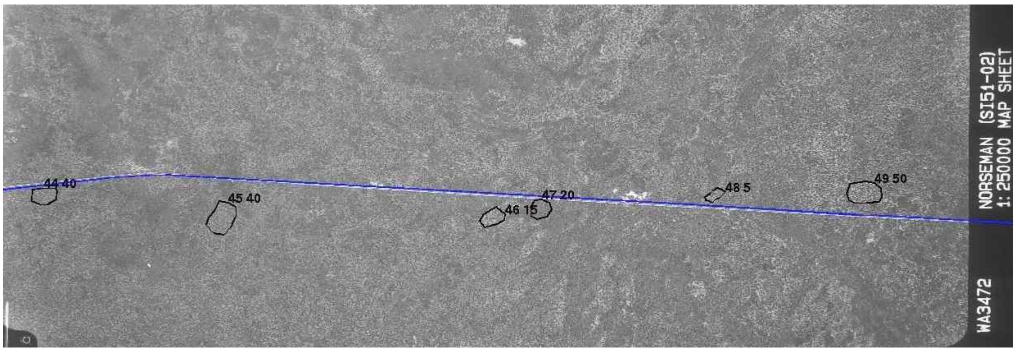


Figure 6 Aerial photograph showing the identification of prospective field sites along a transect based on a road.

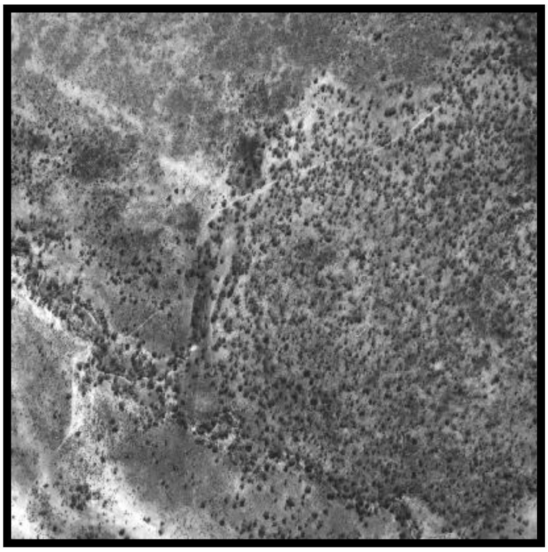


Figure 7 Enlarged section of the aerial photograph showing varying tree densities and open areas. Areas with a homogenous tree cover such as the area circled in red, were targeted as prospective field sites.

Initially there were 324 prospective field sites of which 236 were actually ground surveyed and captured as permanent reference sites for possible future use in monitoring/mapping investigations. Time constraints and site accessibility were important factors in limiting the actual number of sites visited. Field work was undertaken by teams of two or three people from mid May 2001 to July 2001.

6.3. Measurement of crown cover, crown density, projected foliage cover and other site attributes in the field

6.3.1. 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 densitometer. Fifteen steps north, south, east and west from the site centre were paced out and a densitometer reading was taken at each of these points.

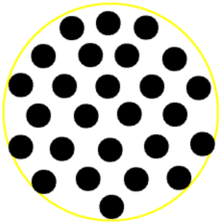
6.3.2. Crown density

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). Up to seven representative crowns were assessed at each field site, with each estimate taken from a random spot under different individual trees. The crown density for the field site was then taken as an average of all the estimates for that site.

6.3.3. 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 per cent crown cover and 75 per cent crown density is calculated as having a PFC of 15 per cent, as illustrated in (Figure 8).



20% crown cover x 75% crown density = 15% PFC

Figure 8 Projected foliage cover is the product of crown cover and crown density

The lower limit of crown cover is 20 per cent for what was to be classified as forest, as shown in (Figure 8) above. When dealing with an automated image analysis system, as we are here, it is necessary to have a precise rule for the boundary between forest and vegetation that contains trees but is below the threshold for classification as forest.

6.3.4. Vegetation stratification and voucher specimen collection

The vegetation was classified using a scheme described by Walker and Hopkins (1990) in an effort to assist with further definition of Beard's vegetation boundaries. In this scheme a structural summary of the vegetation at each site is made with an assessment of the key dominant species, their estimated average height and voucher number recorded for each stratum. Each stratum is classified according to the ecologically dominant species and the vegetation classification is made according to the ecologically dominant stratum. The stratum were separated into seven classes, emergent, tree 1, tree 2, tree 3, shrub 1, shrub 2 and ground. Plant voucher specimens were taken for each ecologically dominant species of each stratum so that a botanist could identify them. All vouchers were lodged with the Western Australian Herbarium; thereby make a permanently referable record for each site (see Appendix 4 for a list of all species collected).

Other ecological information such as evidence of recent fire, soils, geology, ground cover type percentage and disturbance factors was also recorded for each site (Appendix 1).

6.4. Analysis of the Landsat TM image

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 pixel that are visible from above at the time the satellite passes over.

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. If error were to occur from the analysis then this effect would dominate. The reflectance of a forest canopy can display large differences from leaf reflectance when there is a large contrast between trees and understorey vegetation.

The crucial factor in producing spectral maps or enhancements, which reliably display areas of greater than 20 per cent crown cover is that the spectral separation of the dense from the sparse crown cover 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).

6.4.1. *Canonical variate (CV) analysis*

Canonical variate (CV) analysis (Anderson 1958) was used to summarise the separation between field sites. It was applied to densely covered sites versus light to no cover sites. This assists in determining which band spectral combination best separates them from each other. Associated 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 (6 bands = 6 dimensions) spectral space. CV analysis allows the identification of successive band combinations (vectors) which maximise the spectral separation of field sites. These vectors are referred to as canonical vectors and associated with each vector is a canonical root, a number that is an index reflecting the overall degree of spectral separation between field sites along that vector. The sum of the canonical roots gives a measure of the overall separation in all dimensions. The first CV direction is the single axis having the greatest spectral separation. Frequently, the separation in spectral space can be adequately summarised by the first few canonical variates, thus reducing the dimensionality of the field sites while maintaining relevant information on the clustering and separation. Bands that make only a small contribution to the spectral separation of field sites can then be eliminated using band reduction routines. The results may be used to identify useful image enhancements or band combinations, or as in this case an Index image of PFC.

6.4.2. *Index of projected foliage cover from remote sensing (PFCI-RS)*

The procedure allowed models for each strata (one or more IBRA) to be developed that predicted an index of projected foliage cover from remote sensing (PFCI-RS) from the spectral response of a number of Landsat TM bands. The models were then used to produce an index of projected foliage cover for each strata and the whole study area.

6.4.3. *Projected foliage cover from remote sensing (PFC-RS)*

The next step was to convert the index of projected foliage cover from remote sensing (PFCI-RS) to projected foliage cover from remote sensing (PFC_RS) by establishing the relationship between PFCI-RS and projected foliage cover measured in the field (PFC-F). The relationship was then used to produce image of projected foliage cover for each strata and the whole study area.

6.5. Establishing 20 per cent crown cover threshold for forest cover

Establishing 20 per cent crown cover was done by determining the relationship between the projected crown cover from remote sensing and the crown cover measured in the field. This relationship then provided an estimate of the projected foliage cover that equated to a 20 per cent crown cover, which is the non-forest/woodland forest threshold. This process provided a range of thresholds. A value within this range was then used to produce an image of forest cover for each strata and the whole region. The image of forest cover was then evaluated in relation to data for the field sites and also in relation to patterns of crown cover evident from aerial photographs, and the threshold was manually adjusted to provide an optimum match. The output is a draft map of forest cover.

A similar process was undertaken for the 50 per cent crown cover threshold to discriminate areas of woodland forest (20 to 50 per cent crown cover) from areas of open forest (50 to 80 per cent crown cover). No area of closed forest occur in the study area so establishment of the threshold value of projected foliage cover for the 80 per cent crown cover threshold (the open forest/closed forest threshold) was not required.

6.6. Validation of the map of forest cover

To establish the accuracy and reliability of the draft map of forest cover, a field validation of this output was undertaken.

Field Validation Areas were selected from aerial photographs to cover the patterns of forest cover evident on the draft map of forest cover. The field sites were cover the range of crown cover and the geographic extent of the study area. The ten selected Validation Areas each cover an area of about 15 kilometres x 12.5 kilometres or 187 square kilometres From within each of the sample areas, validation sites were either labelled as forest or non-forest. Requirements of each site were accessibility, uniform crown cover and a minimum size of 1 hectare. To maximise the number of sites within each area to visit, sites selected were often close to one another and all had relative easy access. The intent was to have about 30 field validation sites for each of ten field Validation Areas, which was considered an achievable target and adequate to provide an estimate of accuracy of the map of forest cover.

For each field validation site, a geographic positioning system (GPS) location was recorded and measurements taken of crown cover and crown density to provide a measure of projected foliage cover. Where the draft map of forest cover was at variance to the field measurement of forest cover further information on the field validation site was recorded, using the bottom two-thirds of page one of the field validation proforma (Appendix 3) as a prompt, and supported by a photograph. Field work for the validation process was undertaken by teams of two or three people in October 2001.

An error matrix for each field Validation Area was then prepared. This provided information on errors of inclusion (commission errors) and errors of exclusion (omission errors) as well as an estimate of the accuracy of the map of forest cover for each field Validation Area and the overall accuracy for all field Validation Areas. The range and variability in accuracy for the field Validation Areas provided a measure of reliability of the draft map of forest cover.

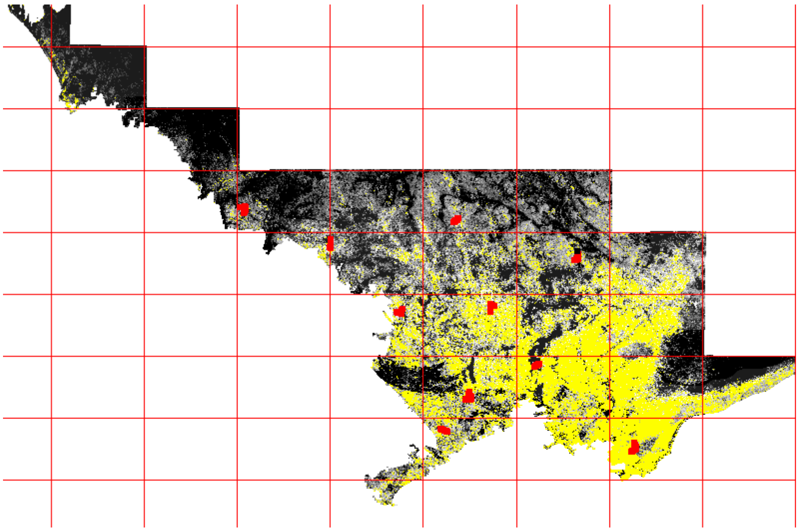


Figure 9 **Draft map of forest cover showing the location of the 10 field Validation Areas (red areas).**

6.7. Adjustment of the threshold of projected foliage cover to produce a final map of forest cover

Results from the field validation exercise were used to adjust the threshold of projected foliage cover that equated to a 20 per cent crown cover. If the results indicated a bias to mapping non-forest areas as forest, then the threshold PFC would be adjusted up. Conversely, if the results indicated a bias to mapping forest areas as non-forest, then the threshold PFC would be adjusted down. The new threshold PFC was applied to the image of projected foliage cover from remote sensing and a final map of forest cover was produced.

6.8. Attribution of the final map of forest cover to forest

The resulting map of forest cover was then attributed with forest formations using data from the Vegetation Database of Western Australia. Vegetation associations in the latter were, in the first instance aggregated to forest formation, and the resulting dataset was then converted to a raster format suitable for integration with the remote sensing forest cover result.

6.9. Management of databases from the project

Information, additional to that required to calibrate and validate the remote sensing forest cover mapping, was also captured during fieldwork operations (see Appendix 1). Initially, to ensure assessment of as many sites as possible during daylight hours, fieldwork proformas were completed in hard copy format on site and later entered into a set of Microsoft Excel spreadsheets. On completion of all fieldwork these digital proformas were validated to ensure consistency with the original hard copy, and shape files created spatially locating each site.

6.10. Sensitivity to the threshold of projected foliage cover

A demonstration of the sensitivity of estimated forest cover to the threshold of projected foliage cover that equates to the 20 per cent crown cover threshold for forest was undertaken. Thresholds for forest cover of 9 per cent PFC, 12 per cent PFC and 15 per cent PFC were applied to the image of projected foliage cover from remote sensing. This was undertaken for the Coolgardie strata. These PFC thresholds were selected as they presented the range of possible values that may equate to the 20 per cent crown cover threshold for forest based on this study and earlier work for the Kimberley region of Western Australia (Behn *et al*. 2001).

6.11. Sensitivity analysis of the effect of a minimum area requirement to qualify as forest

The accepted Australian definition of forest does not include a minimum area requirement. This is in contrast to definitions of forest adopted in some other countries. For example, the United States has an area requirement of at least one acre (0.4 hectare) to qualify as forest (Heinz Center 2002) and the United Nations Food and Agricultural Organisation has a 0.5 hectare requirement.

A sensitivity analysis of the effect of a minimum area requirement to qualify as forest was undertaken using five sample areas within the study area. The draft map of forest cover for these areas was analysed on the basis of four minimum area requirements for forest:

(1) 0.0625 hectare, being one Landsat TM pixel of 25 x 25 metres;

(2) 0.25 hectare;

(3) 1 hectare; and

(4) 4 hectare

The sample areas were geographically well separated and representative of the range patterns of forest cover, from few scattered small patches of forest through to large consolidated area of forest (Figure 10).

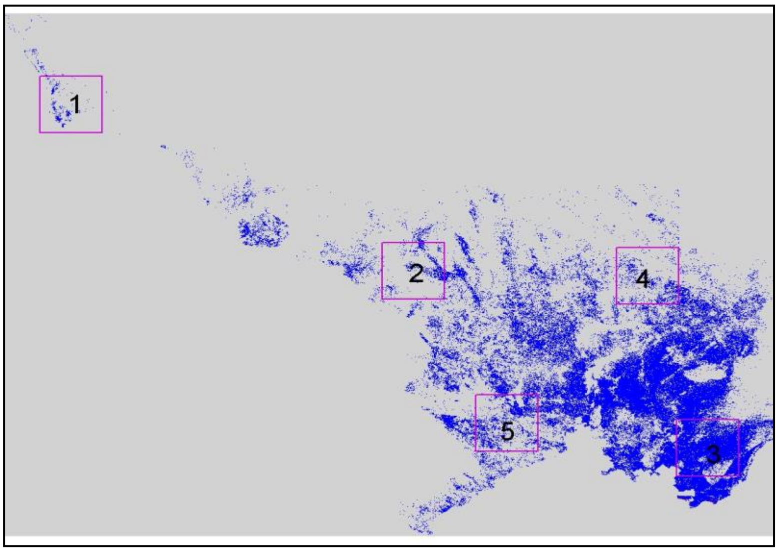


Figure 10 **Draft map of forest cover with forest indicated in blue, showing the location of the 5 sample areas used to test the sensitivity of the effect of a minimum area requirement to qualify as forest.**

6.12. Rainfall anomalies and forest

Tree canopies expand and contract in response to available soil water (Gholz 1982, Pook et al. 1997, Stoneman et al. 1995) which in turn is a function of rainfall in the preceding period and other weather and vegetation parameters. Consequently rainfall data for the study area were analysed to determine rainfall was normal or abnormal, and if abnormal the direction and magnitude of the anomaly. The analysis was used to interpret whether rainfall was likely to have led to abnormal measures of forest cover, obtained through either the Landsat data or the field work.

Rainfall data was acquired from the Bureau of Meteorology for high quality rainfall stations (Lavery et al. 1992) in or around the study area. The deviation of rainfall in the preceding three years relative to the long-term mean average rainfall was calculated for the periods prior to Landsat TM data collection and field work.

7. Results

7.1. Analysis of the Landsat TM image

Data for the Greater Coolgardie strata is presented in (Figures 11 and 12) to illustrate the process of developing a relationship between Landsat TM satellite spectral reflectance values and ground measured PFC, then translating that relationship to a map of forest cover. This procedure was repeated for each of the strata.

7.1.1. Field Site Variation

To maintain consistent outcomes from field description, standard procedures were established and adopted. A canopy cover variation in vegetation density, structure and species often occurs. Also the vegetation changes in a temporal sense and there is an expected error component from the initial cover estimates using the aerial photography in comparison to the actual ground cover estimates.

7.1.2. Canonical variate (CV) analysis

The canonical variate (CV) plot below (Figure 11) shows spectral separation of the measured crown cover for the field plots within the Greater Coolgardie strata. The field sites indicated in blue have little to no cover while those field sites indicated in red have crown cover greater than 30 per cent. Although there is some indication of separation between these crown cover estimates, the separation is weak.

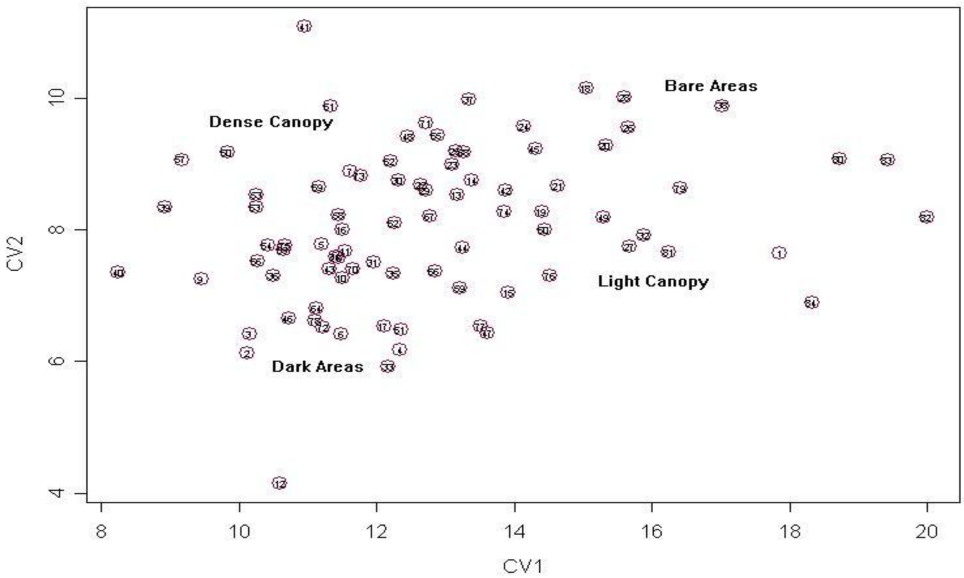


Figure 11 **Canonical variate plot showing the spectral separation of field sites based on crown cover. The field sites indicated in blue have little to no crown cover while those field sites indicated in red have crown cover greater than 30 per cent CV1 on the X-axis and CV2 on the Y-axis.**

(Figure 12) shows spectral separation in relation to the measured projected foliage cover (PFC) for the field plots within the Greater Coolgardie strata. The field sites indicated in blue have little to no foliage projected cover while those field sites indicated in red have a relatively high value for foliage projected cover. The spectral separation is quite strong and provided confidence for the development of an index of foliage projected cover from remote sensing.

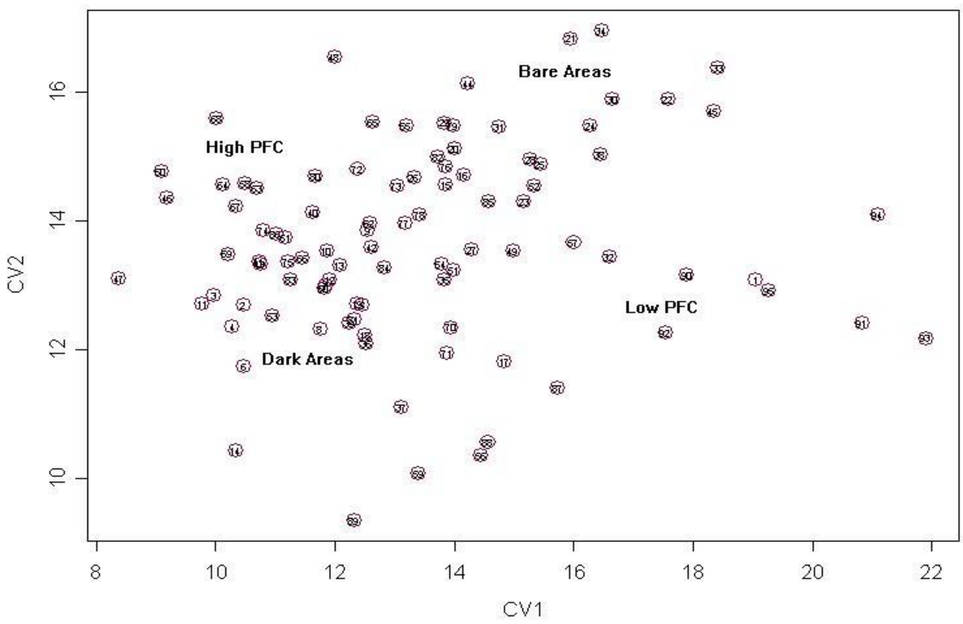


Figure 12 **Canonical variate plot showing the spectral separation of field sites based on projected foliage cover (PFC). The field sites indicated in blue have relatively low foliage projected cover while those field sites indicated in red have a relatively high value for foliage projected cover. CV1 on the X-axis and CV2 on the Y-axis.**

7.1.3. Index of projected foliage cover from remote sensing (PFCI-RS)

Procedures were directed to contrast those field sites that had a high PFC to those field sites with little to no PFC. Spectral Bands 3, 4 and 5 of Landsat TM were the most significant bands separating the sites and represented more than 97 per cent of the spectral separation. An index of projected foliage cover from remote sensing (PFCI-RS) for the Greater Coolgardie strata was established, being a linear combination of the following Landsat TM bands:

PFCI-RS = - (10* Band 3) + (5*Band 4) – (Band 5)

The index was then applied to all pixels in the strata using the Landsat TM data for the three bands, to produce an image of the index of projected foliage cover from remote sensing (PFCI-RS) for the Greater Coolgardie strata (Figure 13). Further analyses established the indices and corresponding images for each of the other strata (Table 6).

The index of projected foliage cover from remote sensing (PFCI-RS) increases with increasing greenness (a combination of Landsat TM Bands 3 and 4) and decreasing Band 5 values. This result is consistent with similar mapping projects conducted elsewhere in Australia (Kuhnell *et al.* 1998, Everitt *et al.* 1987).

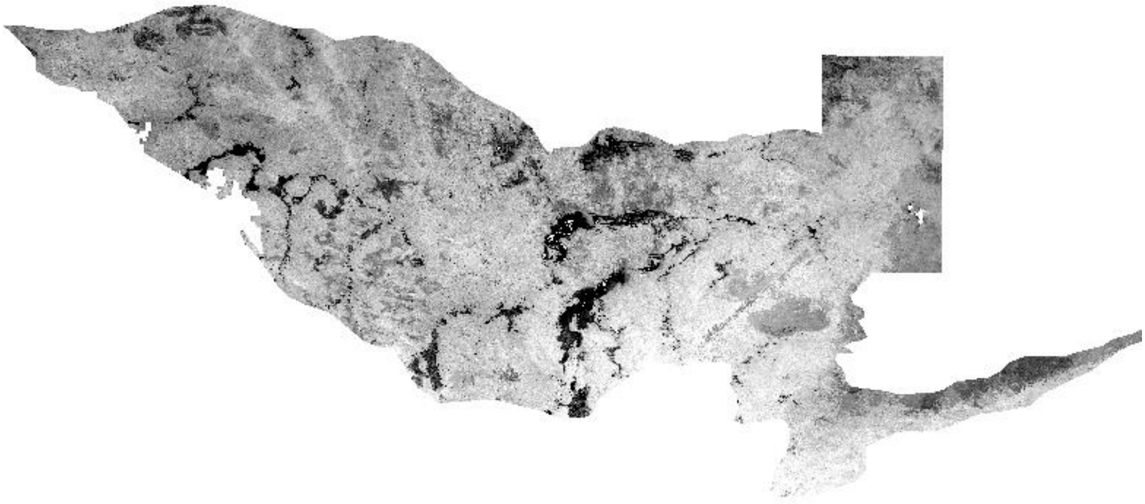


Figure 13 **Index of projected foliage cover from remote sensing (PFCI-RS) for the Greater Coolgardie strata. Black areas had no vegetation and white areas had the highest values of projected foliage cover.**

Table 6 **Indices of projected foliage cover from remote sensing (PFCI-RS) established for each strata within the study area. B3=Landsat TM Band 3; B4=Landsat TM Band 4; and B5=Landsat TM Band 5.**

Strata	Geraldton-Murchison	Coolgardie	Greater Mallee
PFCI-RS	-(2*B3)+(B4)-(2*B5)	-(10*B3)+(5*B4)-B5	-(3*B3)+(3*B4)-B5

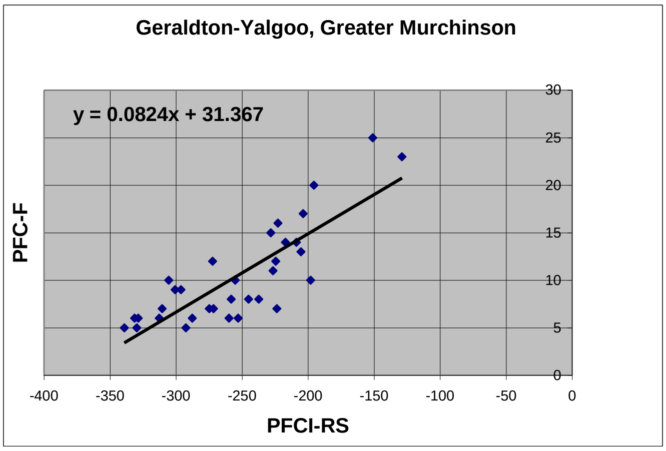
7.1.4. Projected foliage cover from remote sensing (PFC-RS)

Mean values for each of the field sites for the index of projected foliage cover from remote sensing (PFCI-RS) were extracted from the PFCI-RS image. The relationship between these values and projected foliage cover measured in the field (PFC-F) was established (Figure 14). The resultant linear equation was applied to the image of PFCI-RS to produce an image of projected foliage cover from remote sensing (PFC-RS).

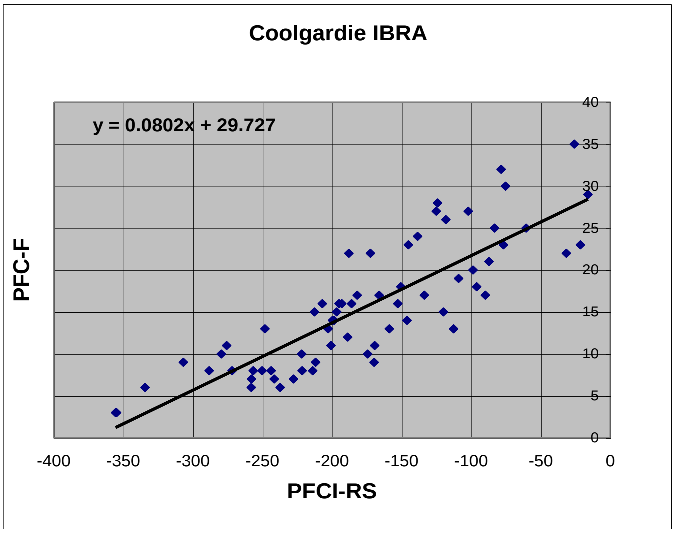
Thus for the Coolgardie strata:

$$\text{PFC-RS} = \text{PFCI-RS} * 0.0802 + 29.727$$

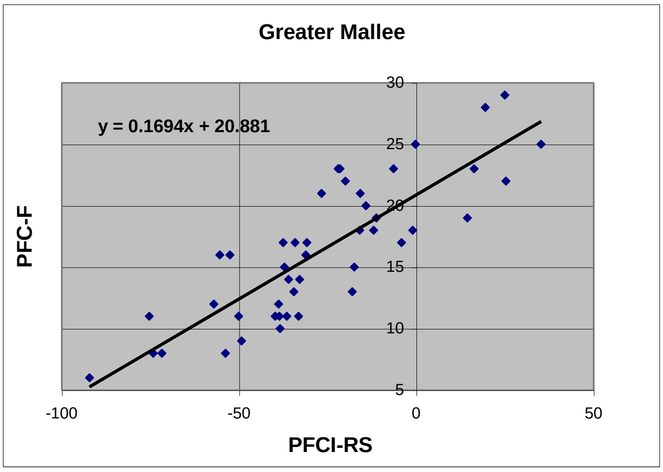
(Figure 13) shows the image of total PFC-RS for the Coolgardie strata with the dark to black areas having no PFC.



(a)



(b)



(c)

Figure 14 **Graphs (a), (b) and (c) show for each region the mean values of PFC estimated from Remote Sensing regressed against field measured PFC.**

7.2. Establishment of the 20 per cent crown cover threshold for forest cover

Figure 15 shows the image of projected foliage cover from remote sensing (PFC-RS), where light areas have relatively high values of PFC whilst the dark areas have relatively low values of PFC. The image of PFC-RS has a value range from 0 (black) to 35 (light), and somewhere in this range is the threshold equating to a 20 per cent crown cover that defines the non-forest/woodland forest threshold. Similarly another value in the range will equate to a 50 per cent crown cover that defines the woodland forest/open forest threshold. The results below illustrate the process for the 20 per cent crown cover threshold.

The relationship between projected foliage cover measured in the field (PFC-F) and crown cover measured in the field (CC) (Figure 16a and b) indicates that a 20 per cent crown cover equates to a projected foliage cover of between 9 and 11 per cent. The lower estimate of projected foliage cover is based on the relationship being forced through the origin whereas the upper value is where the regression equation is not forced through the origin.

Figure 17 shows the relationships between (a) the index of projected foliage cover from remote sensing and crown cover measured in the field by fitting a curve to the data points, and (b) the same data with a straight -line relationship. The figure indicates that a twenty per cent crown cover equates to a PFCI-RS of between -207 and -217. Using these values in the relationship between PFCI-RS and projected foliage cover measured in the field (PFC-F) (Figure 17c) indicates that a 20 per cent crown cover equates to a projected foliage cover of between 12 and 13 per cent.

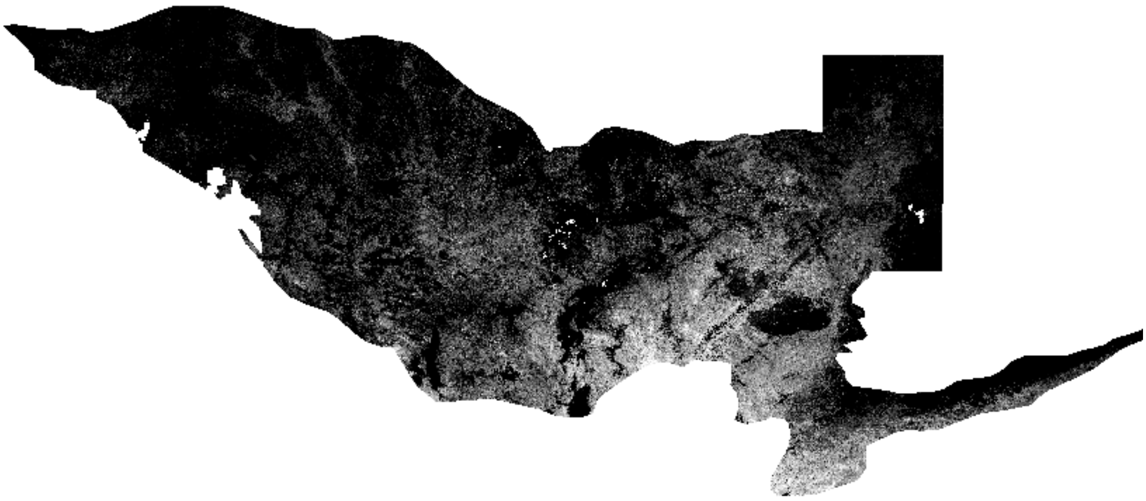
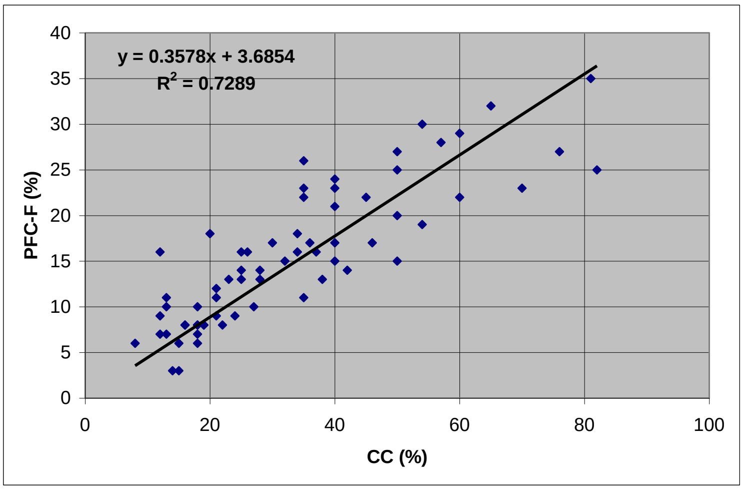
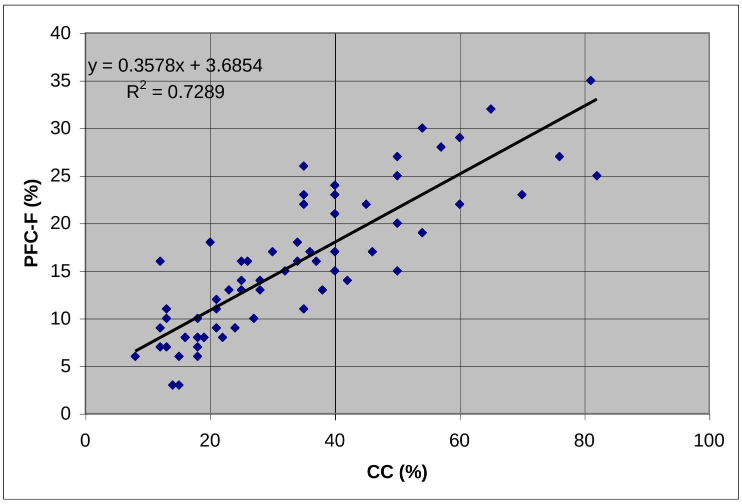


Figure 15 Image of projected foliage cover from remote sensing (PFC-RS) for the Coolgardie strata. White indicates areas with high values of projected foliage cover and black indicates areas with little or no projected foliage cover.

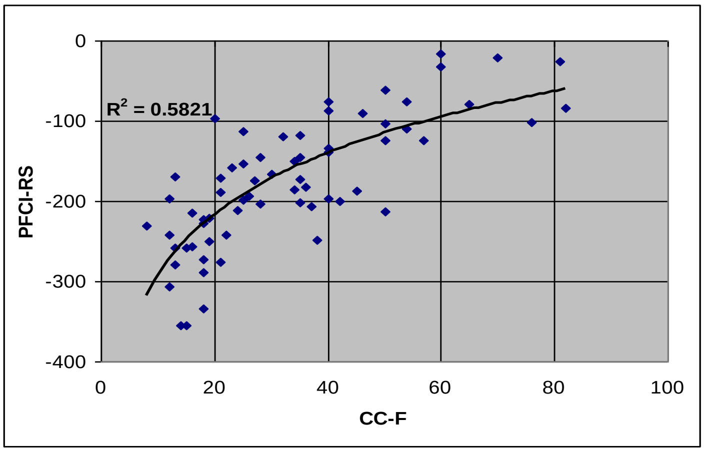


(a)

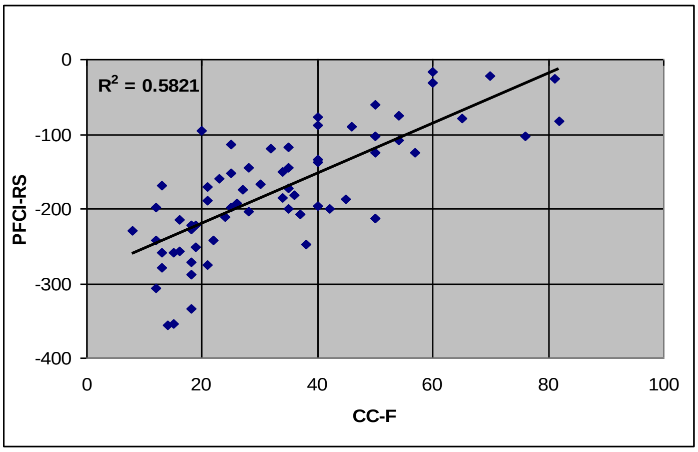


(b)

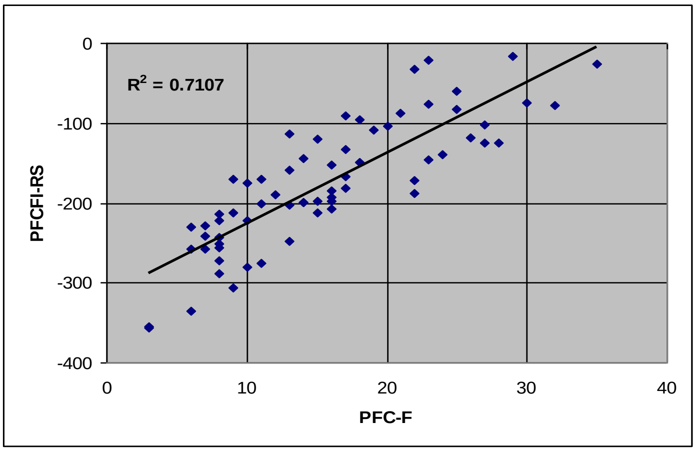
Figure 16 **Comparing field measured canopy cover and PFC it's possible to establish the initial threshold values. 16(a) shows a 20% canopy equals 9%PFC when it's passed through zero whilst 16(b) shows a 20% canopy equal to 11% PFC when its not forced through zero.**



(a) Fitted Curve



(b) Straight-line relationship



(c) Establishing the relationship between PFC and CC.

Figure 17 **Figures 17(a) & 17(b) show the relationship between PFCI and field measured crown cover. Figure 17(c) indicates a 12-13% PFC equates to a 20% crown cover.**

The relationships between these variables indicated a projected foliage cover of between 9 and 13 per cent equated to a crown cover of 20 per cent (the forest threshold). A value of 11 per cent, mid-way in the indicated range, was evaluated by producing a map of forest cover based on this value and comparing the map to information from the field sites and patterns of crown cover apparent on the aerial photographs. The threshold was then adjusted up and then down and the same comparisons undertaken.

This process was required as there are trade offs in adopting any particular threshold value as a result of the many unaccounted for variables that influence the relationships used to establish the threshold value (Figures 16 and 17). For example, a stand with a 20 per cent crown cover, a crown density of 80 per cent (i.e. PFC of 16 per cent) and a dense understorey is more likely to be identified as forest from the remotely sensed data than a stand with a 20 per cent crown cover, a crown density of 30 per cent (i.e. PFC of 6 per cent) and a no understorey.

Based on this evaluation, a foliage projected cover value of 11 per cent was adopted as equating to 20 per cent crown cover. Application of this threshold value to the image of projected foliage cover from remote sensing (PFC-RS) allowed a draft map of forest cover to be produced (Figure 18), where yellow indicates forest and black indicates non-forest.

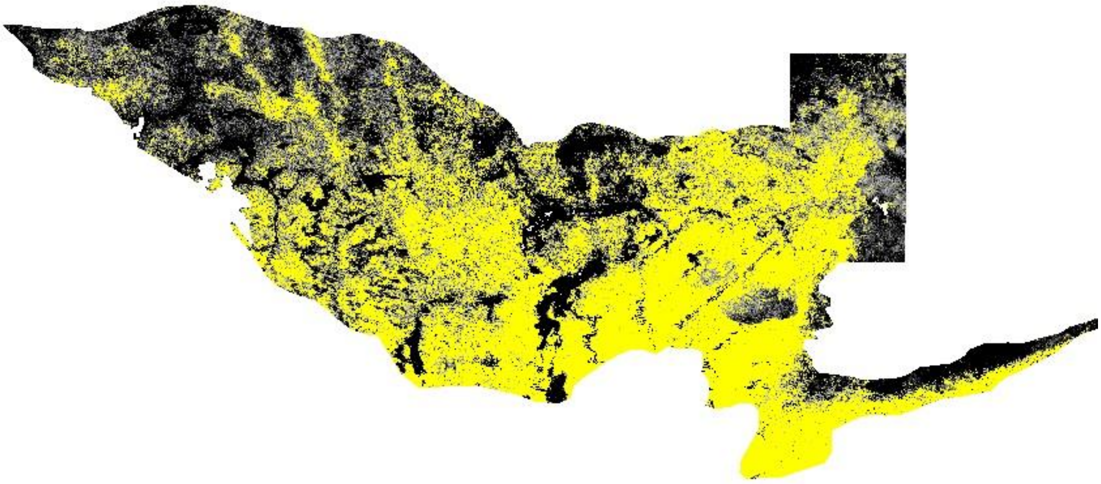


Figure 18 Draft map of forest cover for the Coolgardie strata based on a projected foliage cover of 11 per cent equating to the forest threshold of 20 per cent crown cover. Yellow indicates forest and black indicates non-forest.

7.3. Validation of the map of forest

Error matrices for each field Validation Area in the Coolgardie strata are shown in (Table 8) and all error matrices for the study area are in (Appendix 3). The error matrices indicate the draft map of forest cover had reasonable overall accuracy, but variable reliability.

The validation process estimated an overall accuracy of 80 per cent for the draft map of forest cover for the Coolgardie strata. Accuracy for mapped forest was 70 per cent and appears to have over-estimated the area of forest by mapping one-quarter of the non-forest field validation sites as forest. This interpretation is reinforced by the higher accuracy found in the mapping of non-forest where an accuracy of 88 per cent was found. The conclusion from the validation process for the Coolgardie strata was that the PFC threshold was too low and needed to be adjusted to a higher value.

The overall accuracy for the whole study area (76 per cent) was lower than for the Coolgardie strata (80 per cent). Error was primarily associated with non-forest sites being mapped as forest, with the mapped forest having an overall accuracy of 62 per cent. In contrast, the average accuracy of mapped non-forest was 96 per cent (Appendix 3). The commission errors for the draft map of forest cover were often associated with a dense understorey less than 2 metres in height or vigorous regrowth after major disturbances such as fire. Area 10, with dense understorey, gave 52 per cent accuracy for mapped forest and 100 per cent accuracy for mapped non-forest, giving an overall accuracy of 68 per cent and Validation Area 5, with regrowth after a fire disturbance, gave 29 per cent accuracy for mapped forest and 100 per cent accuracy for mapped non-forest, giving an overall accuracy of 56 per cent.

The reliability of the draft map of forest cover was variable across all the Validation Areas, indicated by the range of accuracy values for the individual field Validation Areas (Table 8). Accuracy ranged from a low of 56 per cent for field Validation Area 5, to a high of 91 per cent accuracy for field Validation Area 4. Mapped forest was less reliable than mapped non-forest, with mapped forest having a low accuracy of 29 per cent for field Validation Area 5 and a high accuracy of 86 per cent for field Validation Area 7.

Field records and the photographs taken of field validations sites in field Validation Area 5 show that fire influenced the structure and density of vegetation for half of the sites mapped as forest that were observed to be non-forest in the field.

Records for field Validation Area 10 show that both fire and dense understorey vegetation affected the accuracy of mapped forest. For field Validation Area 6, many of the sites had dense understorey vegetation that affected the accuracy of mapped forest. Therefore, the poor accuracy of areas mapped as forest is able to be explained in many cases. However, for field Validation Area 8, no reason for the poor accuracy was apparent. One way of improving the accuracy of the map of forest cover would be to use Landsat TM data from multiple dates, thereby overcoming the problems causes by the effects of bushfire.

Table 7 Error matrices for field Validation Vreas 1, 2, 7 and 9 which were within the Coolgardie strata based on the draft map of forest cover.

Validation Area 1			
Validation site observations	***Mapped as forest***	***Mapped as non-forest***	***Accuracy (%)***
Observed as forest	13	2	
Observed as non-forest	3	13	
Accuracy (%)	**81**	**87**	**84**
Validation Area 2			
Validation site observations	***Mapped as forest***	***Mapped as non-forest***	***Accuracy (%)***
Observed as forest	13	2	
Observed as non-forest	6	12	
Accuracy (%)	**68**	**86**	**76**
Validation Area 7			
Validation site observations	***Mapped as forest***	***Mapped as non-forest***	***Accuracy (%)***
Observed as forest	18	2	
Observed as non-forest	3	7	
Accuracy (%)	**86**	**78**	**83**
Validation Area 9			
Validation site observations	***Mapped as forest***	***Mapped as non-forest***	***Accuracy (%)***
Observed as forest	13	0	
Observed as non-forest	7	13	
Accuracy (%)	**65**	**100**	**79**
All Validation Areas			
Overall accuracy (%)	**75**	**88**	**80**

Table 8 Number of field validation sites for each of the field Validation Areas, the accuracy of the draft map of forest cover for each of the field Validation Areas and the overall accuracy.

Field Validation Area	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Number of field validation sites	**31**	**33**	**33**	**33**	**34**	**30**	**30**	**33**	**33**	**31**	**322**
Accuracy of map of unadjusted forest cover (%)	**84**	**76**	**85**	**91**	**56**	**67**	**83**	**73**	**79**	**68**	**76**

7.4. Adjustment of the threshold of projected foliage cover

Using the results from the field validation exercise and the supplementary information collected for the field validation sites, the PFC threshold for the Coolgardie strata was adjusted from 11 to 13 per cent and a final map of forest cover was produced. The adjustment maintained the accuracy of non-forest component and improved the confidence of mapped forest, however no further field validation was done to test this accuracy.

Figure 19 shows the final map of forest cover for the Coolgardie strata after the adjustment to the PFC threshold. Yellow indicates areas of forest and black indicates areas of non-forest. In comparison to the draft map of forest cover (Figure 19), there is a substantial reduction in the mapped area of forest.

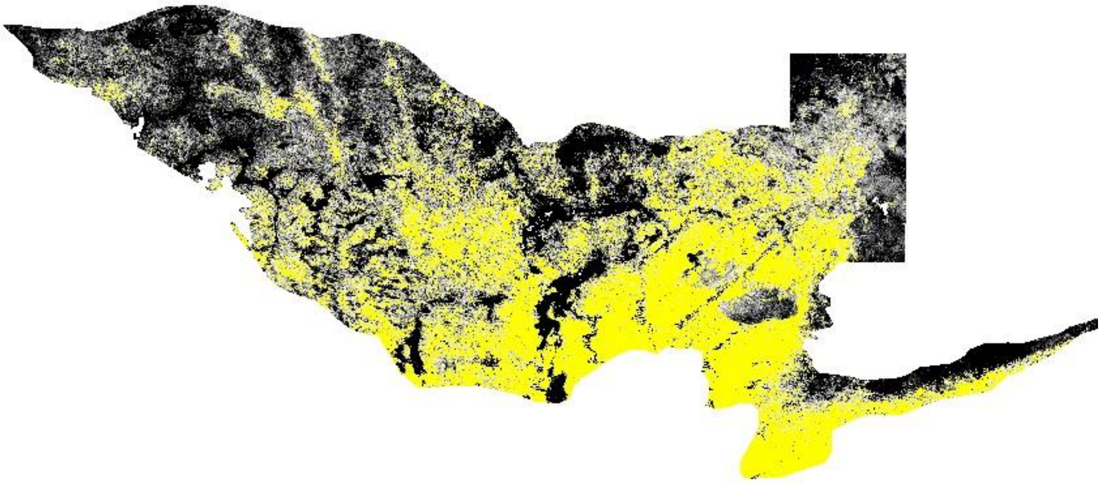


Figure 19 Final map of forest cover for the Coolgardie strata based on a projected foliage cover of 13 per cent equating to the forest threshold of 20 per cent crown cover. Yellow indicates forest and black indicates non-forest.

A similar process of adjustment of the threshold PFC value was undertaken for the other strata. In the case of the Geraldton-Murchison strata, the adjustment was undertaken for each of two sub-strata, as this produced a better match with the field verification site data and supplementary information, and patterns of crown cover on the aerial photographs.

The process of adjusting and establishing the final threshold PFC value was undertaken for both the non-forest/woodland forest threshold (20 per cent crown cover) and the woodland forest/open forest threshold (50 per cent crown cover).

There is no closed forest in the study area so establishment of the threshold PFC for the open forest/closed forest threshold was unnecessary. The threshold PFC values equating to a 20 per cent crown cover (the non-forest/woodland forest threshold) for each strata and sub-strata for the final map of forest cover ranged from ten per cent PFC for the Geraldton-Yalgoo sub-strata to 14 per cent PFC for the Murchison sub-strata (Table 10). The threshold PFC values equating to a 50 per cent crown cover (the woodland forest/open forest threshold) ranged from 25 per cent PFC for the Geraldton-Yalgoo sub-strata to 35 per cent PFC for the Murchison sub-strata.

Table 9 Thresholds of projected foliage cover (PFC) adopted for the final map of forest cover, for each strata and sub-strata of the study area. The thresholds of PFC equate to the 20 per cent crown cover threshold for woodland forest and the 50 per cent crown cover threshold for open forest.

Strata	Geraldton-Murchison		Coolgardie	Greater Mallee
Sub-strata	Geraldton-Yalgoo	Murchison		
Crown cover threshold (%)	PFC (%) equating to the specified crown cover			
20	10	14	13	12
50	25	35	33	30

7.5. Attribution of the final map of forest cover to forest formations

The vegetation associations of the Vegetation Database of Western Australia do not readily aggregate to forest formations which were described from the Goldfor field work. A rule was used to assist in aggregation of the forest formations and a table created. This table includes all vegetation associations inside the project area and also the majority of those outside.

It is important to note that the aggregation of some vegetation associations is somewhat arbitrary. Such associations may in some cases be more appropriately aggregated to a different forest formation than that documented. However, the work required to more accurately define the linkages between vegetation associations in the Vegetation Database of Western Australia and forest formations was beyond the scope of this project. Consequently, when confronted with those attribution clashes discussed in more detail below, precedence was given to the information in the remotely sensed forest cover mapping.

In order to attribute the final map of forest cover with information from the aggregated Vegetation Database of Western Australia, the Database was rasterised and combined with the final map of forest cover.

Table 10 Resulting areas, prior to rationalisation, of the intersection of the remote sensing forest cover mapping and the Vegetation Database of Western Australia aggregated to forest formation.

Forest formation	Forest formation code	Remotely sensed forest cover (%)	Area (ha)
Acacia Low Open Forest *	4	*20 - 50 %*	*65511*
Acacia Low Woodland Forest	1	*20 - 50 %*	*339990*
Banksia Low Woodland Forest	7	*20 - 50 %*	*64113*
Casuarina Low Woodland Forest	14	*20 - 50 %*	*55706*
Eucalyptus Low Open Forest *	29	*20 - 50 %*	*2608*
Eucalyptus Low Woodland Forest	26	*20 - 50 %*	*1601451*
Eucalyptus Medium Woodland Forest	27	*20 - 50 %*	*4035431*
Other Woodland Forest ***	51, 52 or 53	*20 - 50 %*	*810135*
Mixed Species Low Woodland Forest	45	*20 - 50 %*	*460217*
Eucalyptus Low Woodland Forest **	26	*51 - 80 %*	*118*
Eucalyptus Medium Woodland Forest **	27	*51 - 80 %*	*11*
Other Open Forest ***	54, 55 or 56	*51 - 80 %*	*124*
Mixed Species Low Woodland Forest **	45	*51 - 80 %*	*666*

Areas denoted and identified from the field work within the table as Non Forest that intersected with areas of remotely sensed forest cover $\geq$ 20%, were rationalised as Other Forest with the cover component dependent on the remotely sensed forest cover class (51-56). This approach does not resolve height and thus such areas could be attributed with any one of three (low, medium, tall) forest formations. The largest proportion of the remaining result is attributed as medium (11 – 30 metres), and thus Other Woodland Forest and Other Open Forest have been rationalised below to Other Medium Woodland Forest and Other Medium Open Forest.

Inconsistencies between the forest formation from the Vegetation Database of Western Australia and the remotely sensed forest class (1, 4, 7 14, 26, 27, 29, 45, 51, 52, 53, 54, 55, 56) have been rationalised with reference to the remote sensing result. In this manner, Open Forest with a remotely sensed forest cover of 20 to 50 per cent is rationalised as Woodland Forest, and similarly Woodland Forest with a remote sensed forest cover of 51 to 80 per cent is rationalised to Open Forest.

Table 11 Rationalisation of areas in Table 11

Forest formation	Forest formation code	Rationalised forest formation	Rationalised forest formation code	Remotely sensed crown cover (%)	Area (ha)	Rationalised area (ha)
Acacia Low Open Forest *	4	Acacia Low Woodland Forest	1	*20 - 50 %*	*65,511*	***405,501***
Acacia Low Woodland Forest	1	Acacia Low Woodland Forest	1	*20 - 50 %*	*339,990*	
Banksia Low Woodland Forest	7	Banksia Low Woodland Forest	7	*20 - 50 %*	*64,113*	***64,113***
Casuarina Low Woodland Forest	14	Casuarina Low Woodland Forest	14	*20 - 50 %*	*55,706*	***55,706***
Eucalyptus Low Open Forest *	29	Eucalyptus Low Woodland Forest	26	*20 - 50 %*	*2,608*	***1,604,059***
Eucalyptus Low Woodland Forest	26	Eucalyptus Low Woodland Forest	26	*20 - 50 %*	*1,601,451*	
Eucalyptus Medium Woodland Forest	27	Eucalyptus Medium Woodland Forest	27	*20 - 50 %*	*4,035,431*	***4,035,431***
Other Woodland Forest ***	51, 52 or 53	Other Medium Woodland Forest	52	*20 - 50 %*	*810,135*	***81,0135***
Mixed Species Low Woodland Forest	45	Mixed Species Low Woodland Forest	45	*20 - 50 %*	*460,217*	***46,0217***
Eucalyptus Low Woodland Forest **	26	Eucalyptus Low Open Forest	29	*51 - 80 %*	*118*	***118***
Eucalyptus Medium Woodland Forest **	27	Eucalyptus Medium Open Forest	30	*51 - 80 %*	*11*	***11***
Other Open Forest ***	54, 55 or 56	Other Medium Open Forest	55	*51 - 80 %*	*124*	***124***
Mixed Species Low Woodland Forest **	45	Mixed Species Low Open Forest	48	*51 - 80 %*	*666*	***666***

Table 12 Area of each forest formation in the study area. These final areas result from the intersection of the final map of forest cover and the Vegetation Database of Western Australia aggregated to forest formation.

Forest formation	Area (ha)
Acacia Low Woodland Forest	405,501
Banksia Low Woodland Forest	64,113
Casuarina Low Woodland Forest	55,706
Eucalypt Low Woodland Forest	1,604,059
Eucalypt Low Open Forest	118
Eucalypt Medium Woodland Forest	4,035,431
Eucalypt Medium Open Forest	11
Mixed Species Low Woodland Forest	460,217
Mixed Species Low Open Forest	666
Other Medium Woodland Forest	810,135
Other Medium Open Forest	124
Total Forest Area	**7,436,081**
Non Forest	21,687,437
Study Area	**36,559,599**

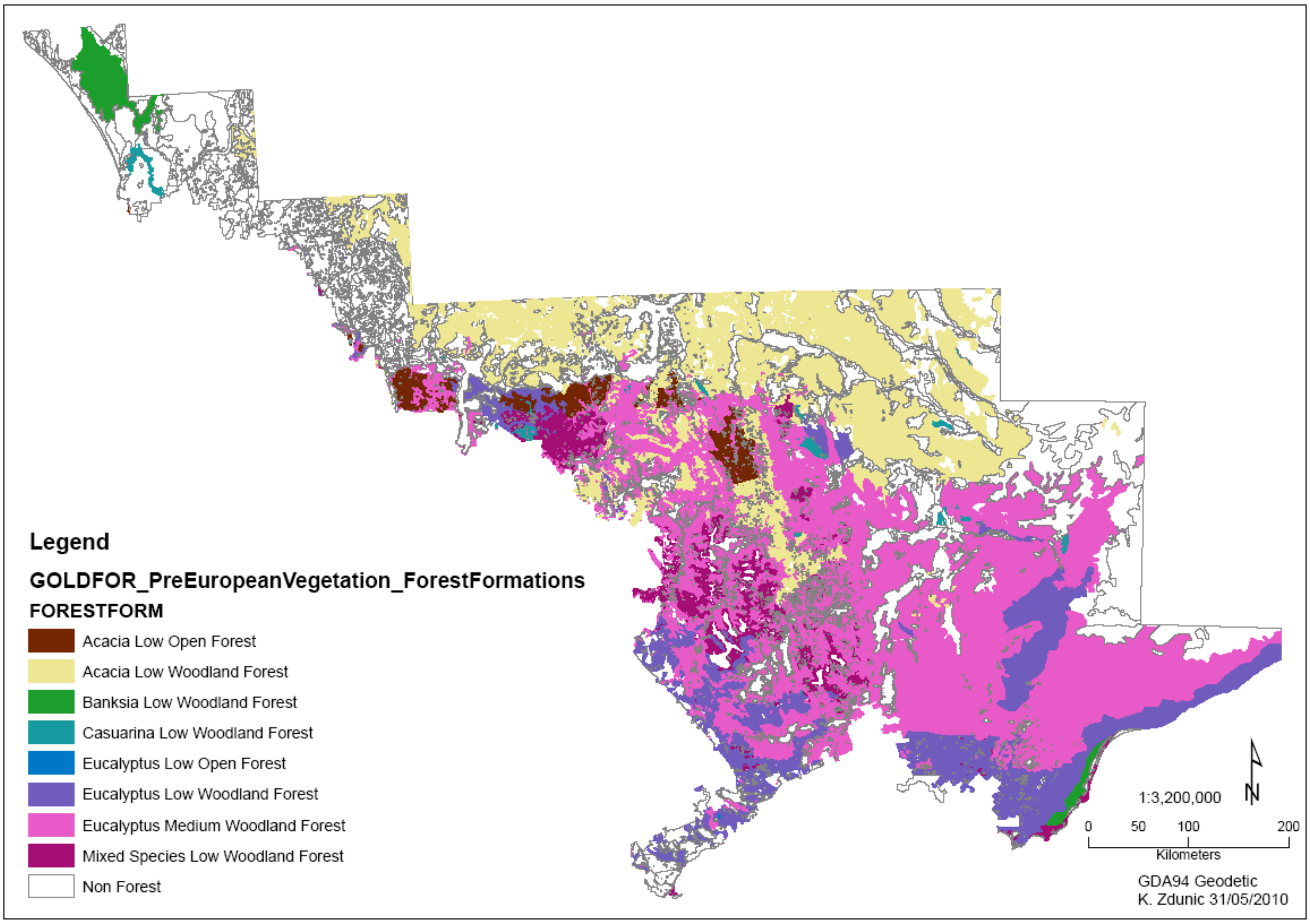


Figure 20 Pre European Vegetation Forest Formation

7.6. Management of data bases from the project

All digital versions of proformas have been validated to ensure they contain the same information as the hard copy proformas collected in the field. This validation did not extend to verification of the quality or accuracy of the information they contain.

Each calibration and validation field site has been spatially located in the shape files *goldfor_calibration* and *goldfor_validation* respectively. Site 216_extra has not been able to be located satisfactorily from field descriptions and has thus not been included in the calibration shape file.

Digital photographs of most sites were collected. Photographs and proformas can be manually linked to the spatial location in the relevant shape file by means of the unique site identifier.

Voucher specimens have been identified and noted within relevant validated calibration proformas. The original validated calibration proformas have been retained as well as those with voucher identifications.

7.7. Sensitivity to the threshold of projected foliage cover

The study has shown that estimated forest cover is very sensitive to the projected foliage cover that is adopted to equate to a crown cover of 20 per cent (the forest threshold). Figure 21 shows the image of projected foliage cover from remote sensing with thresholds for forest cover applied at PFC levels of 9 per cent, 12 per cent and 15 per cent. It is clear that the estimated area of forest in the study area is very sensitive to the PFC threshold with the estimated area of forest more than halving in response to an increase in the PFC threshold from 9 per cent to 15 per cent (Figure 22).

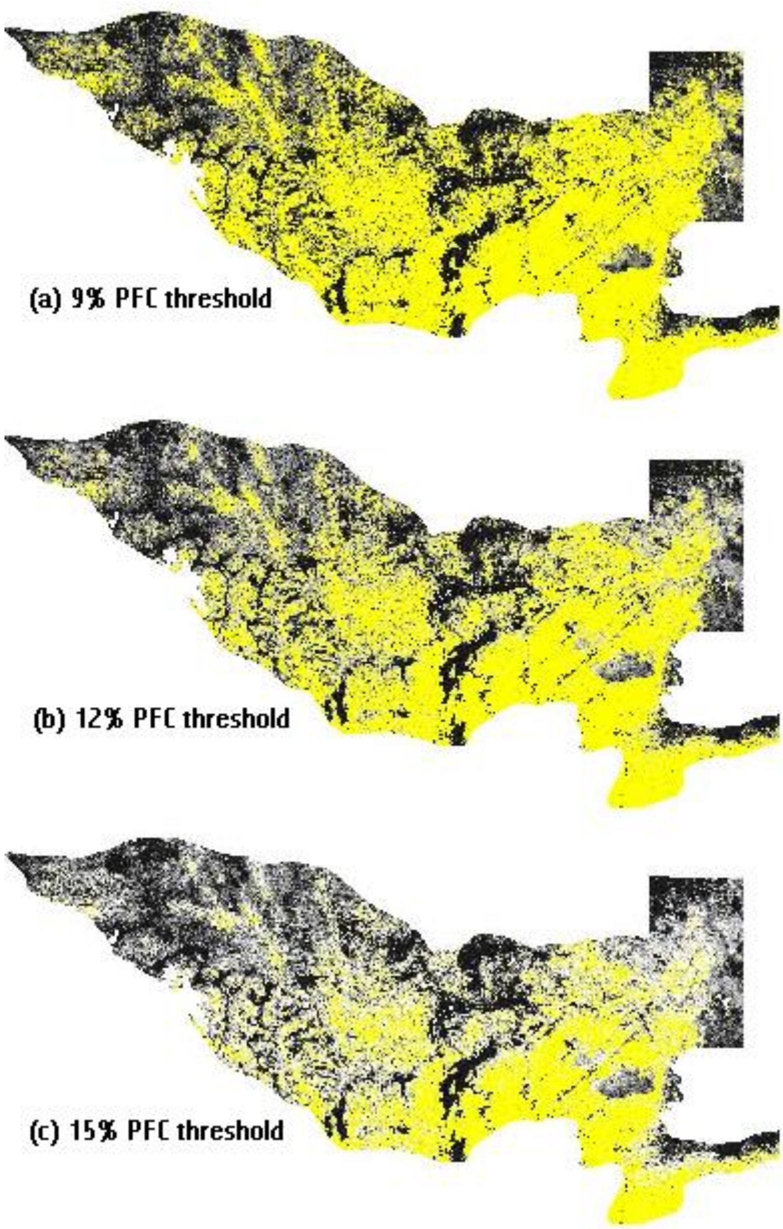


Figure 21 Image of projected foliage cover for the Coolgardie strata with thresholds for forest cover (yellow) applied at projected foliage cover levels of (a) 9 per cent, (b) 12 per cent and (c) 15 per cent. Forest cover is expressed as percentage of the area estimated using a PFC threshold of 9 per cent.

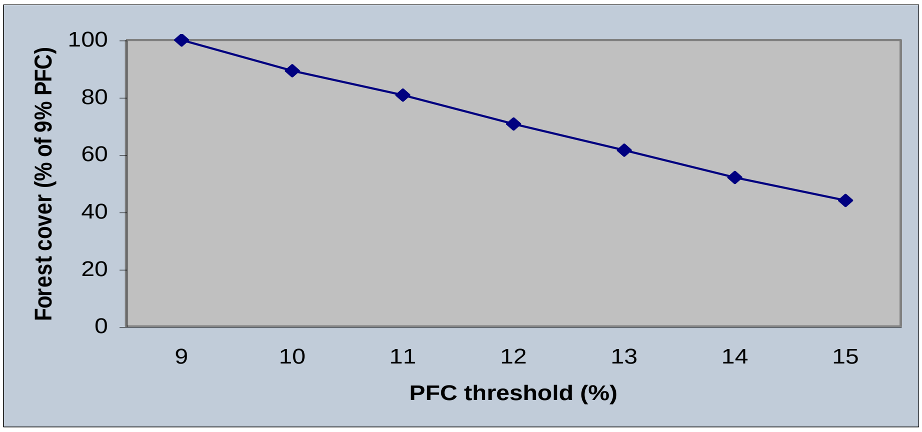


Figure 22 **The effect of the projected foliage cover threshold value adopted to equate to a 20 per cent cover for forest on the estimated area of forest cover for the Coolgardie strata. Forest cover is expressed as percentage of the area estimated using a PFC threshold of 9 per cent.**

7.8. Sensitivity analysis of the effect of a minimum area requirement to qualify as forest

The sensitivity analysis showed that a minimum area requirement to qualify as forest has a large impact on the estimated area of forest in the study area (Figure 23). Validation Area 4, on the eastern part of the Coolgardie IBRA close to the boundary with the Great Victoria Desert and Nullarbor IBRAs, had the highest sensitivity. This is the sample area that had the most scattered distribution of small patches of forest. In this sample area, the area of forest with a 4 hectare minimum area was 29 per cent less than the area of forest a 0.0625 hectare minimum area.

Validation Area 3 had the most complete and consolidated area of forest. Validation Area 3 was least sensitive to a minimum area requirement to qualify as forest as the area of forest with a 4 hectare minimum area was only 2 per cent less than the area of forest with a 0.0625 hectare minimum area.

A 1 hectare minimum area requirement resulted in between 1 per cent and 19 per cent less area estimated as forest compared to the 0.0625 hectare minimum area requirement.

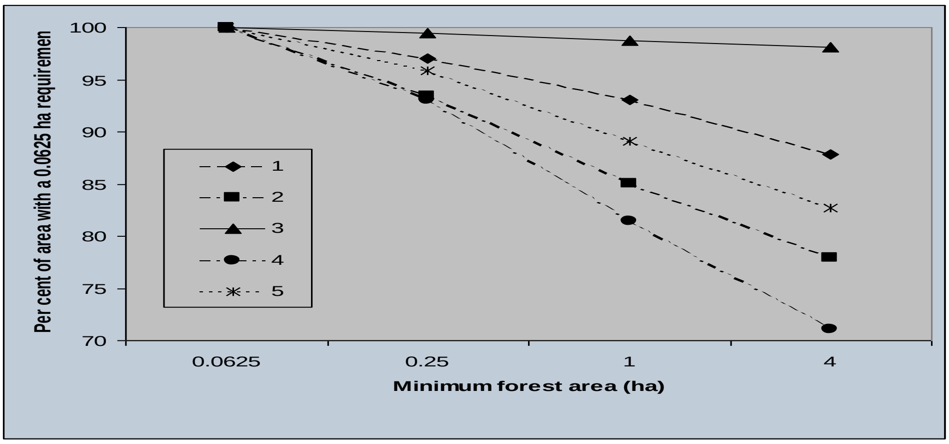


Figure 23 **Sensitivity analysis of the effect of a minimum area requirement to qualify as forest for the five sample areas within the study area. The area of forest with a 0.25 ha, 1 ha and 4 ha minimum area requirement is expressed as a per cent of the area with a minimum area requirement of 0.0625 ha**.

7.9. Rainfall anomalies and forest cover

Rainfall was generally above average both prior to the Landsat TM data being collected in 1996 and 1998 and prior to the field work in 2000. The exceptions to this are for Hyden and Hopetoun in the south-west of the study area where rainfall was average (Hyden) and below average (Hopetoun) in the three years prior to the Landsat data being collected.

The Menzies to Norseman area had well above average rainfall prior to both the Landsat TM data collections in 1996 and 1998, and the field work in 2000.

Table 13 Rainfall for high quality rainfall stations in or near the study area for a three year period prior to Landsat TM data collection and the field work.

<table>
<tr><th>Locality</th><th>Rainfall prior to Landsat TM data acquisition</th><th>Rainfall prior to field work in 2000</th></tr>
<tr><td>Peran</td><td>Above average prior to 1998 (+8%)</td><td>Well above average (+18%)</td></tr>
<tr><td>Wydgee</td><td>Well above average prior to 1998 (+24%)</td><td>Above average (+13%)</td></tr>
<tr><td>Hyden</td><td>Average prior to 1996 (-1%)</td><td>Well above average (+29%)</td></tr>
<tr><td>Hopetoun</td><td>Below average prior to 1996 (-11%)</td><td>Above average (+11%)</td></tr>
<tr><td>Menzies</td><td>Well above average prior to 1998 (+65%)</td><td>Well above average (+31%)</td></tr>
<tr><td>North of Norseman</td><td>Well above average prior to 1998 (+25%)</td><td rowspan="2">Well above average (+23%)</td></tr>
<tr><td>South of Norseman</td><td>Well above average prior to 1996 (+26%)</td></tr>
</table>

7.10. Vegetation

Almost 500 plant voucher specimens were collected as part of the vegetation structural summaries for each site over the course of this study. From this, botanists identified 205 taxa. The best represented genera were *Eremophila* (14 taxa), *Melaleuca* (20 taxa), Acacia (23 taxa) and *Eucalyptus* (45 taxa).

Conservation listed taxa

Of the taxa collected three, are Priority (Poorly Known) conservation listed with the Department of Conservation and Land Management (Atkins 2003). They are:

Desmocladus biformis. Priority 3. *D. biformis* is known from widely separated populations in the south west and north west of the Southwest Botanical province (Western Australian Herbarium 2003). This species was collected in the extreme north west of the study area (voucher AER 536).

Eucalyptus exigua. Priority 3. *E. exigua* is known from a number of populations on or near the boundaries of the Southwest and Eremaean Botanical provinces south west of Kalgoorlie (Western Australian Herbarium 2003). This species was collected in the study area south west of Kalgoorlie (voucher AER 197).

Grevillea stenomera. Priority 2. *G. stenomera* is known only from a few collections in coastal areas of the north Geraldton Sandplains IRBA (Western Australian Herbarium 2003). This species was collected in the extreme north west of the study area (voucher AER 532).

Introduced flora

Only one introduced species was collected as part of the vegetation structural summaries. **Schinus molle* (Anacardiaceae), a tree species found in scattered occurrences across the southwest of Western Australia, was collected in the Kalgoorlie/Menzies area (voucher AER 306).

8. Discussion

8.1. Comparison of this project's map of forest cover with the earlier map

Figure 24 Low Eucalyptus Woodland Forest with recovering canopy and bare to open ground.

Figure 25 Medium Woodland Forest with a significant understorey layer.

Despite the use of an objective definition of forest/non-forest boundary in this way, it is still possible for errors to be made in classifying an area as forest or non-forest. Variations in reflectance values can be due to poor crown condition as a consequence of earlier disturbances such as fire or drought (Figure 24) and so maybe classified as non-forest. 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 10 to 14 per cent PFC range (as described later). The opposite reasoning being areas classified as forest may in fact have sparse crown cover (Figure 25) but have a denser mid-storey or ground-cover that increases its PFC value as estimated from remote sensing.

The final map of forest cover has a number of limitations. A minimum area requirement was not used and patches of forest as small as 0.0625 hectare, being a single Landsat TM pixel, are identified as forest. Application of a minimum area requirement would reduce the estimated area of forest. Secondly, many fire scars of areas below the forest threshold in a landscape generally above the forest threshold were observed from the satellite imagery.

The final map of forest cover therefore represents an underestimate of areas with a potential crown cover of 20 per cent. Thirdly, much of the vegetation in the study area is close to the forest threshold and probably moves above and below the threshold in response to stand age, disturbance events such as fire, and climatic effects such as above or below average rainfall sequences. The final map of forest cover therefore represents the extant area of forest at a particular point in time, and therefore represents an underestimate of areas with a potential crown cover of 20 per cent. Lastly, the attribution of forest cover to forest formations is relatively coarse.

8.2. Fire scars

Fire is a natural part of the environment in the study area (McCaw and Hanstrum 2003) and can have a profound effect on the structure and composition of vegetation (Beard 1967, Hopkins and Robinson 1981, Hobbs 2001). In particular, crown cover may be reduced for many years. Figure 26 shows the impact of a fire some years previous to our field work, on the structure of the vegetation at one of the field validation sites.

Figure 26 **Photograph of field validation site 13 in field Validation Area 10. The impact of a fire a number of years earlier than our field visit is clearly visible on the structure of the vegetation.**

A number of large fire scars were evident on the Landsat TM imagery. These fire scars were evident as large areas of non-forest in an area that otherwise had a component of forest in the landscape (Figure 27). These fire scars clearly reduce the estimated area of forest in the study area as this study has mapped the extant area of forest, not the area of potential forest specified in the definition of forest. Further studies based on remotely sensed information, calibrated with field data, and would have the potential to fill the gaps created by fire scars in a map of areas with a potential crown cover of 20 per cent, based on data from this study.

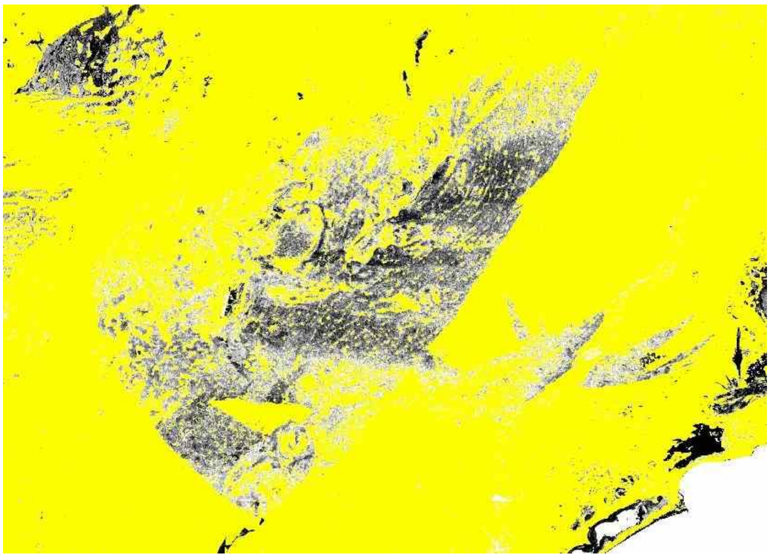


Figure 27 **Draft map of forest cover (yellow) for part of the study area. The large area of non-forest in the middle of the image is an area burnt by a bushfire in March 1991, some 7 years before the Landsat data was collected. The fire scar measures 50 km by 22 km.**

8.3. Rainfall anomalies and forest cover

For the south-west part of the study area (Hyden to Hopetoun) where rainfall was average to below average prior to the Landsat data collection and above average prior to the field work, it is likely there was less foliage at the time of the Landsat TM data collection than at the time of the field work. Consequently, the relationship between remotely sensed PFC and field measured PFC may have overestimated the area of forest cover.

For the rest of the study area where rainfall was above average to well above average both prior to Landsat TM data collection and the field work, relationships used to estimate PFC are likely to be reliable and no under- or over-estimation of PFC is likely. However, it is likely that forest cover was greater than it would have been following periods of average or below average rainfall.

8.4. Sensitivity to the threshold of projected foliage

Estimated forest cover is very sensitive to the projected foliage cover that is adopted to equate to a crown cover of 20 per cent (the forest threshold) (Figure 21).

As a result of this it needs to be recognised that a number of factors could have significantly influenced the results obtained in this study.

Forests are dynamic entities, the density of trees within them changes through time as trees die and as other establish and grow. This process may proceed slowly or undergo sudden change in response to disturbances such as fire. Crown density will vary through time in response to factors such as climate with denser crowns following periods of above average rainfall. Pests and disease can impact crown density as well as survival of older trees and establishment of new trees. Additionally, the understorey component is dynamic and would normally reach a peak density a number of years after fire and then decline until a new disturbance event triggered a new wave of regeneration of understorey plants.

Reflectance from Landsat TM is influenced by soil and atmospheric factors in addition to vegetation factors that were the subject of measurements for this study. Whilst these unaccounted for factors may not greatly influence estimated of forest cover when the forests are well above the threshold for forest cover, they may well have had a significant effect in the study area because so much of the vegetation is close to the threshold for forest.

The time lag between the capture of the Landsat TM imagery (1996 and 1998) and the field work (2001) may also have influenced the results. Whilst this factor may not greatly influence estimates of forest cover for forests in other parts of Australia where the forests are well above the threshold for forest cover, it may well have had a significant effect in the study area because so much of the vegetation is close to the threshold for forest.

8.5. Sensitivity to a minimum area requirement to qualify as forest

This study has shown that the estimated area of forest is very sensitive to a minimum area requirement to qualify as forest, with up to 29 per cent less forest being identified with a 4 hectare minimum area requirement compared to forest with a 0.0625 hectare minimum area requirement. The accepted Australian definition of forest does not include a minimum area requirement, which is in contrast to definitions of forest adopted in some other countries. For example, the United States has a 0.4 hectare minimum area and the FAO has a 0.5 hectare minimum area.

The issue of a minimum area requirement goes to one of the core components of what many people would consider defines a forest.

- Should a single large tree in grassland be considered a small patch of forest?
- Should a group of three or four trees in grassland be considered a small patch of forest?
- Should widely spaced trees or groups of trees with a grassy understorey be considered forest?
- Should a group of a several hundred trees in grassland be considered a small patch of forest?

Many people would accept the latter as forest but would not consider that a single large tree in grassland is a small patch of forest.

Landsat TM has the capacity to identify small patches of forest of one or two large trees as shown in Figure 28 which shows a close up of the draft map of forest cover superimposed (yellow) onto part of an aerial photograph of the Kalgoorlie area. In this case there are a scattering of cells classified as forest, many being single Landsat TM pixels of 25 metre x 25 metre in size. As technologies improve in the future it is likely that the cost of obtaining satellite images with smaller pixel size will reduce and thus the technology will have the capacity to identify even smaller patches of vegetation as forest.

It is recommended that the Australian definition of forest should be reviewed with a view to adding a minimum area requirement. A minimum area requirement should not be imposed on existing high quality maps of forest cover available for some parts of Australia. However, the requirement would improve mapping of forest in other parts of Australia, particularly those parts where new maps are being developed based on satellite remote sensing.

Figure 28 Close up of the draft map of forest cover superimposed (yellow) onto part of an aerial photograph of the Kalgoorlie area.

8.6. Extant forest versus areas with potential crown of 20 per cent

- What constitutes extant forest?
- How small an area is required before it is no longer classed as extant?
- Can a group of trees in an open heath land be classified as extant forest or does it require a larger more contiguous pattern across the landscape?

As the technology improves and there are more accurate measures of the 20 per cent crown cover there will be more emphasis placed on what is extant forest.

- Does vegetation have to be greater than 20 per cent canopy cover before it is classified forest and therefore as extant forest?
- Can an expansive area with less than 20 per cent canopy cover be classified as extant forest?

Twenty per cent crown cover during the Goldfor project was used to determine forest and there was no minimum size to assist in determining the size classification of forest. This in isolation could see a single tree classified as extant forest and most people would have objections to this. In contrast if the area proved to be 20 per cent crown cover made up by a number of trees with expansive crowns then it people are more likely to accept that as an area of extant forest.

Extant forested areas, for the Goldfor project are generally open forests and have areas that are less than 20 per cent crown cover. Even so these forests occupy a large proportion of the landscape. These forests can be naturally open and show up as non forest because they are less than 20 per cent when the projected crown cover is overlayed. Similarly the areas that have a projected crown cover of 20 per cent may not always be classified as extant forest accurately due to natural variation in the canopy. Variation such as a single large tree dominating an area and displaying as forest due to the canopy cover but is still only a single tree.

Extant forest may occur naturally over a larger area but disturbances have affected the area prior to it being recognised with remote sensing. Disturbances such as storm damage, fire, wind throw and changing climate. All can affect the potential crown cover and thus the extant forest. Some of areas have the potential to be greater than 20 per cent canopy cover but do not met the classification because of natural disturbance at time of photography excluding them from being classified as extant forest until natural recovery has occurred.

There will always be variation in the difference between the extant forest and the areas that have the potential to be greater than 20 per cent canopy cover from these natural factors and the sensitivity threshold that PFC brings with it. More frequent photography of the areas would allow a more accurate representation of what is extant forest and what is not because it would show recovering forest from disturbances and also it would allow these disturbances to be monitored and the recovery rate. It could also allow and show changes where extant forest once occurred but has retreated due to natural changes and can allow changes to the forests extent. Unless a minimum size for the classification of forest is established the size used will continue to reduce as the technology allows pixel size to be smaller to identify areas of greater than 20 per cent canopy cover and the extant forest will continue to increase as more areas with the appropriate canopy cover are identified.

8.7. Research and development

Further research and development could improve the map of forest cover for the study area;

- Use of multi-temporal Landsat TM data i.e. data from several dates, to account for the effects of fire scars and vegetation dynamics and therefore provide an estimate of forest cover that better matches the definition of forest in terms of "*mature or **potentially** mature stand height exceeding two metres and with existing or **potential** crown cover of overstorey strata about equal to or greater than 20 per cent*".
- The number of field sites used in this study was constrained by the budget for the study and the timeframe available. The use more field sites, coupled with an increased number of strata, should improve the accuracy and reliability of the map of forest cover. Strata based on vegetation type or other landscape attributes at a finer scale than IBRA may also assist improving accuracy and reliability.
- Different spectral indices and function fitting alternatives (for example spectral unmixing) may provide improved models with increased accuracy.
- The attribution of the forest cover to forest formations is relatively coarse and could be improved by using the Memoirs of Beard (for example, Beard 1978) to improve the attribution of forest formations.

9. Conclusions

The methodology described in this project provided a sound basis for rapid and reasonably accurate mapping forest cover over a very large area, at low cost and in a short period of time. The methodology is suitable to other similar parts of Australia where the use of conventional aerial photography for mapping forest cover cannot be economically justified.

The study estimated the area of forest cover of the Midwest, Goldfield and South Coast regions of Western Australia to be 7,436,000 hectares, which is some 78 per cent less than the map of forest cover used for the 1998 State of the Forest Report. The dominant forest formations are Eucalypt Medium Woodland Forest (4,035,000 hectares), Eucalypt Low Woodland Forest (1,604,000 hectares), Other Medium Woodland Forest (810,000 hectares), Mixed Species Low Woodland Forest (460,000 hectares) and Acacia Low Woodland Forest (406,000 hectares).

Estimated area of forest cover was very sensitive to the threshold of projected foliage cover that equates to the 20 per cent crown cover threshold that defines forest. Using a 15 per cent projected foliage cover as the threshold resulted in an estimated forest cover of less than half that estimated with a 9 per cent projected foliage cover as the threshold.

The sensitivity analyses also showed that a minimum area requirement to qualify as forest has a large effect on the estimated area of forest in the study area, with up to a 29 per cent difference for one sample area between the estimate based on a 4 hectare minimum area requirement compared to the estimate based on a 0.0625 hectare area requirement.

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11. APPENDIX 1: Proforma used for recording information at field sites.

GOLDFOR VEGETATION MAPPING RECORDING FORM		
SITE NUMBER:		
SITE DESCRIPTION:		
SITE PHOTO NUMBER:		
VALIDATION OF CROWN COVER ESTIMATE FROM AERIAL PHOTO		
INITIAL ESTIMATE OF CROWN COVER:		
CROWN COVER:		
COMMENTS:		
CROWN:	INDIVIDUAL CROWN MEASUREMENTS:	MEAN:
DENSITY/OPENESS:		

LANDFORM			**SLOPE**		
SITUATION:	ELEMENT:	PATTERN:	TYPE:	SLOPE : (degrees)	ASPECT: (degrees)

SITE SKETCH/NOTES
see original hardcopy

SOILS surface only and other details if easily attained

SOURCE	RELIABILITY	HEBR CODE	ADD DATA	PPF/MU	COLOUR	TEXTURE
	HIGH MED LOW					

SURFACE

GEOLOGY outcrop only				**NVIS CLASSIFICATION**
SOURCE	RELIABILITY	HEBR CODE	MAP UNIT	STRUCTURAL FORMATION:
MAP CUTTING CORE OUTCROP	HIGH MED LOW			

LITTER: %	ROCK: %	BARE GROUND: %	CRYPTOPHYTE: %	TOTAL = 100%

GOLDFOR VEGETATION MAPPING RECORDING FORM

DISTURBANCE	AMOUNT	AGE	PRESENCE/TYPE	STRATUM	SEVERITY/SPECIES
STORM DAMAGE					
LOGGING					
RINGBARKING					
EXTENSIVE CLEARING					
GRAZING					
FERAL DIGGING					
ROADWORKS					
FIRE					
SALINITY					
WEEDS					
FLOODS					
TERMITE MOUNDS PRESENT					
WATER RUN ON SURFACE:					
EROSION:		EROSION TYPE:			

GOLDFOR VEGETATION MAPPING RECORDING FORM

SITE NUMBER:

STRUCTURAL SUMMARY identify major species in each strata

STRATUM	AVERAGE HEIGHT	KEY SPECIES	VOUCHER NUMBER
EMERGENT			
TREE 1			
TREE 2			
TREE 3			
SHRUB 1			
SHRUB 2			
GROUND:			

NFI VEGETATION CLASS:

NOTE:
Vegetation to be classified according to ecologically dominant stratum

12. APPENDIX 2: Field data collection methods

1. *Locating the site*: The sites were located using a Garmin Mark II Global Positioning unit. Waypoints of the site centre were entered into the GPS unit and the "goto" function used to take us through to the centre of the site.

2. *Site description*: A description on the location of the site was determined using distance from the road and distance from the nearest town or named geographical feature.

3. *Site photographs*: At the site centre the signboard with the site number and date was set up. The scale 'staff' was hammered into the ground at right angles. Not all the sites had the signboard in place; the board got wet and damaged and was no long useable. The 'staff' is white marked with 25 cm black increments as a scale. One or two photographs of the site, with the signboard and staff in the fore ground were taken. The direction of the photographs was chosen to be representative of the site and to include the full vegetation stratification.

4. *Crown cover*: The crown cover was assessed using a densiometer. Fifteen steps north, south, east and west from the site centre were paced out. Four densiometer readings, one north, south, east and west were taken. After each set of readings a running average cover was calculated. If the mean was fluctuating, further readings were taken at multiples of fifteen steps in a north, south, east and west direction from the centre point Once again four densiometer readings were taken at each of these points. The final cover reading was then compared to the crown cover estimate from the aerial photograph. If the actual cover varied greatly from the initial estimate, the site was assessed to establish why this was the case and notes made on the site proforma. Understorey could sometimes be incorrectly read from the aerial photograph as part of the canopy. This lead to a false cover estimate from the aerial photograph.

5. *Crown density*: The crown density was determined using the per cent scales from the Australian Soil and Land Survey Handbook: Field Handbook (2^{nd} edition). Up to seven representative estimates were taken from the crown canopy strata. Each estimate was taken from a random spot under a different individual crown. The density was then taken as an average of all the estimates.

6. *Soils and Geology*: A handful of soil, collected just below the surface, was wetted and checked for texture (shearing ability and coherence) against the Revised Standard Soil Colour Charts. The colour was assessed against the Standard Soil Colour Charts. Any exposed outcropping or rock was also noted. If the rock type was unknown a sample was collected for further assessment. Litter, rock, cryptophyte and bare ground percentage cover were estimated.

7. *Disturbance*: The site was assessed for past disturbance including logging, erosion, weeds, mining, flood and fire. Extent and age of the disturbance was noted on the proforma.

8. *Vegetation*: Each strata (Tree1, Tree2, Emergent, Shrub 1, Shub2 and Ground Cover) was assessed to determine the dominant species in each. Voucher specimen(s) were collected if the species was unknown. Other species in each strata were also noted if identification was possible and/ or the species was ecologically important. The average height was estimated using the second field person as a scale or using the estimated 'rule of thumb' method standing a fixed distance from the tree base. The crown cover and average height was then used to determine the NFI and NVIS classification. If the average Tree1 height was less than 2m and/or the cover less than 20% no classification was determined.

13. APPENDIX 3: Error matrices for all field Validation Areas based on the draft map of forest cover.

Validation Area 1			
Validation site observations	**Mapped as forest**	**Mapped as non-forest**	**Accuracy (%)**
Observed as forest	13	2	
Observed as non-forest	3	13	
Accuracy (%)	**81**	**87**	**84**
Validation Area 2			
Validation site observations	**Mapped as forest**	**Mapped as non-forest**	**Accuracy (%)**
Observed as forest	13	2	
Observed as non-forest	6	12	
Accuracy (%)	**68**	**86**	**76**
Validation Area 3			
Validation site observations	**Mapped as forest**	**Mapped as non-forest**	**Accuracy (%)**
Observed as forest	11	0	
Observed as non-forest	5	17	
Accuracy (%)	**69**	**100**	**85**
Validation Area 4			
Validation site observations	**Mapped as forest**	**Mapped as non-forest**	**Accuracy (%)**
Observed as forest	12	0	
Observed as non-forest	3	18	
Accuracy (%)	**80**	**100**	**91**
Validation Area 5			
Validation site observations	**Mapped as forest**	**Mapped as non-forest**	**Accuracy (%)**
Observed as forest	6	0	
Observed as non-forest	15	13	
Accuracy (%)	**29**	**100**	**56**
Validation Area 6			
Validation site observations	**Mapped as forest**	**Mapped as non-forest**	**Accuracy (%)**
Observed as forest	11	0	
Observed as non-forest	10	9	
Accuracy (%)	**52**	**100**	**67**
Validation Area 7			
Validation site observations	**Mapped as forest**	**Mapped as non-forest**	**Accuracy (%)**
Observed as forest	18	2	
Observed as non-forest	3	7	
Accuracy (%)	**86**	**78**	**83**
Validation Area 8			
Validation site observations	**Mapped as forest**	**Mapped as non-forest**	**Accuracy (%)**
Observed as forest	7	0	
Observed as non-forest	9	17	
Accuracy (%)	**44**	**100**	**73**
Validation Area 9			
	Mapped as forest	**Mapped as non-forest**	**Accuracy (%)**
	13	0	
Observed as non-forest	7	13	
Accuracy (%)	**65**	**100**	**79**
Validation Area 10			
Validation site observations	**Mapped as forest**	**Mapped as non-forest**	**Accuracy (%)**
Observed as forest	11	0	
Observed as non-forest	10	10	
Accuracy (%)	**52**	**100**	**68**
All Validation Areas			
Validation site observations	**Mapped as forest**	**Mapped as non-forest**	**Accuracy (%)**
Observed as forest	115	6	
Observed as non-forest	71	129	
Overall accuracy (%)	**62**	**96**	**76**

14. APPENDIX 4: Species list for vascular plant species collected during the study as part of the vegetation structural classification for each site.

The family sequence is based on Engler's phylogenetic classification of plant families. The collector's number for each specimen is included in parentheses after the species authority. The * symbol represents species which are introduced weeds. See Atkins (2001) for an explanation of the DCLM Priority flora listings (shown in the right hand column as "P" and then a number for the level).

Family	Species
Cupressaceae	*Callitris canescens* (Parl.)S.T.Blake (AER 160)
Cupressaceae	*Callitris drummondii* (Parl.)F.Muell. (AER 590)
Cupressaceae	*Callitris tuberculata* R.Baker & H.G.Smith (AER 107,119)
Poaceae	*Austrostipa ?hemipogon* (Benth.)S.W.L.Jacobs & J.Everett (AER 571)
Poaceae	*Austrostipa scabra* (Lindl.)S.W.L.Jacobs & J.Everett (AER 393)
Poaceae	*Eragrostis lanipes* C.E.Hubb. (AER 288)
Poaceae	*Monachather paradoxus* Steud. (AER 286)
Poaceae	*Triodia sp.* (AER 111,182,240,402)
Cyperaceae	*Lepidosperma* sp. A2 Island Flat (GJK 7000) (AER 214)
Cyperaceae	*Lepidosperma viscidum* R.Br. (AER 199)
Cyperaceae	*Mesomelaena pseudostygia* (Kuek.)K.L.Wilson (AER 531,545)
Ecdeiocoleaceae	*Ecdeiocolea monostachya* F.Muell. (AER 110,505,522)
Restionaceae	*Desmocladus biformis* B.G.Briggs & L.A.S.Johnson (AER 536)
Dasypogonaceae	*Lomandra effusa* (Lindl.)Ewart (AER 105,198)
Boryaceae	*Borya constricta* Churchill (AER 183)
Casuarinaceae	*Allocasuarina aff. campestris* (Diels)L.A.S.Johnson (AER 431)
Casuarinaceae	*Allocasuarina campestris* (Diels)L.A.S.Johnson (AER 114,120,128,181,272,521,543,548,588)
Casuarinaceae	*Allocasuarina corniculata* (F.Muell.)L.A.S.Johnson (AER 241)
Casuarinaceae	*Allocasuarina sp.* (AER 403)
Casuarinaceae	*Allocasuarina spinosissima* (C.A.Gardner)L.A.S.Johnson (AER 106)
Proteaceae	*Banksia attenuata* R.Br. (AER 560)
Proteaceae	*Banksia elderiana* F.Muell.& Tate (AER 112,242)
Proteaceae	*Grevillea acuaria* Benth. (AER 140)
Proteaceae	*Grevillea hookeriana* Meisn. subsp. *apiciloba* (F.Muell.)Makinson (AER 122)
Proteaceae	*Grevillea didymobotrya* Meisn. subsp. *didymobotrya* (AER 113)
Proteaceae	*Grevillea eriostachya* Lindl. (AER 118)
Proteaceae	*Grevillea stenomera* F.Muell (AER 532)
Proteaceae	*Hakea bucculenta* C.A.Gardner (AER 575)
Proteaceae	*Hakea erecta* Lamont (AER 124b,211)
Proteaceae	*Hakea lorea* (R.Br.)R.Br. subsp. *lorea* (AER 301)
Proteaceae	*Hakea orthorrhyncha* F.Muell. var. *orthorrhyncha* (AER 513)
Proteaceae	*Hakea pandanicarpa* R.Br. subsp. *crassifolia* (Meisn.)R.M.Barker (AER 563)
Proteaceae	*Hakea sp.* (AER 591)
Proteaceae	*Stirlingia latifolia* (R.Br.)Steud. (AER 544)
Santalaceae	*Exocarpos aphyllus* R.Br. (AER 170,218,347,443)
Santalaceae	*Santalum acuminatum* (R.Br.)A.DC. (AER 262)
Santalaceae	*Santalum lanceolatum* R.Br. (AER 193,300)
Chenopodiaceae	*Atriplex nummularia* Lindl. (AER 248)
Chenopodiaceae	*Atriplex nummularia* Lindl. subsp. *spathulata* Aellen (AER 227,355)
Chenopodiaceae	*Atriplex stipitata* Benth. (AER 400)
Chenopodiaceae	*Atriplex vesicaria* Benth. subsp. *appendiculata* (Benth.)Parr-Smith (AER 233,353,356,462,247)
Chenopodiaceae	*Atriplex vesicaria* Benth. (AER 136)
Chenopodiaceae	*Chenopodium sp.* (AER 528)
Chenopodiaceae	*Halosarcia halocnemoides* (Nees)Paul G.Wilson subsp. *catenulata* Paul G.Wilson (AER 439)
Chenopodiaceae	*Halosarcia lepidosperma* Paul G.Wilson (AER 229)

Chenopodiaceae	*Maireana diffusa* Paul G.Wilson (AER 556)
Chenopodiaceae	*Maireana erioclada* (Benth.)Paul G.Wilson (AER 351)
Family	**Species**
Chenopodiaceae	*Maireana pyramidata* (Benth.)Paul G.Wilson (AER 411)
Chenopodiaceae	*Maireana triptera* (Benth.)Paul G.Wilson (AER 257,392)
Chenopodiaceae	*Rhagodia ulicina* (Gand.)Paul G.Wilson (AER 438,553)
Chenopodiaceae	*Sclerolaena diacantha* (Nees)Benth. (AER 557)
Amaranthaceae	*Ptilotus obovatus* (Gaudich.)F.Muell. var. *obovatus* (AER 266,278,280,293,399,407,417)
Pittosporaceae	*Cheiranthera preissiana* Turcz. var. *preissiana* (AER 540)
Mimosaceae	*Acacia acuminata* Benth. (AER 460,554,557,502)
Mimosaceae	*Acacia acuminata*(narrow phyllode variant) Maslin ms (AER 101,141,146,174,395)
Mimosaceae	*Acacia aneura* Benth. (AER 299)
Mimosaceae	*Acacia blakelyi* Maiden (AER 518)
Mimosaceae	*Acacia burkittii* Benth. (AER 315)
Mimosaceae	*Acacia colletioides* Benth. (AER 143,169,221,237,504)
Mimosaceae	*Acacia coolgardiensis* Maiden subsp. *effusa* R.S.Cowan & Maslin (AER 297,310,311,316,414,430,445,456,457)
Mimosaceae	*Acacia ?coolgardiensis* Maiden subsp. *effusa* R.S.Cowan & Maslin (AER 406, 427)
Mimosaceae	*Acacia erinacea* Benth. (AER 155,427,466)
Mimosaceae	*Acacia hemiteles* Benth. (AER 167,260,274,391,426,458)
Mimosaceae	*Acacia jennerae* Maiden (AER 104,135,223,450,578)
Mimosaceae	*Acacia leptospermoides* Benth. subsp. *leptospermoides* (AER 524,576)
Mimosaceae	*Acacia ligulata* Benth. (AER 526)
Mimosaceae	*Acacia merrallii* F.Muell. (AER 190,195,212,236,344,390)
Mimosaceae	*Acacia neurophylla* W.Fitzg. subsp. *erugata* R.S.Cowan & Maslin (AER 549)
Mimosaceae	*Acacia resinosa* R.S.Cowan & Maslin (AER 282)
Mimosaceae	*Acacia rhodophloia* Maslin (AER 290,408,412,429)
Mimosaceae	*Acacia ?rhodophloia* Maslin (AER 283)
Mimosaceae	*Acacia ?rigens* G.Don (AER 437)
Mimosaceae	*Acacia sp.* (AER 103,129,313,463,512)
Mimosaceae	*Acacia stowardii* Maiden (AER 273,308,416,464)
Mimosaceae	*Acacia ?stowardii* Maiden (AER 302)
Mimosaceae	*Acacia tetragonophylla* F.Muell. (AER 291,296,421,447)
Mimosaceae	*Acacia verricula* R.S.Cowan & Maslin (AER 448)
Caesalpiniaceae	
Papilionaceae	*Bossiaea walkeri* F.Muell. (AER 153, 343)
Papilionaceae	*Gastrolobium tetragonophyllum (E.Pritz.)Crisp* (AER 585)
Papilionaceae	*Pultenaea elachista* (F.Muell.)Crisp (AER 329)
Papilionaceae	*Templetonia retusa* (Vent.)R.Br. (AER 327)
Zygophyllaceae	*Zygophyllum ovatum* Ewart & Jean White (AER 358)
Rutaceae	*Microcybe multiflora* Turcz. subsp. *multiflora* (AER 154,201)
Rutaceae	*Phebalium canaliculatum* (F.Muell.& Tate)J.H.Willis (AER 452)
Euphorbiaceae	*Beyeria brevifolia* (Muell.Arg.)Benth. var. *brevifolia* (AER 158)
Euphorbiaceae	*Beyeria lechenaultii* (DC.)Baill. var. *drummondii* (Muell.Arg.(Gruning) (AER 130)
Anacardiaceae	* *Schinus molle* L. (AER 306)
Sapindaceae	*Dodonaea amblyophylla* Diels (AER 552)
Sapindaceae	*Dodonaea inaequifolia* Turcz. (AER 541)
Sapindaceae	*Dodonaea microzyga* F.Muell. var. *acrolobata* J.G.West (AER 376)
Sapindaceae	*Dodonaea pinifolia* Miq. (AER 294, 442)
Sapindaceae	*Dodonaea stenozyga* F.Muell. (AER 328)
Sapindaceae	*Dodonaea viscosa* Jacq. subsp. *angustissima* (DC.)J.G.West (AER 405,569)
Rhamnaceae	*Stenanthemum stipulosum* Rye (AER 216)
Malvaceae	*Sida* sp. Unisexual (NH Speck 574) (AER 418)
Sterculiaceae	*Brachychiton gregorii* F.Muell. (AER 295)
Sterculiaceae	*Lasiopetalum angustifolium* W.Fitzg. (AER 538)
Frankeniaceae	*Frankenia fecunda* Summerh. (AER 234)
Frankeniaceae	*Frankenia sp. (AER 285)*
Thymelaeaceae	*Pimelea gilgiana* E.Pritz. (AER 535)

Myrtaceae	*Balaustion pulcherrimum* Hook. (AER 117)
Myrtaceae	*Beaufortia ?interstans* F.Muell. (AER 564)
Family	**Species**
Myrtaceae	*Callistemon phoeniceus* Lindl. (AER 593)
Myrtaceae	*Calothamnus formosus* Hawkeswood subsp. *rigidus* Hawkeswood (AER 510)
Myrtaceae	*Eremaea pauciflora* (Endl.)Druce var. *pauciflora* (AER 121)
Myrtaceae	*Eucalyptus calycogona* Turcz. subsp. *calycogona* (AER 138,377)
Myrtaceae	*Eucalyptus celastroides* Turcz. subsp. *celastroides* (AER 249,264)
Myrtaceae	*Eucalyptus celastroides* Turcz. subsp. *virella* Brooker (AER 387)
Myrtaceae	*Eucalyptus clelandii* (Maiden)Maiden (AER 436)
Myrtaceae	*Eucalyptus cooperiana* F.Muell. (AER 332)
Myrtaceae	*Eucalyptus cyclostoma* Brooker (AER 362,364,365)
Myrtaceae	*Eucalyptus diptera* C.R.P.Andrews (AER 238b)
Myrtaceae	*Eucalyptus dundasii* Maiden (AER 225)
Myrtaceae	*Eucalyptus ebbanoensis* Maiden subsp. e*bbanoensis* (AER 465)
Myrtaceae	*Eucalyptus effusa* Brooker subsp. *effusa* (AER 200,255,354)
Myrtaceae	*Eucalyptus eremicola* Boomsma (AER 187,276,337,340,457,466,359)
Myrtaceae	*Eucalyptus eremophila* (Diels)Maiden subsp. *eremophila (*AER 126,156,206,359,586,583)
Myrtaceae	*Eucalyptus erythrocorys* F.Muell. (AER 529)
Myrtaceae	*Eucalyptus ewartiana* Maiden (AER 454)
Myrtaceae	*Eucalyptus exigua* Brooker & Hopper (AER 197)
Myrtaceae	*Eucalyptus flocktoniae* (Maiden)Maiden (AER 150,384,533)
Myrtaceae	*Eucalyptus flocktoniae* (Maiden)Maiden subsp. *flocktoniae* (AER 570)
Myrtaceae	*Eucalyptus gracilis* F.Muell. (AER 317,341,348)
Myrtaceae	*Eucalyptus grasbyi* Maiden & Blakely (AER 401,435)
Myrtaceae	*Eucalyptus griffithsii* Maiden (AER 191,259,394,469)
Myrtaceae	*Eucalyptus horistes* L.A.S.Johnson & K.D.Hill (AER 159)
Myrtaceae	*Eucalyptus hypolaena* L.A.S.Johnson & K.D.Hill (AER 363)
Myrtaceae	*Eucalyptus incrassata* Labill. (AER 559)
Myrtaceae	*Eucalyptus leptopoda* Benth. (AER 281)
Myrtaceae	*Eucalyptus lesouefii* Maiden (AER 243)
Myrtaceae	*Eucalyptus longicornis* (F.Muell.)Maiden (AER 163,168,271,349,379,397,421)
Myrtaceae	*Eucalyptus loxophleba* Benth. subsp. *lissophloia* L.A.S.Johnson & K.D.Hill (AER 215,508)
Myrtaceae	*Eucalyptus loxophleba* Benth. subsp. *loxophleba (AER 539)*
Myrtaceae	*Eucalyptus loxophleba* Benth. subsp. *supralaevis* L.A.S.Johnson & K.D.Hill (AER 550,555)
Myrtaceae	*Eucalyptus loxophleba ssp.? (AER 555)*
Myrtaceae	*Eucalyptus melanoxylon* Maiden (AER 354)
Myrtaceae	*Eucalyptus obtusiflora* DC. (AER 527,554)
Myrtaceae	*Eucalyptus oleosa* Miq. (AER 269)
Myrtaceae	*Eucalyptus oleosa* Miq. subsp. *oleosa* (AER 312)
Myrtaceae	*Eucalyptus pileata* Blakely (AER 145,573)
Myrtaceae	*Eucalyptus platypus* Hook. subsp. *congregata* Brooker & Hopper (AER 558)
Myrtaceae	*Eucalyptus platypus* Hook. subsp. *platypus* (AER 359)
Myrtaceae	*Eucalyptus pleurocarpa* Schauer (AER 519,562)
Myrtaceae	*Eucalyptus quadrans* Brooker & Hopper (AER 331,332)
Myrtaceae	*Eucalyptus ravida* L.A.S.Johnson & K.D.Hill (AER 184)
Myrtaceae	*Eucalyptus salmonophloia* F.Muell. (AER 175,276,307)
Myrtaceae	*Eucalyptus salubris* F.Muell. (AER 140)
Myrtaceae	*Eucalyptus sheathiana* Maiden (AER 196, 378,380)
Myrtaceae	*Eucalyptus sp.* (AER 321,378,501)
Myrtaceae	*Eucalyptus spreta* L.A.S.Johnson & K.D.Hill (AER 370,373)
Myrtaceae	*Eucalyptus transcontinentalis* Maiden (AER 132)
Myrtaceae	*Eucalyptus yalatensis* Boomsma (AER 320,333,336)
Myrtaceae	*Eucalyptus yilgarnensis* (Maiden)Brooker (AER 142,171,177,220,253,326,383)
Myrtaceae	*Eucalyptus youngiana* F.Muell. (AER 298)
Myrtaceae	*Leptospermum erubescens* Schauer (AER 589)
Myrtaceae	*Melaleuca torquata* Barlow (AER 568)
Myrtaceae	*Melaleuca acuminata* F.Muell. subsp. *acuminata* (AER 185,587)

Myrtaceae	*Melaleuca brophyi* Craven (AER 507,561)
Myrtaceae	*Melaleuca cardiophylla* F.Muell. (AER 537)
Family	**Species**
Myrtaceae	*Melaleuca coccinea* A.S.George (AER 210)
Myrtaceae	*Melaleuca cordata* Turcz. (AER 109)
Myrtaceae	*Melaleuca cucullata* Turcz. (AER 566)
Myrtaceae	*Melaleuca eleuterostachya* F.Muell. (AER 366,503)
Myrtaceae	*Melaleuca halmaturorum* Miq. (AER 592)
Myrtaceae	*Melaleuca lecanantha* Barlow (AER 324)
Myrtaceae	*Melaleuca nematophylla* F.Muell. (AER 546)
Myrtaceae	*Melaleuca pauperiflora* F.Muell. subsp. *fastigiata* Barlow (AER 100)
Myrtaceae	*Melaleuca quadrifaria* F.Muell. (AER 342,371)
Myrtaceae	*Melaleuca sapientes* Craven (AER 207)
Myrtaceae	*Melaleuca sheathiana* W.Fitzg. (AER 165,192,205,217,382)
Myrtaceae	*Melaleuca sp.* (AER 124,322,520,530,534)
Myrtaceae	*Melaleuca strobophylla* Barlow (AER 325,334)
Myrtaceae	*Melaleuca teuthidoides* Barlow (AER 133,1551,157,164,176,204)
Myrtaceae	*Melaleuca uncinata* R.Br. (AER 161,180,182,209,213,239,516,584)
Myrtaceae	*Micromyrtus obovata* (Turcz.)J.W.Green (AER 115)
Myrtaceae	*Thryptomene baeckeacea* F.Muell. (AER 453)
Myrtaceae	*Thryptomene kochii* E.Pritz. (AER 162)
Myrtaceae	*Thryptomene sp.* (AER 131,506,525)
Myrtaceae	*Thryptomene strongylophylla* Benth. (AER 517)
Myrtaceae	*Verticordia sp. (AER 582)*
Epacridaceae	*Leucopogon hamulosus* E.Pritz. (AER 125)
Apocynaceae	*Alyxia buxifolia* R.Br. (AER 172,238a,267)
Convolvulaceae	*Wilsonia humilis* R.Br. (AER 224,372)
Lamiaceae	*Pityrodia sp. (AER 226)*
Lamiaceae	*Westringia rigida* R.Br. (AER 232)
Lamiaceae	*Westringia sp.* (AER 319)
Solanaceae	*Solanum lasiophyllum* Poir. (AER 279,422)
Solanaceae	*Solanum orbiculatum* Poir. subsp. *orbiculatum* (AER 509)
Myoporaceae	*Diocirea acutifolia* Chinnock ms (AER 166)
Myoporaceae	*Eremophila caerulea* (S.Moore)Diels subsp. *caerulea* ms (AER 189,194)
Myoporaceae	*Eremophila caperata* Chinnock ms (AER 449)
Myoporaceae	*Eremophila clavata* Chinnock ms (AER 202)
Myoporaceae	*Eremophila compacta* S.Moore subsp. c*ompacta* (AER 284)
Myoporaceae	*Eremophila dempsteri* F.Muell. (AER 152,182b,222,230,231,318,350,360,388,404,461,357)
Myoporaceae	*Eremophila forrestii* F.Muell. subsp. *forrestii* ms (AER 309,446)
Myoporaceae	*Eremophila interstans* (S.Moore)Diels subsp. *virgata* (W.Fitzg.)Chinnock ms (AER 246)
Myoporaceae	*Eremophila miniata* C.A.Gardner (AER 440)
Myoporaceae	*Eremophila oppositifolia* R.Br. subsp. *angustifolia* (S.Moore)Chinnock (AER 265)
Myoporaceae	*Eremophila rugosa* Chinnock ms (AER 258)
Myoporaceae	*Eremophila scoparia* (R.Br.)F.Muell. (AER 270,432)
Myoporaceae	*Eremophila serrulata* (A.DC.)Druce (AER 413)
Myoporaceae	*Eremophila sp.* (AER 256,261,292,304,381,414,416,467)
Myoporaceae	*Myoporum acuminatum* R.Br. (AER 373)
Myoporaceae	*Eremophila ?glandulifera* Chinnock ms (AER 303)
Goodeniaceae	*Scaevola spinescens* R.Br. (AER 179,219,235,251,275,396,420,441)
Asteraceae	*Cratystylis conocephala* (F.Muell.)S.Moore (AER 178)
Asteraceae	*Cratystylis subspinescens* S.Moore (AER 410)
Asteraceae	*Olearia calcarea* Benth. (AER 139)
Asteraceae	*Olearia dampieri* (DC.)Lander subsp. dampieri ms (AER 523)
Asteraceae	*Olearia exiguifolia* (F.Muell.)Benth. (AER 346)
Asteraceae	*Olearia incana* (D.A.Cooke)Lander ms (AER 244,345,352,361,369,374,389,434)
Asteraceae	*Olearia minor* (Benth.)Lander (AER 144,173)
Asteraceae	*Olearia muelleri* (Sond.)Benth. (AER 323,338,375,386)