REVIEW AND INTEGRATION

OF FLORISTIC CLASSIFICATIONS

IN THE SOUTH-WEST FOREST REGION

OF WESTERN AUSTRALIA

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EXECUTIVE SUMMARY

Mattiske Consulting Pty Ltd was commissioned by the Australian Nature Conservation Agency to review and integrate the floristic classifications in the South-West Forest Region of Western Australia.

This project has enabled a review of the main data bases available for vegetation classifications in the South-West Forest Region of Western Australia. The authors have attempted to integrate the previous vegetation classification systems and have proposed a methodology for the second phase of this project associated with defining the vegetation at a range of scales in the South-West Forest Region of Western Australia. The key basis to this methodology is the linkages between the geology, geomorphology, soils and landforms and climatic factors as underlying causal determinants of the resulting native vegetation cover in the South-West Forest Region. Havel and Mattiske have developed the relationships between the factors to design a vegetation classification system that integrates all the previous relevant vegetation classification systems and vegetation mapping studies in the region. This conceptual model of relationships will require field testing and data analysis in the vegetation mapping phase of the regional forest assessment process.

Background Data Review

Prior to reviewing the available data on vegetation there was a need to review the historical information known on the vegetation in the South-West Forest Region. This report has attempted to review the critical studies that may be relevant to the vegetation classification and vegetation mapping projects. In undertaking this review it has become evident that a range of other data sets are critical for the vegetation mapping project. Evidence is presented to support the concept that the vegetation reflects the underlying geology, landforms, soils and climate. These relationships were observed and recorded by people from the early days of European settlement through the settler's selection of dominant species in determining fertile soils and moister soils. In recent decades, the scientists have confirmed many of these relationships in different areas of the South-West Forest Region; although only in a few instances have the spatial relationships between vegetation and underlying causative factors been mapped.

Vegetation Data Review

A review of the historical vegetation data has been undertaken to identify the major gaps for the proposed mapping exercise. Additional data collection was not undertaken during this phase of the project, however the gaps have been defined prior to the vegetation mapping project.

Two main types of gaps occur in the data sets, namely:

- The first gap relates to the deficiencies in the spatial spread of the data sets. The areas which require intensive sampling include the partially cleared area between Busselton and Augusta, the Blackwood Plateau (or Donnybrook Sunklands) and some of the cleared areas east of Manjimup (Tone River area).

- The second gap relates to areas which have already been covered but which require infill sampling. Examples of these areas include the central forest areas from Collie to Nannup and in the south-eastern forests where the previous studies covered restricted areas.

The level of vegetation data is high in large sections of the South-West Forest Region, although the majority of the data has been collected for the development of floristic or vegetation classification systems rather than for vegetation mapping. Potential specific site data exceeds 30,000 locations;

however large sections of this data are the property of various stack holders such as mining companies and scientific researchers. Negotiation for access to some of this data will require further work in the vegetation mapping project.

Previous vegetation maps have been produced at a scale of 1:1,000,000 (Beard 1981); 1:250,000 (Beard 1979a, 1979b and 1979c; Smith 1972, 1973 and 1974; Heddle *et al.* 1980), 1:50,000 (Heddle *et al.* 1980 - base maps for published 1:250,000 maps) and 1:10,000 (Mattiske through E.M. Mattiske and Associates and Mattiske Consulting Pty Ltd for various client projects in the South-West Forest Region).

Although the level of data is high there is an uneven spread of the data and this will require rationalisation in the second phase of the vegetation studies associated with the Regional Forest Agreement. Field sampling will be based on:

- The underlying climatic zones, as determined by the interpretation of Gentilli and verification by BIOCLIM data.

- The underlying soil and landform maps for the region (where available, the authors recognise that complete coverage is intended through another related project). If time permits and the areas are relatively undisturbed (not cleared and not severely degraded by grazing and urbanization), sampling will be based on a minimum of two (10m x 10m) sites per soil and landform mapping units.

- The extent of the previous detailed site recordings (point data which may include data from other authors studies, permanent plot data and data collected by Mattiske for various clients). This coverage will be audited internally using the DAM tool kit supplied.

Further details of the proposed methodologies are summarised in the following text. If time permits the data collection will be undertaken at three levels, namely:

- establishment of permanent Vegetation Plots (recording all species present and their respective height and percentage foliage cover in a 10m x 10m plot),

- recordings along transects to review relationships of previous soil, landform and vegetation relationships as defined by previous authors in the South-West Forest Region, and

- observations will be carried out along roads and tracks to check boundaries of the vegetation mapping units against underlying landform and soil mapping units.

Proposed Vegetation Mapping Methodology

The proposed methodology for the vegetation mapping is summarised in the following text. All data sets will be defined in terms of types of data, currency of data, availability of data, format of data and quality of data. A reliability index has been developed for both the data sets and the standard of vegetation mapping.

A conceptual model of five layers of interaction have been proposed to define the relationships between the different vegetation classification systems. These layers were tested by reference to the more intensively studied and mapped northern jarrah forest. The preliminary design work for the southern and central areas indicates that the approach holds validity there also, as the key determining factors are reflected in the resultant vegetation. For example, many of the indicators defined in the lowest layer can be utilised on similar environments irrespective of their geographical location.

There were marked differences in the vegetation classification systems, which was at times accentuated by their respective methodologies. Despite differences in data analyses it has been possible to integrate the detailed work of Havel (1968, 1975a, 1975b), Strelein (1988), McCutcheon (1978 and 1980), Inions *et al.* (1989, 1990a, 1990b), Wardell-Johnson *et al.* (1989) and E.M. Mattiske and Associates and Mattiske Consulting Pty Ltd (1979 - 1996) into an edaphic net, covering the range of climatic zones as developed from the work of Gentilli (1989). This edaphic net with linkages to the site-vegetation types and vegetation mapping units will require further testing and validation during the vegetation mapping project. In view of the degree of complexity this report has concentrated on the northern jarrah forest examples, but the design phase for the various regions, has also been commenced.

On the basis of the example cited for the northern jarrah forest it is possible to link the five layers from the groupings of indicator species developed by Havel (1975a) through to the broad structural formations as utilised by Beard (1979a, 1979b and 1979c) and Smith (1972, 1973 and 1974). This five layer conceptual model is based on the underlying determining landforms, soils and climate which determine the resultant vegetation.

During the vegetation mapping project there will be a need to integrate the following data sets:

- the digital BIOCLIM data from ERIN for the South-West Forest Region (available now),
- the digital data for the soil and landform mapping units (various authors being re-mapped and integrated by Agriculture Western Australia) (draft available now for the vast majority of the project area),
- the topographical and drainage data for the South-West Forest Region (Department of Land Administration) (available now),
- the base cadastral, roads and ownership data for the South-West Forest Region (Department of Conservation and Land Management) (available now),
- the clearing data sets held by the Department of Conservation and Land Management (available now, although being updated),
- the data for the various vegetation classification systems developed in the South-West Forest Region (in various data formats now for some projects; others will need negotiation with owners and authors of datasets),
- the previous vegetation mapping data for the System 6 areas (Heddle *et al.* 1980),
- the new polygon and point data sets collected for the vegetation mapping project (available now; although needs digitising for 1:50,000 scale interpretation), and
- the new additional data sets collected during the proposed field work program.

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1. INTRODUCTION

1.1 Objectives

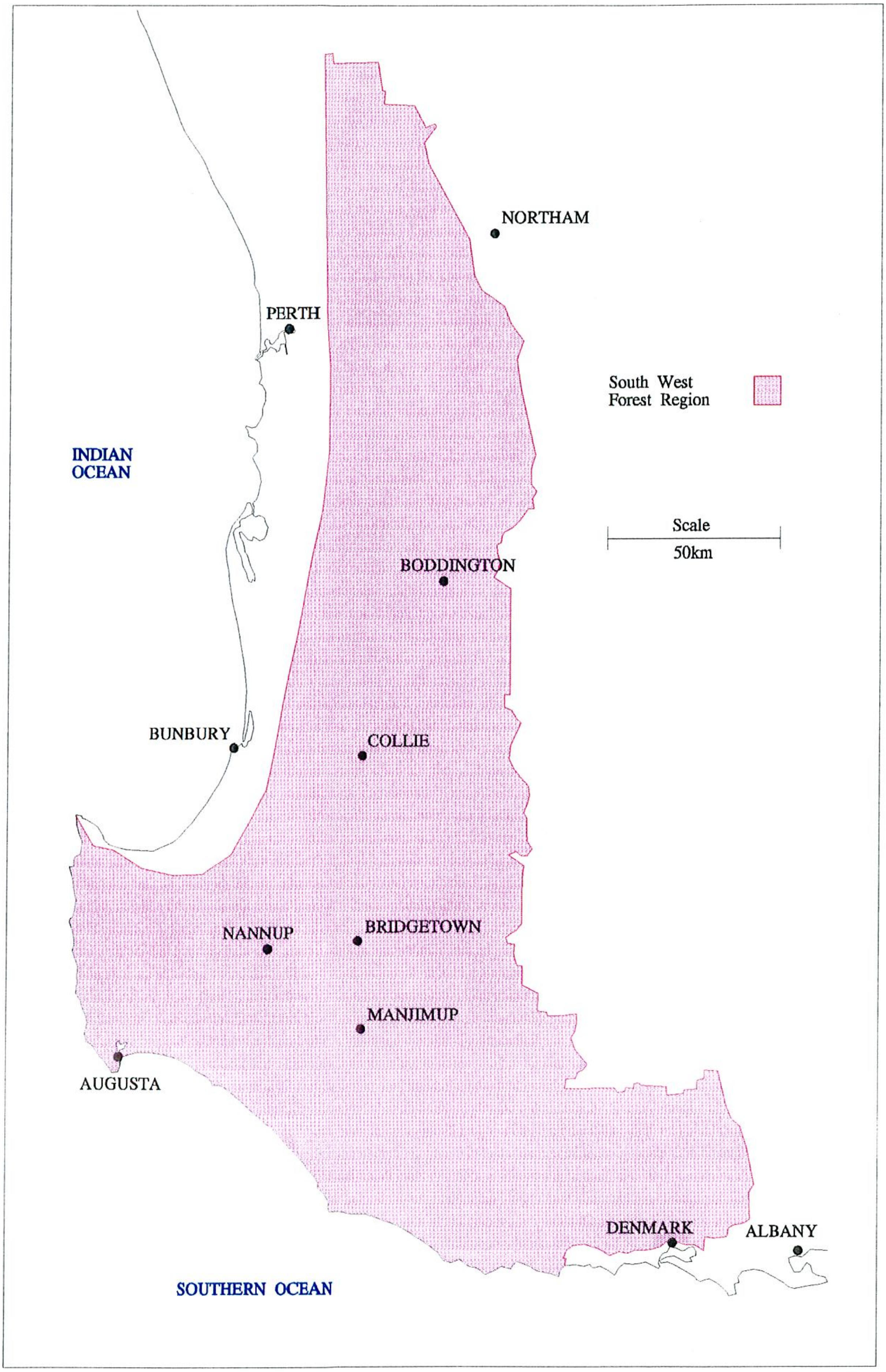
The main objectives of this project were:

- to review the floristic and vegetation classification systems within the South-West Forest Region of Western Australia, defined as the Regional Forest Agreement area by the joint agreement between the Commonwealth agencies and the Western Australian Government (Figure 1),
- to integrate the available data on the floristic classifications in the South-West Forest Region of Western Australia,
- to identify the data-bases that will be required for the vegetation mapping project, and
- to prepare a report summarising the findings.

1.2 Work Programme

The work for this project was considered to fall into the following main phases (Table 1):

- Liaison and Communication with researchers.
- Review the Data and Literature
- Review and Formulate Proposed Methodologies for Data Collection and Vegetation Mapping.
- Preparation of a report summarising the findings.



LOCATION OF SOUTH WEST FOREST REGION OF WESTERN AUSTRALIA

FIGURE 1

Table 1: Work Plan for Review of Floristic Classifications and Integrate Historical Classifications for the South-West Forest Region

Objective 1: Liaison and Communication with Researchers	
Strategy No.	**Strategy**
1a	Contact all key researchers and request information on published and unpublished information (both with Government and Private Industry).
1b	Contact any further personnel or publications/reports that have been highlighted during the initial contact with key researchers.
1c	Hold technical meetings with key personnel in CALM and the Commonwealth.
1d	Visit Eastern States to review metadata structures and previous CRA assessment data to optimise and facilitate the Western Australian process.

Table 1: Work Plan for Review of Floristic Classifications and Integrate Historical Classifications for the South-West Forest Region (continued)

Objective 2: Review of Data and Literature	
Strategy No.	**Strategy**
2a	Arrange for copies of all relevant publications (published and unpublished) to be centrally located to assist in the review.
2b	Review (including assessment of the scope of the studies, methodologies, applicability of methods to the south-west region) all local published and unpublished documents.
2c	Compare these local publications with the national and international publications on floristic classifications and vegetation mapping systems.
2d	Document the methodologies used previously in the south-west forest region, including a review of existing classifications.
2e	Document the datasets using ANZLIC core metadata as well as a statement of scale, list of attributes and definitions of each attribute.
2f	Merge datasets into one database.
2g	Review the methodologies in a local, national and international context.
2h	Review the adequacy of the datasets for the proposed CRA assessments and define additional needs for data (definition of gaps, field survey work, digital capture of current data), including priorities for field sampling.
2i	Review the relevance of the previous extensive site-vegetation type mapping (1:10,000) and the vegetation complex mapping (1:50,000 and 1:250,000) in the System 6 area (a third of the project area) with techniques used in other States and Internationally.

Table 1: Work Plan for Review of Floristic Classifications and Integrate Historical Classifications for the South-West Forest Region (continued)

Objective 3: Review and Formulation of Proposed Methodologies	
Strategy No.	**Strategy**
3a	Prepare advice on the suitability of different methodologies for the proposed mapping of vegetation complexes for the CRA assessments, using agreed systematic and transparent criteria. . proposed methodology for site selection (previous inadequacy of data set, data coverage etc.), site sampling (floristics, geology, landforms, soils, climatic conditions, structure, slope, aspect etc.), types of sampling regimes (size of sampling location and regularity) and attributes to be collected and data evaluation methods. . proposed methodology for detailed "site-vegetation type" or ecosystem mapping and the relationships with the higher order vegetation complexes, soil and landform mapping and other environmental factors defined. . proposed methodology for defining boundaries on the site-vegetation mapping and vegetation complex mapping. . prepare the reliability indices on the mapping standards.
3b	Prepare advice on the suitability of different methodologies for the proposed linking of vegetation mapping units at 1:100,000 (e.g. East Gippsland - ecological vegetation classes).
3c	As required review the adequacy of current software and computer systems for digitising, data base management and data analysis required for the CRA assessment.
3d	Design and develop database formats jointly with the Commonwealth and CALM.

Table 1: Work Plan for Review of Floristic Classifications and Integrate Historical Classifications for the South-West Forest Region (continued)

Objective 4: Reporting	
Strategy No.	**Strategy**
4a	Prepare a detailed report which: . reviews existing data sets (site specific and polygon datasets), . outlines the methodologies used in evaluating these datasets, . recommends methods for mapping the planned vegetation at the site-vegetation type (1:10,000 in selected and specific areas to validate relationships between vegetation and environmental factors), vegetation complexes (1:50,000 over the entire project area) and the equivalent of the ecological vegetation systems (1:100,000 which will be reduced to 1:250,000). . provides examples of the potential data sets and the relationships of data required for the CRA assessment project.

2. REVIEW OF DATA AND LITERATURE

The early settlers recognised the relationships between some of the dominant trees and the underlying site conditions as there was substantial selective clearing on the more fertile soils which supported yarri (*Eucalyptus patens*) or York gum (*Eucalyptus loxophleba*) and little clearance of jarrah which occurred on the poorer infertile gravelly soils. Subsequent work by the early foresters broadly utilised the more distinctive relationships in assessing land use options and environmental impacts.

2.1 Early Floristic Mapping

Gentilli (1979a and 1979b) summarised and reviewed the early floristic maps. The first floristic map was produced by C.Woodhouse in the Surveyor-General's Office in 1880. This map (at a scale of 1:1,170,000) covered the forest areas within the State and was the first attempt to define forests in the area from Moore River to Pallinup River. This map distinguished the six dominant tree species - jarrah *(Eucalyptus marginata)*, karri (*Eucalyptus diversicolor*), 'white gum' (wandoo, *Eucalyptus wandoo*), 'tooart' (tuart, *Eucalyptus gomphocephala*), York Gum (*Eucalyptus loxophleba*) and 'red gum' (marri, *Eucalyptus calophylla*). This early work illustrated the distribution of the dominant tree species in the South-West Forest Region of Western Australia.

This early work was followed by a series of successive floristic maps which illustrated the broader floristic regions within the State (Drude 1884, Sievers 1895). This earlier tradition of floristic maps of dominant forest species was continued by Moore (Ednie-Brown 1896, 1899), Lane-Poole (1920) and latter by Hall *et al.* (1970), Chippendale (1973) and Brooker and Kleinig (1990). In recent years substantial taxonomic studies have led to revisions of many of the species which dominate the South-West Forest Region including the subdivision of Jarrah(*Eucalyptus marginata*) into three subspecies (Brooker and Hopper 1993) and wandoo (*Eucalyptus wandoo*) into 4 species and 6 species and or subspecies (Brooker and Hopper 1991).

Additional information extracted by Gentilli (1979a and 1979b) refers to the intercontinental distributions of species, such as *Podocarpus* (Bader 1960) which may reflect past geological and climatic changes. Therefore there is a distinct value in these individual species floristic maps to illustrate paleofloristics in the south-west region of Western Australia.

2.2 Early Vegetation Mapping

An early attempt at vegetation mapping was undertaken by Schimper (1898) who highlighted the first attempt to show sclerophyllous woods in the South-West region of the State. Shortly after Diels (1906a and 1906b) produced the first structural map of Australian vegetation.

2.3 Diels 1906a and 1906b

The botanical collections and descriptions in southwestern Australia date back to colonization in the 1830 (Drummond), the first major attempt to classify and map the vegetation was that of Diels (1906a and 1906b) in his classic Die Pflanzenwelt von West Australien sudlich des Wendeskreises - The Plant World of Western Australia South of the Tropic.

The work of Diels was ambitious as it was undertaken at a time when transport was limiting, and perceptive as it defined relationships between the vegetation and the underlying environmental factors, especially climate and soils. The key perception was that the vegetation of the South-West has no counterpart in Mediterranean regions elsewhere in the world, in particular the presence of tall trees with vertical leaves, the strong development of hard-leaved shrubby understorey and the replacement of the grasses and annuals by perennial herbs of the families Cyperaceae and Restionaceae. He also identified the great floristic richness of the vegetation in spite of, or perhaps because of, the extreme infertility of the sandy and gravelly soils.

Turning specifically to the jarrah(*Eucalyptus marginata*) forest, Diels delineated it by the 750 mm isohyet. He recognised that edaphically favourable sites compensate for lower rainfall in the most easterly extension of the species. Jarrah is associated with gravelly uplands, but its extension on to the sandy coastal plain, with a corresponding reduction in structure from tall forest to woodland, was recognised. Among the outstanding features of the forest, Diels lists its grey, dull appearance, except in valleys; the purity of its overstorey that, apart from marri (*Eucalyptus calophylla*), no species enters into; the uniformity of the small-tree understorey, restricted to eucalypt regeneration and a few Proteaceous species; and the diversity of the shrubby ground vegetation, which contrasts so strongly with the floristic paucity of the tree strata.

In dealing with individual tree species, he associated marri (*Eucalyptus calophylla*) with moist, fertile sites, sheoak (*Casuarina fraseriana* - now *Allocasuarina fraseriana*) with sandy soils, *Banksia grandis* with gravelly uplands, *Melaleuca preissiana* and *Banksia littoralis* with swamps, and *Banksia attenuata* and *Banksia menziesii* with deep sands. Of the eastern species, wandoo (*Eucalyptus wandoo*) was considered to be restricted to heavy-textured soils underlain by clay, alternately wet in winter and dry in summer, and *Casuarina huegeliana* (now *Allocasuarina huegeliana*) to granite outcrops. These were rather generalized conclusions, which could be made readily by anyone acquainted with the forest. Nevertheless, they were virtually overlooked in subsequent years. Even more surprising was his perception of the distribution patterns of the smaller perennials. He associated the genera *Petrophile* and *Isopogon* with sandy gravels, *Gastrolobium* with dry gravels, and *Viminaria*, *Cladium* (syn. *Baumea*), *Boronia*, *Astartea* and *Agonis* with swamps. Of the families, he considered Epacridaceae to be most restricted by external conditions, but relatively poorly developed in the moister south; Myrtaceae to be bimodal, with strongest occurrence in swamps and sands; Restionaceae to be largely restricted to swamps; and Orchidaceae to be controlled more by fire than by edaphic conditions.

In dealing with structure, Diels emphasized epharmonic convergence, which he described as the possession of similar leaf types and forms of branching by widely different taxonomic units growing under similar environmental conditions.

Another of his remarkable perceptions was the recognition of a north-south trend in species distribution, as well as the more obvious east-west one. He considered that the optimum of the jarrah forest occurred in the middle Blackwood Valley. *Acacia nigricans*, *Hypocalymma cordifolium*, *Pteridium aquilinum* (now *Pteridium esculentum*), *Adiantum aethiopicum* and *Trymalium billarderii* (now *Trymalium floribundum*) were listed as the under-growth associates of jarrah on optimum sites.

In the wandoo woodland east of the jarrah forest, he considered the undergrowth to be a depauperate version of the jarrah undergrowth, more xerophytic in nature. He named *Mirbelia spinosa*, *Gastrolobium obovatum* (now *Gastrolobium calycinum*?), *Hakea lissocarpha* and

Hakea marginata as the main shrub species, and referred to the occurrence there of the herbaceous "everlastings" of the family Asteraceae, in particular *Helipterum manglesii, Helipterum cotula, Millotia tenuifolia* and *Waitzia acuminata*.

Apart from the forest formations, Diels also described swamp and granitic rock formations, giving a brief enumeration of species for each.

As a plant geographer, Diels was interested in endemism, which has considerable bearing on the detection of plant indicators. He considered the jarrah forest to be relatively poor in endemics amongst its 875 species, with the endemism at a maximum near its northern limit, where the climatic gradient is steepest. For the South-West province as a whole, he listed *Lyginia, Anarthria, Dasypogon, Kingia, Phlebocarya, Conostylis, Synaphea* and *Nuytsia* as first-class endemics, that is without any relations outside, and *Loxocarya, Diplolaena, Platytheca, Tremandra, Hypocalymma, Calothamnus* and *Andersonia* as second-class endemics, that is with some relations outside but markedly different from them.

Finally, Diels subdivided the south-west province into seven botanical districts. The survey area falls chiefly into the eastern upland portion of the Darling District, described as gravelly, hilly country within the 600 to 1000 mm rainfall zone, also containing some swampy alluvium and sands. Jarrah is used as the character species. The north-east portion of the area falls into Diels' Avon District, and the south-east portion into the Stirling District.

2.4 Other Early Vegetation Mapping

Several authors contributed to the vegetation mapping in the period from 1906 to 1940, although these studies were relatively minor for interpretations in the south-west region. Hardy (1911) defined the forest areas as "winter rain forest" which recognised the potential role of climate conditions in determining forest boundaries.

Gardner's (1923) description was no more than a brief summary of Diels' work; which culminated in a vegetation map in 1928.

Geisler (1930) included the dominant floristic element in each plant formation and his accuracy on the dominant species appears to reflect a certain degree of regional knowledge of the State. The overall description of the vegetation of Western Australia by Gardner (1944) elaborated on the work of Diels, and added to the knowledge of areas not visited by him, but the scheme of classification was essentially that of Diels. The jarrah forest was mentioned only briefly, with no additional information.

Prescott's (1931) vegetation map is well known, although it did not differ substantially from the earlier work of Gardner (1928, 1934). Wood (1950) published a map which included a more realistic appraisal of the characteristics of the Australian vegetation. These three latter authors all recognised the significance of climate in determining forest types, although some differences were noted in their interpretations on "wet sclerophyll forest", "dry sclerophyll forest" and "temperate Eucalyptus rain forest" and "mesophytic forest".

2.5 Forests Department - Aerial Photographic Interpretations

Following the Second World War, the Forests Department utilised the technology developed for aerial reconnaissance to map the areas under its control from black and white photography. The outcome of this photo-interpretation work was mapped at a scale of

1:63,360 and by 1970 covered the entire forest region to the stage where it could be used by Smith (1972, 1973, 1974), Beard (1979a, 1979b and 1979c) and Heddle *et al.* (1980a), in association with their own vegetation mapping work. The Aerial Photographic Interpretation (API) maps chiefly described and mapped the structural features of the vegetation, such as height, class and crown cover. Only some of the species can be identified on the aerial photographs as only some dominant species have characteristic structural features, for example karri (*Eucalyptus diversicolor*), rock sheoak (*Allocasuarina huegeliana*) and the swamp paperbark (*Melaleuca preissiana*).

2.6 Holland 1953

In Holland's (1953) study of eucalypt distribution patterns, no new work was reported, apart from one transect and one small pot trial. The transect spanned the topographical gradient from lateritic upland to wet alluvium, that from jarrah through wandoo and marri to flooded gum (*Eucalyptus rudis*). Relatively few associated species were named. Marri was considered to be more flexible in its habitat requirements than jarrah, which was considered to be incapable of competing on good soils and to have a narrow tolerance to moisture fluctuations. A novel idea was the recognition of eroded valleys as migration routes. The present distribution of species was considered to be the result of past expansions and contractions. Presumably this was based on studies in the southern Eremean region as no detailed evidence was presented for the jarrah region.

2.7 Williams 1932 and 1945

The chief source of early detailed ecological information is Williams (1932, 1945), who carried out two small-scale site-vegetation studies in the north-western corner of the survey area. One of these was situated on Cohen Brook, a minor tributary of the Helena River, at the point where it descended from the Plateau on to the coastal plain. The other was situated in the valley of the Darkin River, the main tributary of the Helena River, approximately 27 km inland from the edge of the Plateau. The areas covered were 17.8 ha and 74.5 ha respectively. In both cases, the landscape was, by local standards, strongly dissected, the laterite capping occupying a very much smaller proportion of the total landscape than was true of the northern jarrah as a whole. Consequently there was much outcropping of the underlying rocks, namely granite with epidiorite dykes. In the Darkin study, a narrow zone of alluvium was also encountered. Painstaking detail was collected, with the position of each tree being mapped and total enumeration of all perennials being carried out on one per cent of the area on a 20m x 20 m grid. The second survey was somewhat less detailed. On the basis of these surveys, Williams described several associations and consociations, the latter being communities dominated by a single tree species: *Eucalyptus calophylla*, *Eucalyptus wandoo*, *Eucalyptus marginata* and *Eucalyptus patens*. A successful attempt was made to relate these to underlying soils and rocks. Williams concluded that the units were too heterogeneous to be described as associations in the narrow sense. They could be better described as edaphic complexes. Regarding the plant indicators, he concluded that plant communities were indicative of soil conditions, but that individual tree species, and in particular individual shrub species, were of limited value for this purpose.

He found that the species complex of the lateritic uplands differed markedly from the species complex of the dissected landscape and soils derived from fresh-rock exposures. Within the latter group he found species with preferences for soils derived from granite and epidiorite respectively. Yet another set of species was associated with the moist alluvium. A number of species failed to show any edaphic preferences.

Soil surveyors of the Forests Department usually recorded, in the course of their work, plants considered to be associated with a particular site or soil type. The work has never been brought up to a stage of clear-cut conclusions similar to those of Williams. The reasons for this were the less-detailed and less-consistent recording, the milder environmental gradients, and the less-abrupt vegetational changes.

2.8 Williams 1955 and Sochava and Korchagin 1970

William's map in 1955, followed on from the earlier studies of Wood (1950) and was based on strictly structural characteristics. Sochava and Korchagin (1970) in adapting William's 1955 map defined twenty-three types of vegetation which raised the degree of classification for the State. Since William's work a series of maps have been produced for Australia including Cochrane (1967), Moore (1970) and later Carnahan (1976).

2.9 Speck 1958

The next study of south-western vegetation was that of Speck (1958), who worked within the framework established by Diels, but introduced several new methods and ideas. Although his work was not strictly quantitative, greater details are incorporated, particularly on Diels' Irwin Botanical District. From his data he attempted a classification of plant communities using the nomenclature of Beadle and Costin (1952), slightly modified for local conditions but retaining the emphasis on structure as the first criterion of classification. Three major formations were described; forest, woodland and scrub. The latter was defined as depauperate trees or shrubs in a continuous stratum, with subordinate shrub layer but poorly-developed herb stratum. The three formations were further subdivided into 24 sub-formations and 62 plant communities, largely, though not exclusively, described as association. The association was defined as a climax community in which the dominant stratum exhibited a quantitatively uniform composition throughout its range. The dominants were used as the characteristic species. The associations were grouped by structure into formations, and by similarities in both floristic composition and structure into alliances. The use of profile diagrams to illustrate the structure of plant communities was one major advance on the work of Diels.

Although Speck rejected the use of edaphic complexes (for example, the swamp formation of Diels) as classification units, he recognized their usefulness in mapping. In order to cope with un-mappable combinations of associations he used the concept of 'vegetation system', defined as an area of country in which there was a definite pattern of associations and alliances determined by a comparable pattern of soils and topography. In this aspect he came very close to the land system concept proposed by Christian and Stewart (1953)

Within the northern forest region, Speck recognized three vegetation systems. Of these, the Darling System, which covers the Darling Scarp and the western margin of the Plateau, contains some youthful streams and has an annual rainfall of over 890 mm. The Bannister System, which was restricted to the eastern margin of the area, away from the Scarp, lacks youthful streams and has an annual rainfall of between 500 and 1000 mm. Each has a set of plant communities ranging from the *Eucalyptus marginata* to *Eucalyptus calophylla* high forest to *Eucalyptus wandoo* woodlands. However, whereas the Darling System was described as the 'prime' jarrah forest, the Bannister System was merely looked upon as its poorer eastern extension. The associations observed were: (I) *E. marginata*; (ii) *E. marginata-E. calophylla* and (iii) *E. wandoo* in both systems; (iv) *Eucalyptus patens* and (v) *Eucalyptus megacarpa* in Darling only; (vi) *Eucalyptus wandoo-Eucalyptus accedens* and (vii) *E. accedens* in Bannister only. Profile diagrams, structural formulae and brief species lists were used to illustrate the high forest of *E. marginata-E. calophylla* and the tall, temperate woodland of *E. wandoo-E. calophylla*. Only brief mention, without any species list, was made of *E. patens* and *E. megacarpa* associations. North of the Darling and Bannister Systems, that is north of the Avon River, Speck described the Chittering System, characterised by strong dissection of the plateau and the predominance of woodland rather than forest.

It is obvious that Speck was aware of the continuous variation within the forest, as shown in his profile illustrating a xerosere from high forest on deep soils to mosses and lichens on granitic outcrops. However, he was limited in exploring this by the broad-scale nature of his study and his acceptance of Beadle and Costin's (1952) classification. The recognition of vegetational continuity was also implied in his climatic series, which arranged associations along gradients of decreasing rainfall. The relevance of Speck's work is that it provides a broad framework within which the more detailed survey of the northern jarrah forest can be fitted.

2.10 Lange 1960

Lange (1960) related climatic and edaphic factors to distribution of tree species in the Narrogin district. Although his study area was east of the Darling Range, many of the tree species studied by him occur within the survey area, and their distribution in a drier climate throws considerable light on their site requirements. Lange found that the 500 mm isohyet was the main dividing line between the western species characteristic of acid, lateritic soils and high rainfall, such as *Eucalyptus calophylla, Eucalyptus marginata, Eucalyptus rudis, Banksia grandis* and *Nuytsia floribunda*, and the eastern species characteristic of the calcareous, alkaline soils of the dry inland, such as *Eucalyptus salmonophloia* and *Eucalyptus longicornis*. However, a number of tree species, namely *Eucalyptus wandoo, Eucalyptus loxophleba, Eucalyptus astringens, Acacia acuminata* and *Casuarina huegeliana* (now *Allocasuarina huegeliana*) straddle the 500 mm isohyet. Whenever the western species occur east of the dividing line, it is invariably as outliers on deep lateritic soils or on sandy soils in moisture-gaining depressions. He attributed the disjunct occurrence of the western species to an arid period in the late Quaternary, as postulated by Crocker (1959). The overall effect of increased aridity was the contraction of these species to favourable sites.

2.11 Churchill 1961 and 1968

Past climatic fluctuations were the subject of palynological investigations by Churchill (1961-1968), who was concerned primarily with the vegetation of the extreme south-west, in particular the balance between *Eucalyptus marginata, Eucalyptus calophylla* and *Eucalyptus diversicolor*. He found that the present distribution was largely determined by the rainfall of the wettest and driest months of the year, indicating that availability of water was a major influence. By contrast, no such relationship with temperature data was found. Major changes in pollen spectra were dated to 3000 B.C., 1200 B.C., A.D. 400 and A.D. 1200. He concluded that a drier climate, favouring the increase of *Eucalyptus calophylla* at the expense of *Eucalyptus diversicolor* (now largely restricted to high-rainfall areas along the south-western and southern coast) probably occurred between 3000 and 5000 B.C., and between A.D. 500 and 1200. Moister climatic conditions favouring *Eucalyptus diversicolor* probably occurred prior to 3000 B.C., between 500 B.C. and A.D. 500 and from A.D. 1500 onwards. The incorporation of charcoal in the peat deposits indicated that fire has been part of the environmental complex for at least 7000 years. The three species discussed appear to have very wide edaphic tolerances within the high-rainfall belt. Churchill's conclusions about the northern limits of *Eucalyptus marginata* and *Eucalyptus calophylla* on the coastal plain were too sweeping, in that they ignored some of the less-accessible outliers. As a result, he tended to underestimate the ameliorating effect of shallow ground water and high organic matter in strongly-leached sands.

In addition to his study of the forest dominants Churchill also investigated the distribution of some of the smaller tree species and shrubs. Because of the relevance of his findings to this study, the grouping of plant species in south-western Australia on the basis of their geographical distribution are given below:

a. Species confined to cool, moist south-western coast (the karri region) - *Eucalyptus diversicolor, Casuarina decussata* (now *Allocasuarina decussata), Agonis juniperina, Chorilaena quercifolia.*

b. Species confined to the karri region and the wet western edge of the Great Plateau between Collie and Mundaring - *Bossiaea aquifolium, Eucalyptus megacarpa, Banksia verticillata* (now *Banksia seminuda), Oxylobium lanceolatum.*

c. Species confined to the karri region, the western edge of the Great Plateau, the lower west coast and adjacent Blackwood Plateau - *Trymalium spathulatum* (now *Trymalium floribundum), Agonis linearifolia, Albizzia lophantha, Hakea amplexicaulis.*

d. Species of the karri region and the Blackwood Plateau, with small outliers along the western edge of the Great Plateau - *Kingia australis, Agonis parviceps, Hakea lasiantha, Podocarpus drouyniana.*

e. Species of the karri region, the Blackwood Plateau, the western edge of the Great Plateau and the coastal plain south of Perth - *Xylomelum occidentale, Adenanthos obovata* (now *Adenanthos obovatus), Pteridium esculentum.*

f. Species of the southern and western jarrah forest, the Blackwood Plateau and the karri region - *Xanthorrhoea gracilis, Leucopogon verticillatus, Bossiaea linophylla.*

g. Species occupying most of the area south-west of the line from Albany to Gingin, with a few small outliers to the east and north (particularly Mt. Leseuer) *Eucalyptus marginata, Eucalyptus calophylla, Eucalyptus patens, Casuarina fraserana* (now *Allocasuarina fraseriana), Banksia grandis, Banksia littoralis.*

h. Species occurring virtually throughout the south-west region from Kalbarri to Albany - *Macrozamia riedlei, Banksia attenuata, Xanthorrhoea preissii, Dryandra floribunda* (now *Dryandra sessilis), Hakea prostrata, Eucalyptus rudis,* (absent, south coast) *Acacia cyanophylla, Melaleuca rhaphiophylla, Melaleuca parviflora* (now *Melaleuca preissiana), Nuytsia floribunda.*

It will be seen that up to this point the groups increasingly occupy larger proportions of the south-west region by advancing into the drier, hotter, continental north-east, for example:

i. Species occurring throughout the whole of the south-west region with the exception of the high-rainfall area of the karri and jarrah region and the Blackwood Plateau - *Casuarina glauca* (now *Casuarina obesa), Hakea trifurcata, Acacia microbotrya, Melaleuca uncinata.*

j. Species differing from (I) only in that they extend west through the Avon Valley and south along the Darling Scarp for varying distances, but are absent from the coastal plain - *Eucalyptus wandoo, Borya nitida, Casuarina huegeliana* (now *Allocasuarina huegeliana), Santalum acuminatum, Acacia acuminata.*

k. Species of the predominantly narrow coastal belt along the west and south coasts - *Agonis flexuosa, Eucalyptus gomphocephala, Dasypogon bromeliaefolius* (now *Dasypogon bromeliifolius), Banksia ilicifolia.*

l. Species of the northern coastal plain, with outliers east of south-east of the main forest region - *Stirlingia latifolia, Eucalyptus decipiens, Banksia menziesii, Adenanthos cygnorum, Conospermum triplinervium, Banksia prionotes.*

m. Species of the inland, not entering jarrah region - *Eucalyptus salmonophloia, Eucalyptus salubris.*

n. Species of the far inland (outside the wheatbelt) - *Callitris preissii, Codonocarpus cotinifolius, Brachychiton gregorii, Triodia basedowii, Acacia aneura, Acacia sibirica, Eucalyptus camaldulensis, Eucalyptus kingsmillii.*

o. Species of the western wheatbelt and eastern margins of the forest - *Eucalyptus astringens, Eucalyptus accedens, Eucalyptus macrocarpa.*

p. Species of the south-east wheatbelt and south-east coast - *Eucalyptus platypus, Eucalyptus occidentalis, Hakea corymbosa, Eucalyptus tetragona.*

Although several specific details of these studies by Churchill have now been challenged, the latter studies of Churchill and Speck marked the end of an era, in that they were the last of the studies done without the help of the computer. Basically the studies up to the this stage set the frame work for future vegetation studies and described the broad vegetational trends in southwestern Australia in terms of physical environment and to a lesser degree, in terms of recent past. The only exception was the study of Williams which dealt with the fine-scale relationships between vegetation and the soil.

2.12 Specht 1970

Specht (1970) developed a new system of vegetation mapping for Australia based on projective foliage cover and height of the tallest stratum. Although this study was not confined to the South-West Forest Region of Western Australia it enabled a degree of consistency to be developed in the work undertaken in the region and also enabled some uniformity with other classification systems throughout Australia. This systems relied on the main structural characters and dominant floristics (e.g. open forest of jarrah-marri).

2.13 Smith 1972, 1973 and 1974

Smith (1972, 1973 and 1974) carried out a series of vegetation mapping projects in the Collie, Pemberton to Irwin Inlet and Busselton and Augusta areas of the South-West, Western Australia for the Department of Agriculture under the auspices of the Western Australian Vegetation Survey Committee. The initial mapping was carried out at the scale of 1:250,000, using aerial photo interpretation. The earlier work in this field, incorporated in the Forests Department's API (Aerial Photo Interpretation) was also utilised and aerial photo interpretation was supplemented by field surveys. The criteria used in the description and classification of vegetation were the life-form and height of the tallest tree stratum and the projective foliage cover of the tallest stratum expressed as percentage. These criteria were incorporated into the descriptive title of the structural vegetation type, such as high open forest, low woodland or heath.

Sources of information for this mapping were the 1967 aerial photographs at a scale of 1:40,000 and the Forests Department's Aerial Photographic Interpretation (API's) plans which provided some additional information on vegetation structure and principal trees occurring in forested areas. In addition traverses by motor vehicle and on foot were made during the period June 1971 to August 1972 covering the routes illustrated on the border of the vegetation map. Vegetation was mapped on the basis of structural criteria of the tallest stratum. Subdivisions of these formations are on the basis of plant associations which are indicated by means of symbols. Criteria used in the structural classification were life-form, height and density. This mapping was most effective around the coastline, where the vegetation varies from herbland to forest. It was moderately effective in the karri region, where it distinguished well between the tall open forest of karri, marri and tingle and the open forest of jarrah. It was also fairly effective at the eastern margin of the forest, where it distinguished between the open forest of jarrah and the woodland of wandoo. It was relatively ineffective in the main central belt of forest, the bulk of which fell into the category of open forest dominated by jarrah.

2.14 Havel 1968, 1975a and 1975b

The next attempt at the classification of the forests and woodlands of the region was that of Havel on the northern Swan Coastal Plain between 1965 and 1968. Whilst geographically the study was outside the main region under consideration, it is significant that the concepts and methodologies that dominated the forest classification for the next two decades were developed and tested there under a relatively simple and narrow set of edaphic, topographic and climatic conditions. Had it been applied to the main forest region initially, it may have been given up as too difficult. In addition, many of the ecological groupings defined there, and the relationships established between soil fertility and soil moisture regimes, are highly relevant to three of the regions within this project, namely the Blackwood plateau, the Scott Plain and the South Coastal Plain, with whom it shares the prevalence of infertile, siliceous soils and mild topography.

The first point of departure from previous studies was that it was undertaken as applied ecological project, in which understanding of the vegetational patterns was not the end in itself, but only a means to an ecologically land management system. Basically this study, was undertaken as a basis for land classification for plantation forestry. Its initial aim was to use of vegetation to predict site productivity, because great depth of the coastal sands made soil surveys difficult and of limited use.

The second major point of departure was that new methodology was adopted. This was not deliberate. To begin with, methodology of European forest ecology was examined in detail. However, it was found that the well defined plant associations of Braun Blanquet and the clearly defined biogeocenosis concepts of Sukachev, that worked for the European vegetation strongly modified and fragmented by millennia of human impact, were of limited use in southwestern Australia, where the relatively undisturbed and species rich forest and woodland understorey lacked clearly defined boundaries and tended to form continua in which the changes were progressive. It was therefore concluded that the European methodology of

Braun-Blanquet school would be neither feasible nor representative of the true situation on the ground. Attention was therefore turned to other European approaches to vegetation classification. The author then reviewed the application of the vegetation-based site classification system of Cajander (1926) and Ilvessalo (1929) in Finland. The concept of a continuum of forest types, based on the composition of the understorey was more applicable to the situation in the southwest. However problems were encountered when the method was tried under local conditions. Its success in Finland was made feasible by the relatively depauperate and simple vegetation of that country. However, the simple, subjective methodology appropriate there was inadequate to deal with complex and species rich vegetation of the South-West Forest Region of Western Australia.

Attention turned to more objective methodologies for dealing with continua. Of these the most attractive was that of Pogrebnjak (1955), namely that of ordination (edaphic net) developed for the forest-steppe transition in Ukraine. A similar method to that of Pobrebnjak's approach was subsequently used successfully in the United States of America by Whittaker (1956). It proved good for painting a broad picture of the relationships between vegetation and the environment The problem with all these methods was that the vegetation was arranged on the basis of environmental parameters. However, what was needed in south-western Australia was the understanding of vegetation patterns that could be used to infer environmental conditions. There was a methodology that already attempted that, namely the ordination through environmental indices, developed in the United States of America by Bray and Curtis (1957). The essence of this approach was that as the vegetation reflects environmental conditions, the vegetation patterns should reflect the environment. This methodology of Bray and Curtis was also tried, but at that stage it proved fairly subjective and labourious.

Attention therefore turned to computer based classifications being developed in Australia by Goodall (1954, 1963), who at the time was working for CSIRO in Western Australia. This methodology was factor analysis, or more precisely principal component analysis. It was objective and capable of handling large volumes of data. With Goodall's's guidance and help a system was developed that has been used over the next twenty years over much of the south-western forests.

The pattern of the sampling was cluster of plots in native vegetation which surrounded the experimental pine plots. There were four tree plots of 40m x 10m, within each of which were nested two shrub sub-plots of 4m x 4m (metric equivalent of 13ft x 13ft). The parameters recorded were the basal area of the trees and the presence of the understorey shrubs and perennial herbs, converted into frequency over the eight subplots. Within each plot, soil samples were taken at two levels, equivalent to 0-1 and 1-2m, which were analysed in the laboratory for soil reaction and the percentages of iron and organic matter, known to be the chief determinants of moisture and nutrient holding capacity of the sands.

Because of the limitation of the programme and the data set, the shrub data had to be reduced to thirty species of moderate to high frequency.

The output of the principal component analysis of the 67 clusters, which for the purpose of the analysis were considered as one sampling unit, was readily interpreted. Even the preliminary stage of the output, that of distribution of the individual species within the principal component space, indicated that the degree of leaching of the soils was an important determinant of vegetational patterns. Several species emerged as possible indicators of this factor. This was confirmed when the scores for plots were calculated, the position of the plots within the principal component space plotted and the soil parameters entered against them.

A consistent progression was established from the plots with the highest percentage of iron, and hence the least leached, to those with the lowest percentage of iron and hence the most leached. The second most important environmental factor that emerged was of moisture availability. By inputting the frequency data of individual species in the plots into the principal component framework, it was possible to assess their value as indicators of the soil parameters. By inputting the performance of the exotic pines into the framework it was shown that these responded to the same environmental factors as the native species, and that the performance of exotics could be predicted on the basis of the indicator species.

As the exotic trial plots used in the original analysis did not adequately cover the full range of environmental factors, the extreme sites, in proximity to swamps and limestone outcrops, were studied by Pogrebnyak's (1955) method of edaphic net. To obtain data for these, transects were established in locations where a clear catena of edaphic conditions existed, such as from swamp to dune crest, and from dune swale to limestone outcrop. The dimensions of the segments of these transects were comparable to that of the earlier phase of the study, namely tree plot 20m x 20m, containing eight shrub and herb quadrats each. As in the case of the earlier sampling, soil samples were taken, but instead of being only once-off samples of chemical parameters, they were continued as bi-monthly samples of soil moisture contents for a full year. Subsequently they were resumed on yearly basis as part of a environmental study of the effect of natural rainfall fluctuations and groundwater extraction on groundwater levels (Heddle 1980) and have continued up to the present time. Combined with annual reassessment of the vegetation data they provide on of the longest studies of vegetation dynamics in Australia (1965-1996) (Havel 1968; Heddle 1980; E M Mattiske and Associates 1995). The study had influence beyond its original narrow objective site classification.

The edaphic nets developed on the basis of the transect surveys confirmed and expanded the findings of the principal component analysis, and on their combined basis eleven site vegetation types were defined, each with a set of indicator species. The types were considered to be noda in a multidimensional continuum, not narrowly defined plant associations of the European classification systems.

Many of the indicator species have reemerged subsequently as indicators in vegetation studies of other regions, where they are largely, though not exclusively, associated with silicious sands. Significantly, they emerged as indicators even in regions with nearly twice the rainfall of the northern Swan Coastal Plain.

Before the results of the studies were published, the workability of the system was tested by extensive field surveys covering 3307ha in five localities. The differences due to fertility, which are reflected in the composition of the shrub stratum, were more difficult to map, due to the reliance on ground surveys. Those due to water availability, which is reflected in the composition and structure of the tree overstorey, were detectable on aerial photos. It was found possible to map the site-vegetation types effectively. by a combination of ground surveys and aerial photo-interpretation.

Subsequently, the classification was applied to the bulk of the State Forest on the Swan Coastal Plain north of Perth. One of the significant by-products of this was that several areas of high ecological diversity were recognised and set aside and became part of the reserve system, with economic activity being directed to areas of low diversity, better suited for broadscale mechanised operations.

With the site-vegetation classification of the northern Swan Coastal Plain completed and site mapping becoming a routine procedure in late sixties, Havel turned his attention to the northern jarrah forest (Havel 1975a and 1975b). The initial objective was similar to that for the northern Swan Coastal Plain, though it was widened to include the productivity assessment of indigenous hardwood forests as well as the potential for plantation establishment. However, as the work proceeded the social and economic environment entered a period of rapid change (Havel 1989). Economic developments such the expansion of the bauxite mining and of water harvesting made timber harvesting, which was already declining, less significant than it had been for the past century. The growth of public concern over these activities, over the salinisation of the streams and over the spread of the dieback disease changed the perception of the forest from an economic resource to that of protector of water supplies, a recreational resource and an entity with a value of its own, requiring protection and conservation. By the end of the study the objective of the vegetation surveys changed to the provision of sound ecological base for conservation and multiple purpose management.

As the area to be classified and mapped was greatly more extensive (732,600 ha cp to 51,030 ha) and diverse (in terms of geology and climate), changes in methodology also became necessary. Fortunately, the developments in computer technology and quantitative ecology were equally rapid. The plots were located next to pilot plots of exotic species, growth plots of indigenous species and virgin forest, that is locations with greatest significance to forest management. The sampling comprised 320 plots of 40m x 40m, each containing 16 quadrats (subplots) of 1m x 1m. Total enumeration of all trees in terms of basal area was carried on the large plots and total enumeration of perennial shrubs and herbs in terms of percentage cover on all the subplots. The enumeration of the vegetation was accompanied by soil sampling and the description of the topographic and edaphic features of the plot. The analysis of the soil data included both physical and chemical (pH, N, P, K, Ca, Mg, CEC and Saturation) features.

In spite of the rapid development of computer technology the data pool (364 perennial species on 5120 quadrats) required reduction before computation could be carried out to a satisfactory conclusion. The cover values for the 16 quadrats within each tree plot were summed up, and the frequency of occurrence of the individual species within the data base was used to eliminate those too rare to be of practical use in mapping or too common to have discriminatory power. Species which could not be reliably identified on foliage alone were also excluded, as much of the data collection had to take place in the dry season, after flowering ceased. In any case, the capacity of the program then available for the principal component analysis was limited to 80 species. Difficulties were experienced even after reduction to 80 species, in that the program could not proceed beyond the calculation of the correlation matrix. The groupings of the species on the correlation matrix indicated correspondence with the more obvious plant groupings in the field. The correlation matrix was therefore used to further reduce the number of species by eliminating those that failed to show adequate correlations with other species and would therefore be unlikely to be of value as indicators.

With the reduced data pool it was possible to progress the principal component analysis up to the stage of normal loadings for the species, and to advance it by auxiliary programs (FACVA) to obtain scores for the plots, so that it would be possible define ecologically equivalent or at least similar sites. To facilitate the examination of the relationships between the plots, of their physical properties and of the vegetation within them, a special display program (CORD) consisting of a 20 x 20 matrix for any combination of two principal components was developed. Within this matrix the plots were allotted according to their scores on the relevant components, and attributes of the plots were then displayed. This made it possible to relate the principal component axes to environmental variables and to patterns of species distribution, and ultimately to subdivide the four-dimensional continuum into constellations of species with similar physical and biological attributes.

The program was also used to test the discriminatory capacity of any species, by observing how tightly or loosely the species were grouped within the principal component space, to which component it was responding or for which group or groups of plots, or for which environmental attribute, it could serve as an indicator. Altogether 128 species were tested, and of these 55 were chosen for the second run of the principal component analysis.

The ultimate output of the process was the definition of 19 plot groups, defined by 23 groups of indicator species. The range of environmental attributes such as topography and soils was also described for each plot group, defined as site-vegetation type. The types were considered to be noda in a four-dimensional continuum, not tight plant association sensu Braun-Blanquet. They were indexed by letters of alphabet for convenience in field mapping, as the definition by indicator species, which would require the names of several species, would be too cumbersome.

Alternative methods of classifications were also used, namely the monothetic divisive classification, using programs DIVINF and DIVINFRE, and the agglomerative polythetic classification using program CLASS. Of the two classifications, CLASS appeared to be more robust and better able to deal with a continuum. The groupings of plots (normal analysis) that it generated were homogeneous and similar to that arrived at by the ordination process described earlier. The process by which they were arrived could not be readily traced, because each division was based on several species. The grouping of species (inverse analysis) was less satisfactory, giving some very small and some very large groups. The process also gave no indication about the value of individual indicator species, other than by showing their association with the groups of plots defined by the normal analysis.

The monothetic divisive classification (DIVINF and DIVINFRE) had the advantage that the successive divisions, based on single species (normal analysis) or single plot (inverse analysis), could be more easily traced, but the process was less robust, because it was based on single individual, and the groups generated were less homogeneous. The groups derived by a long succession of negative decisions were particularly vulnerable, as they had little in common other than the absence of the species or plots used in the division process, and were thus quite heterogeneous.

At this stage, which is the stage at which many classifications are terminated and reported, there was no guarantee that the categories defined were not merely mathematical abstractions without a counterpart in the real world. In order to test this, and also to relate the site-vegetation types to landscape and climate, mapping was undertaken on a number of test areas spanning the range of climatic and geomorphological variation in the northern jarrah forest from west to east. The areas mapped were mostly catchments of tributaries of the Canning River, which traverses the region from east to west, except for the easternmost one which was situated on the headwaters of a tributary of the Dale River. Those on the Canning River reflected the deepening dissection of the landscape as the river flows from the divide with the Dale River towards the coastal plain. The test areas ranged in size from 1823 to 2789 ha, and totalled 8783 ha.

The objectives of the surveys were:

a) the existence of the site-vegetation types in real space,
b) the reliability of predictions about relationships between the plants and the environment,
c) the feasibility of mapping the types rapidly, with the use of aerial photographs, and
d) the feasibility of inferring vegetation from geomorphology and climate.

The surveys were carried out along traverses across the grain of the country, to maximise the information collected. In the initial survey of a strongly dissected catchment close to the headquarters the traverses were 400 m apart and observations were made at 100 m intervals. For the more distant and generally less dissected catchments this was increased to 800m x 200m. At each observation point standardised observations were made on environmental parameters such as topography, rock outcrops soil texture and condition of the forest in terms of height, basal area, logging impact and disease occurrence, and on the occurrence of plant indicators defined by the earlier study. The data thus collected was transferred to standard forestry maps at the scale of 1: 15840, and the maps encoded for use with the MIADS (Map Information and Display System) of Amidon (1964,1966), imported for that purpose from the United States of America and adjusted for local use. The map data was entered by means of numerical code for cells 4mm x 5mm, equivalent to 0.54 ha on the metric scale.

The MIADS system made it possible to overlay maps and assess the degree of covariance or coincidence between the various mapped attributes, by combining two encoded maps and producing a combination map and a set of tables giving the area and the proportion of the total area falling into each combined category.

A program (CONTAB) was developed locally to convert the output for MIADS into multidimensional contingency tables and to subject these to test for goodness of fit (Fienberg 1970). This was done using the Chi-square test, which assesses whether the relationship between what would be expected on basis of chance alone, and what is actually observed in the field and recorded on maps.

On the basis of these tests it was established that the site-vegetation types exist in real space. Two of the types established by the ordination process were not located on a mappable scale on any of the test areas, though they have been located in other areas subsequently. Two types were found to be too broadly defined and were subdivided by reference to related types, e.g. AY, with some characteristics of both type A and Y. A whole new complex of types, from woodlands to herbfields, with pattern too fine to be separated into mappable individual types, was found on the rocky slopes of the Cooke monadnock and was defined as a new category G.

It was also confirmed that site-vegetation relationships exist in real space, eg that types A, B and W are invariably found on water-gaining sites, and site-vegetation types T, S and Z on uplands. Similar relationships were found to hold for climate, soil texture and soil fertility.

It was also found that only extreme sites, such as rocky slopes and swamps, on which the height and density of the tree stratum were significantly reduced, could be mapped on the basis of aerial photography. For bulk of the types the stand features visible on aerial photos were not sufficiently distinct.

However, it was also found that there was a strong relationship between site-vegetation types and geomorphic surfaces. Each combination of a geomorphic surface and climatic zone was associated with a set of site-vegetation types, generally arranged in topographic continuum, such as from a water-shedding ridge to water-gaining lower slopes and valley floor. As the geomorphic surfaces could be mapped from aerial photos, they provided the means for preliminary mapping of large areas for land use planning on an ecological basis. The precision of this mapping could be subsequently improved by ground surveys.

The mapping of the extensive areas of forest made it possible to examine the factors controlling the occurrence of the tree species within the region, the chief of which was found to be the availability of water. This, in turn, was determined on broad scale by climate and on local scale by topographical position and the depth of the soil profile accessible to tree roots. It was this that determined the dominance of jarrah on the deeply weathered lateritic uplands over a wide range of climatic zones, and its displacement by more drought tolerant species on truncated soils of the valley slopes, especially in lower rainfall of the east and north.

2.15 McArthur and Clifton 1975

In the southern half of the study area, a broadscale account of landforms and vegetation was developed by McArthur and Clifton (1975) for the Pemberton district as an aid to land use planning. Some of the concepts developed by them were a starting point for subsequent more detailed studies, in much the same way that the work of Speck (1958) did in the north.

Basically they first reviewed past soils studies in light of new the nomenclature of Northcote (1974), and then defined the dominant soil types within the region and then mapped several subdistricts arranged in a continuum from the Darling Plateau in the north, through the dissection of the plateau toward the southwest, the zone of isolated granitic hills and broad sandplains further south and finally the southern coast, with its succession of sand dunes. In each survey area they described an association of soils and having discussed the component soil types, they looked at the relationship between these soil types and the vegetation that they carried in the light of climatic conditions.

They described the vegetation in terms of Specht's (1970) formations, but also gave tables of component species for these formations. Whilst their description of vegetation is largely just descriptive and not base on any formal analysis of quantitative samples, it is a very useful first step in the right direction for the southern region.

This study recognised that the distribution of the species and vegetation formations was controlled by combination of rainfall, soil, landform and aspect. There was a recognition that the climatic gradients across the area were influencing the vegetation; although the single most significant factor in determining the vegetation was the soil. The authors defined the main vegetational features and characteristics in relation to the soil associations (Balbarrup, Perup, Nyamup, Pemberton, Boorara, Chudalup, Blackwater, Quagering, Meerup, Yeagerup, Carey, Coolyarbup and d'Entrecasteaux). As reflected in other earlier studies, there was a recognition that there were subsets of vegetation units within these soil associations which largely reflect subtle soil and soil moisture changes.

2.16 Loneragan 1978

Concurrently and parallel with the work of Havel, but independent of him, Loneragan (1978) studied the interface between forests and woodlands of jarrah(*Eucalyptus marginata*) and wandoo (*Eucalyptus wandoo*). The two studies had much in common: both took the earlier work of Speck (1958) as a starting point, both derived their methodology from and received advice and assistance from Goodall (1954). There was even an overlap in the study area, in that Loneragan derived his samples from the northeastern quadrant of the area covered by Havel, and extended it further to the north and east. The chief differences were in the objectives of the studies and resources available to the two researchers.

Whereas Havel's objective was applied and considerable resources, especially in terms of manpower, were available to him, Loneragan work was done toward a PhD thesis and was limited in resources. By the very choice of methodology both implicitly accepted the possibility that the vegetation of southwestern Australia forms a continuum. Whereas Havel's objective was the subdivision of that continuum into manageable segments useful in forest management, Loneragan asked the more basic question such as whether the continuum really existed and whether it could be subdivided in a statistically valid way.

Whereas Havel's samples were tied to locations of significance of forest management and were to that degree predetermined, Loneragan's samples were located on stratified random basis, though he was forced to make concessions to logistics by accepting only samples within 0.8 km of a road. An important specification made by Loneragan was that no sample could be closer than 50m from any well-defined stream bed, which automatically eliminated the moist end of the vegetation continuum as a whole.

Ultimately Loneragan selected 122 sample plots. The data collected by Loneragan was comparable, in that trees were recorded on 48m x 48m plots in terms of numbers and basal area, and shrubs and herbs were recorded on 16 1m x 1m quadrats. The shrub species were recorded in terms of frequency out of the sixteen quadrats, and in terms of canopy cover on the four central quadrats. The environment was described in terms of geomorphology, topography and soil, the latter both in terms of field profile and laboratory sampling of physical and chemical properties. Rainfall for the plot was estimated statistically.

The statistical analysis of the data was more extensive than that of Havel (1975a). The tree data was first tested for the homogeneity of distribution. The enumeration of the tree species indicates that extreme sites, that is those very wet, very sandy or very drought prone were not sampled, namely - no *Melaleuca preissiana, Banksia littoralis, Banksia attenuata* or *Allocasuarina huegeliana*, which are typical of these sites, were included in the test.

The principal component analysis (PCA) was used as the most convenient method of dealing with the environmental (site) data. This elucidated the relationship between the site descriptors, namely that they formed a continuum. It indicated that most sites in the high (over 750 mm annual rainfall) were on the gravel deposits of the mildly sloping stable surface of the old plateau and had coarse texture. By contrast most of the sites below the 625 mm annual rainfall had finer texture and higher level of nutrients, indicating greater dissection of the lateritic plateau, described by Clifton as erosional surface. Most of the sites presumably occurred on the dissection caused by eastward flowing tributaries of the Avon River. The coarsest texture, of more that 70% of coarse sand, was found on sites described by Clifton as depositional.

Ordination of the tree data by means of PCA omitted species of low frequency, namely *Eucalyptus patens, Acacia acuminata* and *Acacia saligna (Acacia cyanophylla)*, all of which tend to occur in valleys, thus further pushing the data set toward the uplands. The remaining species were first evaluated in terms of Importance Value (IV), percentage Constancy (%C) and number of occurrences (n), and ordered in terms of their dominance within the stands. Jarrah(*Eucalyptus marginata*) and marri (*Eucalyptus calophylla*) occurred in 91 stands, wandoo (*Eucalyptus wandoo*) in 55 stands and powderbark wandoo (*Eucalyptus accedens*) in 18 stands, mainly as dominants or co-dominants. All residual non-eucalypt trees (*Persoonia longifolia, Persoonia elliptica, Banksia grandis* and *Allocasuarina fraseriana*) occurred as subordinate species, mainly in stands dominated by jarrah.

The first component separated three of the understorey species (*Persoonia longifolia*, *Banksia grandis* and *Allocasuarina fraseriana*) from the rest. The second principal component indicated polarization between jarrah and wandoo. The third component separated powderbark wandoo (*Eucalyptus accedens*) from the rest.

The distribution of the stands (samples) within the factor space was strongly clustered and skewed, presumably because transformation of the factor scores to square root, which tends to correct the clustering tendency, was not used. Nevertheless, Loneragan was able to draw contour lines of the Importance Value of the species within the framework. The main trend was along the second component, namely dominance of jarrah at the negative end and wandoo at the positive end. The three subordinate species (*Persoonia longifolia, Banksia grandis* and *Allocasuarina fraseriana*), declined in parallel to jarrah. Marri declined marginally from negative to positive, and was nowhere very significant. Powderbark wandoo came in near the centre of the continuum and peaked and declined rapidly. Loneragan considered the outcome of the analysis to support the earlier classification of Speck (1958), except in so far that Speck's associations were shown to be overlapping components of a continuum rather than discrete classes.

Loneragan also related the principal component axes of the tree analysis to environmental data by means of regressions and obtained significant correlations, both to raw environmental data and to component scores of the PCA based on them. The strongest correlations were those between the PCA scores on trees and rainfall and silt/clay fraction. The correlations with chemical attributes such as N, P and K were weaker. Loneragan also subjected the tree data to clustering using Goodall's Probabilistic Similarity Index (PSI) and derived six major groups. In some of these there was a clear dominance of one tree species, such as wandoo (T1), powderbark wandoo (T2) and jarrah(T4, 5 and 6). Marri was not a clear dominant in any group but an associate of all other species. In the T3 cluster all four eucalypts were present in significant proportions. In T4 jarrah was accompanied by all other species, both the eucalypt co-dominants and non-eucalypts sub-ordinates (*Banksia grandis, Allocasuarina fraseriana, Persoonia elliptica* and *Persoonia longifolia)*. Wandoo and powderbark wandoo were absent from T4 and T5. In T5 the only subordinates were *Banksia grandis* and *Persoonia longifolia,* in T6 all four non-eucalypt were present. By comparing the PSI clustering with Speck's (1958) structural classification the three groups dominated by wandoo (T1-3) fell largely into Speck's woodland formation, those dominated by jarrah(T4-6) into forest formation. The matching was less clear at the level of floristic associations, in that several associations fell into one PSI cluster, and several PSI clusters into one association. The location of the PSI clusters within the survey region was quite informative, the wandoo and powderbark wandoo dominated clusters falling largely into the northern and eastern sectors, though there were westward extensions of the wandoo clusters, in particular T1, along the river valley systems. Of the jarrah-dominated clusters the T4 cluster extended from east to west, whereas the T5 and T6 clusters were largely confined to the southwest. Loneragan concluded in the light of the above findings that the two major groupings, namely the wandoo alliance (T1-3) and the jarrah-marri alliance (T4-6) comprised two vegetation systems related to two different environments.

Loneragan did not attempt to relate these findings to Havel's site-vegetation types, though this is relatively easy. In the wandoo dominated clusters T1 is largely equivalent to Havel's types Y and L and T3 to M. Similarly in the jarrah dominated clusters T5 represents Havel's types R and T and T6 represents mainly P and S. Loneragan's T2 has similarity to Havel's type M, but warrants a separate category, as it occurs largely outside the area sampled by Havel and is distinguished from M, Y and L by the dominance of powderbark wandoo, *Eucalyptus accedens.* Only the highly polyspecific and geographically widespread T4 cluster is problematic, in that the presence of all eight species in one group is highly unlikely. Loneragan shows only 3 plots to contain all four subordinate species, and six more that contain three subordinate species. These plots occur in the component space from which wandoo and powderbark wandoo are absent. It is therefore likely that the T4 is a heterogeneous cluster generated by the computing process, and covers the a wide range of Havel's types, including the H and Z types prevalent in the eastern region.

Loneragan's analysis of the understorey (shrub and herb stratum) was much less conclusive, probably because it was based on 42 most common species. It was possible to identify a connection between the ordination based on the understorey species and the two main subdivisions of the tree based classification, namely the wandoo and the jarrah-marri alliances, and between the understorey ordination and the environmental factors. The chief difficulty was in obtaining a meaningful subdivision of the understorey ordination. Similarly it proved difficult interpret the clusters derived by the PSI analysis of the understorey. The clusters had a very uneven distribution, more than half of the plots falling into one large cluster and the remainder into five small clusters. The clusters did not correspond closely to any structural or floristic classifications of Speck (1958), or to Loneragan's tree-derived clusters. Loneragan therefore concluded that the overstorey and the understorey varied fairly independently of each other.

It is possible to relate some of the features of Loneragan's ordination and some of the clusters of his classification of the understorey species to Havel's broad indicator groups, as they share a few species. However, the bulk of the species used by Loneragan were rejected by Havel on the basis of preliminary analysis as being of limited use as indicators. Similarly, the bulk of Havel's indicators would have failed to pass Loneragan's criterion of commonness. Those broad indicators shared by the two authors, such as *Hakea lissocarpha* and *Lepidosperma angustatum,* show similar trends in relation to trees and environmental factors. By using common species Loneragan demonstrated that the vegetation of the region forms a continuum. By using less common species with greater discriminatory power Havel was able to subdivide this continuum into meaningful segments. Neither author was able to define discrete ecological groupings.

2.17 McCutcheon 1978 and 1980

In the late seventies, McCutcheon (1978, 1980) commenced the study of the vegetation of the northern half of the Blackwood Plateau using Havel's methodology. The primary objective was to define if, and to what degree, vegetation mapping could be used in site assessment for pine plantations in that region, which at the time was covered by low quality jarrah forest. Vegetation was therefore to be studied as potential indicator of site quality, as done earlier by Havel on the Northern Swan Coastal Plain. The chief difference was that the area in which the test was to be carried out had already been surveyed by McCutcheon for soils. The methodology adopted by McCutcheon was basically that of Havel, though his plots were circular (20m radius for trees and 10m radius for shrubs and herbs). The recording was confined to 72 common species of the region, recorded on an abundance scale. The data was subjected to principal component analysis.

The first stage of the analysis produced the loadings of the species within the component space (first four components), and these were subsequently converted to component loadings for the plots.

The distribution of species within the factor space, representing the relationships of the individual one to another, resembled the patterns obtained by Havel on the Northern Coastal Plain and on the sandier soils of the Darling Plateau. In addition there were groups of species specific to the Blackwood plateau and the southern forest region.

To facilitate the delineation of vegetation types four-dimensional models of the component space were built. On the combined basis of the distribution of the species and plots within the component space six vegetation types were established. The definition of the types was made difficult by the fact that the types were obviously segments of a multi-dimensional continuum. The chief components determining the vegetation patterns were the presence of lateritic horizons in the subsoil, the texture of the soil and soil moisture conditions as determined by soil characteristic and topographical position. The level of soil fertility, which is almost universally low in this region of lateritised and reworked sediments, found expression through the texture of the soil, the heavier textured soils having better nutrient retention capability and hence being more fertile than the deep leached sands. Quite strong correlations were found between the vegetational gradients and the soil parameters.

Ultimately, six vegetation types were defined. The choice of a such low number of types probably arose out of the low number of soil types described for the area (7). The species were then tested as to their capacity to define the vegetation types. The indicator groups formed were designed specifically to assist in soil surveys. The six vegetation types were found to be too broad to allot individual observations to them and numerous intermediate types were generated. In particular, the influence of vegetation typical of lateritic soils was found to extend, to some degree, to 47% of all sites.

When the relationship between soil survey and vegetation surveys were examined statistically, the picture was less consistent. The vegetation types typical of deep leached sands, moist fine textured loams of the valley floors and the poorly drained soils of intermediate texture could be defined on basis of vegetation alone. The less leached sands, and in particular soils with gravelly horizons within them, required probing, as the vegetation was not seen as being sufficiently precise in defining the effective depth of soil.

The value of the study to this project is that it has established good ecological relationships for an area in which ecological work has otherwise been at a very low level, and has provided a good, tested set of indicator species. Its chief limitation is that it drew its samples from, and was tested for its effectiveness on a relatively restricted area of 1990 ha, though its was subsequently used as an aid to site classification over a much wider area.

2.18 Beard 1979a, 1979b, 1979c and 1981

Later on the vegetation mapping in the southwest was taken up by Beard (1979a, 1979b, 1979c) who mapped the remaining regions of the southwest (Perth, Pinjarra and Albany & Mt. Barker) at the 1: 250,000 scale and than combined his maps and those of Smith (1972, 1973 and 1974) into the Swan Vegetation Map at 1:1,000,000 (Beard 1981). In the explanatory notes Beard went far beyond structural vegetation mapping and discussed natural regions, climate, geology, geomorphology and human influences, as well as discussing vegetation plant formation, vegetation series and vegetation system level. He also explored the factors that control the distribution of plants, in particular trees. Where floristic information was available, as in the northern jarrah forest, it was incorporated into the discussion of the structural types. Beard's work also went beyond that of Smith in that he mapped not only the residual vegetation, but extrapolated potential vegetation into areas already cleared for agriculture. His structural mapping, expressed in colours, was augmented by alphanumeric annotation which identified the principal floristic components of the structural types, especially trees. The 1: 1,000,000 map sheet shares the limitations of the 1: 250,000 sheets on which it is based, namely the inability to subdivide the bulk of the forest on structural or floristic criteria.

2.19 Bettenay *et al.* 1980

Bettenay *et al.* (1980) carried out a description of the experimental catchments in the Collie Area of the South-west, Western Australia. The vegetation was mapped by using the method described by Havel (1975a and b), who delineated 21 distinct ecological types in the northern jarrah forest. In small areas, such as the Collie catchments, it is possible to increase the number of types by mapping variants of the major ecosystems using a combination of coding letters which are relevant to the area. In addition to the vegetation species used by Havel, a reconnaissance of the catchments was made, and any plant species which showed promise as an indicator of a particular ecotype was added to the booking sheet. These were assessed at the completion of the survey, and retained or discarded accordingly.

The recording and mapping of vegetation was facilitated by the survey grid, and boundaries were plotted directly on the base maps by pacing from the survey pegs, and by the use of contours. Interpretation of aerial photographs was also used for checking the boundaries of some types.

2.20 Heddle 1979 and Heddle *et al.* 1980a

Heddle (1979) and Heddle *et al.* (1980a) developed the interpretation of vegetation patterns in relation to the underlying causal relationships with landforms, soils and climate through the vegetation complex mapping for the Darling System (System 6 mapping). This area covers approximately a third of the South-West Forest Region. In the development of this mapping technique Heddle *et al.* (1980a) relied heavily on the previous studies in the area and in particular the detailed site-vegetation type work of Havel (1975a and 1975b), the Aerial Photographic Interpretation (API) mapping held by the Forests Department of Western Australia (which was also used by Beard 1979a and 1979b, as well as Smith 1974), the topographic data held by the Department of Land Administration, the landform and soil mapping of Churchward and McArthur (1980), the previous vegetation mapping by Smith (1974) for the Collie area. The studies by Beard (1979a and 1979b) were being developed concurrently with those of Heddle *et al.* (1980a) and therefore the essentially structural formation mapping of Beard was not available to Heddle *et al.* (1980a) at the time of the mapping.

The concept of the vegetation complexes enabled Heddle, Loneragan and Havel (1980a) to address the linkages between the detailed site specific studies by Havel (1975a and 1975b) and the regional mapping level which was similar to the land system approach of Christian and Stewart (1953) used in the Katherine - Darwin region.

The mapping by Heddle *et al.* (1980a) depicted the original plant cover and attempted to integrate the more detailed site-vegetation type mapping by Havel (1975a) and the distinctive relationships with the underlying landforms and soils and climatic patterns. All mapping was undertaken at a scale of 1:25,000 and 1:50,000 with the assumption that all line work would be reduced by a factor of 5 for the maps deliverable at a scale of 1:250,000. This necessitated some rounding off of detail for reduction purposes.

During the mapping project detailed field work was undertaken in selected areas (see Russell block, Mattiske 1976) and broad reconnaissance work was undertaken over the extensive road and track system throughout the project area. All original field notes and maps are held by Mattiske (nee Heddle), as the former principal author of Heddle *et al.* (1980a).

2.21 Christensen 1980

In the late 1970's, Christensen undertook a range of studies on the marsupials (*Bettongia penicillata* and *Macropus eugenii*) in the Perup forest areas, located in the areas east of Manjimup. Although the prime purposes of this study were to investigate the vertebrate fauna species, detailed recordings were undertaken on the vegetation and fauna habitats. In view of the location of this data, an attempt was made to locate the baseline flora and vegetation data collected by Christensen (1980).

The survey data was collected at a range of sites in the Perup area and while not site specific it has been possible to re-locate the general location (to within 500m) for integration into this current mapping project. Site point data collected only covers 73 common and indicator species. The species were ranked on a scale of 1 to 5 (as designed by Havel 1975a) and were recorded within 149 circular plots (20m radius). Although this data is limited in some aspects it still will provide a series of valuable reference points for the area near Manjimup.

2.22 Trudgen 1984

Trudgen (1984) carried out the survey of the Westdale-Dobaderry group of reserves. The reserves cover a wide range topographic and edaphic features. This diversity led Trudgen to describe sixty-two vegetation types, composed of 337 species, from an area of 4005 ha. Some of these types were described using Havel's nomenclature, e.g. wandoo types Y, L and M; others as combination of Havel's types, e.g. MG, YF; or as subtypes e.g. J. & J. Number of types were described de novo, as not covered by Havel, e.g. *Banksia prionotes* open woodland; or as sufficiently different to warrant separate definition, e.g. Flooded Gum types d, e & f. The survey consisted of aerial photo-interpretation at scale of 1:40,000, followed examination in the field of the areas of uniform texture on the photographs, chiefly by traverses along tracks in a four wheel drive vehicle, supplemented by foot traverses. Some of the types occupied areas too small to be mapped at 1:40,000. Trudgen considered the types defined to be composed of a range of plant communities, chiefly as varied understorey under a relatively small number of dominants. Trudgen's description of the vegetation of the reserves approaches the fineness of detail of some Braun-Blanquet associations, without the labourious identification of the "faithful" species.

Trudgen's report and the earlier published studies (Havel 1975a and 1975b) were used by Campaign for Native Forests (Cahill 1984) to put forward a proposal for a very large wandoo reserve of 111630 ha along the eastern boundary of the State Forest from Mundaring to Wandering. The proposal contained no new information relevant to classification and mapping of vegetation.

2.23 Geomorphological Mapping

Although geomorphical mapping does not strictly fit into the category of vegetation mapping, it can be an important aid to vegetation mapping, particularly in regions where floristic differences are not reflected in the structure of the vegetation and are thus not mappable from aerial photographs. This is the case in the jarrah forest, where one species is dominant over hundreds of thousands of hectares with only minor structural variation.

The importance of geomorphology in determining the soil patterns, and hence vegetation patterns, has been recognised in Western Australia for some time. The earliest of this work dates to the 1920's and 1930's (Clarke 1926, Jutson 1934), but the main relevant development began in the agricultural areas (Mulcahy *et al.* 1961), and then in the forested areas (Mulcahy *et al.* 1972, Finkl 1976). It was at this stage that the linkages between geomorphology and plant ecology were developed through mapping of vegetation over a range of geomorphic units. The geomorphological mapping was extended by McArthur *et al.* (1977) to the Murray catchment and by Churchward and McArthur (1980) to the entire forested region north of the Blackwood River.

From the early stages geomorphologists and forest ecologists interacted, chiefly with the latter utilising the maps of the former or co-operating with them (McArthur and Clifton 1975, Churchward and Batini 1975, McArthur *et al.* 1977). On occasions the forest ecologists drew attention to landforms which, on basis of their vegetation studies, warranted new landform categories, such as the Cooke landform (Havel 1975b).

McArthur and Clifton (1975) extended the geomorphological mapping to the south coast near Pemberton, dealing not only with geomorphology, but also with vegetation and land use. Their work was subsequently expanded by Churchward *et al.* (1988) to cover the bulk of the south coast from Northcliffe to Mt Manypeaks. The descriptions provided in this latter work facilitated the establishment of linkages between the geomorphology, landscape and vegetation.

Parallel to the work of the CSIRO Division of Land Resources by Mulcahy, McArthur and Churchward, the Department of Agriculture commenced the Land Resources Series which assisted in filling in some of the gaps in geomorphological mapping. Initially the latter mapping did not include areas of State Forest. The areas mapped were the Darling Range, east of Perth (King and Wells 1990) and the Northam Region (Lantzke and Fulton 1992). In the southern region, Tille and Lantzke surveyed the Busselton - Margaret River - Augusta area in 1990. The last study of Churchward in Manjimup (1992) formed part of this series. Currently work is in progress on the Blackwood Plateau between Tille and Lantzke's and Churchward's maps and the largest as yet unmapped area south of the Blackwood and east of Manjimup. There have been minor differences in the approach from the CSIRO and Department of Agriculture researchers, nevertheless both approaches have provided linkages between geomorphology and vegetation which will facilitate the vegetation project for the South-West Forest Region in Western Australia.

2.24 Development of Dieback Mapping in relation to Site-vegetation Type Mapping

After Havel (1975b, 1979a and b) demonstrated the relationship between site-vegetation types and the occurrence of the dieback disease caused by *Phytophthora cinnamomi,* various agencies and consulting groups used site-vegetation type mapping as a means of predicting the disease risk and potential hazard. Shearer *et al.* (1987) sought to refine the most critical range of the vegetation continuum for dieback expression. The relationship between site-vegetation types and the expression of the dieback disease in the southern region was defined by Strelein (1988) and later refined by Grant and Blankendaal (1988). Extensive areas have been subsequently mapped from the point of view of dieback hazard using plant indicator species and vegetation as an aid in mapping. In this latter work the emphasis has been on the interface between the P and S site-vegetation types as defined by Havel (1975a and b) which is considered to be the best predictor of the highly susceptible and less susceptible sites.

Shearer and Tippett (1980) placed an emphasis on the hydrological aspects of Havel's site-vegetation type classification, such as shedding of moisture from convex slopes and steeply dissected slopes, and the accumulation of moisture in weakly dissected landscapes with concave slopes and depressions. They also related severity of impact of the disease to the floristic composition of the particular site-vegetation types, in particular the proportion of species from the highly susceptible families, Proteaceae and Epacridaceae.

2.25 Havel Land Consultants 1987

Havel Land Consultants (1987) has carried out environmental impact studies for the Water Authority of Western Australia. The studies were primarily predictions of the likely impact of dam and pipeline construction, on the vegetation within State Forest and Reserves. An appropriate technology was developed for the purpose. The field work consisted primarily of across-the-valley transects covering the likely areas to be inundated. The vertical reference frame developed for the proposed engineering works was utilised to reference all observations of vegetation and the relevant environmental factors. The data was entered into OMNIS programme on Apple Computer and the impact determined by specifying the level of inundation for the varying engineering options. The observations were carried out along transect lines at 50m intervals and consisted of total numeration of all species on circular plots with radius varied according to the size of the vegetation component being observed, eg largest for trees and smallest for herbs. The OMNIS database made it possible to extract information on the occurrence of any individual species anywhere within the river basin studies. The main benefit from the ecological point of view is the strong accent on vertical distribution of the plants and of edaphic and topographic features. Because of the accent on river basins the study made up for the deficiencies of earlier studies in which there was a bias towards the upland surfaces of the Darling Plateau. The basin studied covered quite a wide climatic range as well as considerable geological variation. The northern most of the river basin study (Mundaring) combined low rainfall with strong development of non-granitic basement rocks especially migmatite, as well as steeper than usual slopes. Consequently the dominant vegetation types were those containing wandoo woodlands Y, L and M and shrublands of type G. There was an abnormally high development of indicators of fertile sites. The lower Canning basin and the North Dandalup basins contained vegetation of more normal type, that is, developed mostly on granitic basement rock with only moderate degree of dissection. The types encountered were correspondingly of the more common types (W, C, T, Q, P) though there was still a considerable development of types G and R. The upper Canning basin (south Canning) consisted primarily of very broad mildly sloping valleys with extensive flat floors that were poorly drained. The dominant types in this catchment were therefore types A, B, W and Y. The definition of types was carried out to a finer degree than Havel's 1975b, in that a high proportion were classified as being intermediate types. It was also found necessary to subdivide the extreme types inadequately covered by Havel classifications, that is A and especially G. All the types classified as R, G or their derivatives were subjected to additional analysis using Minimum Spanning Tree (MST) programme EM420 (program developed by E.M. Mattiske and Associates, which is based on the published work of Rohlf 1973). The programme delineated clusters which were summarized in the form of Minimum Spanning Trees and Linkage Dendrograms.

2.26 Strelein 1988

The work of Strelein (1988) on the Darling Plateau south of the Blackwood River and on the adjacent Southern Coastal Plain had as its objective the classification of the southern jarrah forest as an aid to forest management, in particular silviculture. It also followed the methodology of Havel, to greater degree and to a further extent than that of McCutcheon. The classification was not seen as an aid to soil survey, but as an objective in its own right.

The sampling was stratified on the basis geomorphological classification of McArthur and Clifton (1975). There was a tendency to link the sample plots along a transect, the degree to which this was done being determined by the variability of the sampling area. The sampling plots were circles with 20 m radius, within which the set of indicator species was assessed on the basis of cover. The tree stratum was described in detail on the basis of several silvicultural and mensurational parameters. Each plot was also sampled for soil, in form of soil profile description and a laboratory sample, which was subsequently analysed for both physical and chemical parameters.

Strelein subjected the original data set to preliminary statistical analysis using Reciprocal Averaging program RECAV (Hill 1973), which proved of limited use because it tended clump the data excessively. A locally developed program MAYHAP, which derives a matrix of V-coefficients (Krebs 1972) helped in the understanding of underlying environmental factors and assisted in the reduction of the data pool to a manageable size for the principal component analysis (PCA), which was the main statistical tool used. The program used was SPSS R-type with varimax rotations. To reduce clumping and congestion square root transformation was used. The initial output, the loadings on the components, was used to constructs a four dimensional model of the location of the various species within the component space. The model made it possible to interpret the interspecific relationships and to assess the underlying factors. The second stage of the output, namely component scores for the plots obtained by the use of program FACVA, was also used to construct a four dimensional model showing the position of the plots within the component space. To facilitate interpretation, the component scores were also used to develop a set of two dimensional diagrams by means of the CORD ordination program, in which any of the plot attributes could be displayed. The plot parameters examined were soil and site data as well as the individual species present on the plots. The first component reflected soil structure and fertility, in a continuum from leached sandy duplex soils to more fertile earths with gradational profile. The second component combined climate and dissection, from the deeply incised valleys in the moist southwest to the drier plateau in the northeast. The third component reflected moisture regime and texture, from sandy swamps to dry loams. The fourth component reflected fertility and soil drainage.

Using the four-dimensional models, Strelein defined a set of site-vegetation types, which he then examined in terms of vegetation components and site attributes, using the program CORD and Discriminant Analysis from the SPSS package. He also used the same combination of programs to define the silvicultural characteristics of these types.

The chief value of this study is the meticulous way in which Strelein tested a very wide range of indicator species, both in terms which environmental factors they reflect and the precision with which they do it. Only a minute fraction of these analyses is actually displayed in the report, but the original computer outputs are still available.

Some of the site-vegetation types defined by Strelein bear considerable similarity to Havel's northern site-vegetation sites and even are identified with the same letters of alphabet, though in addition to the indicators that respond to edaphic factors almost irrespective of climate there are also indicators which reflect the cooler and moister climate of the southern jarrah forest. In addition there are types which bear no close resemblance to the northern types but reflect the dominance of depositional rather than erosional processes on the southern coastal plain.

Regrettably, Strelein's work was not progressed to the next stage of actually mapping areas of the southern forest to test if his types are real and to determine what part of the landscape they occupy and how extensive they are. Before leaving the field, Strelein did, however, attempt to relate his site-vegetation types to the geomorphological classification of Churchward *et al.* (1988), which was in process of development in the southern forest region at the time.

Although Strelein restricted his sampling to jarrah forest, there are two of his types that contain small proportion of karri and provide an overlap with and link to the corresponding study of the karri forests by Inions *et al.* (1990a and 1990b). Its also links up with the classification of the southern coastal plain by Wardell-Johnson *et al.* (1989), which overlaps with it in extreme southeast.

2.27 Inions *et al.* 1989, 1990a and 1990b

The studies of Strelein (1988) and Inions *et al.* (1989, 1990a and 1990b) marked the beginning of a new era in vegetation classification in southwestern Australia. In a sense Inion's work is transitional, at least in the objective, in that vegetation was still studied as a means to an end rather than an end in itself. The purpose of his study was to derive criteria for the classification of the regenerated forests of karri, for the purposes of economic management. The location of the sample plots was also management-driven, in that they corresponded to permanent inventory plots used to monitor growth of the stands. As the inventory plots were well stratified across the geographic range of karri, the linkage was not necessarily detrimental.

Altogether Inion sampled 204 plots distributed over the main range of karri from south of Nannup to Irwin Inlet east of Walpole.

Inion's study also resembled earlier studies in its accent on environmental factors as well as the vegetation, in fact it probably represents the most thorough study of this kind in Western Australian forests. The climatic data for the plots was derived by means of the Bioclimatic Prediction System of Booth *et al.* (1988) and included parameters which would not be normally available, such as radiation and evaporation, as well as seasonal variation in the more common criteria such as rainfall and temperature. The sampling of the soil parameters was also more detailed than in earlier studies, combining both superficial and deep sampling, at 10 cm depth and below.

However, it was in terms of analytical methodology that the study marked a major advance, based on corresponding advances in mathematical statistics and computer capability. The environmental parameters were standardised, a matrix of dissimilarities calculated and the polythetic agglomerative strategy using unweighted pair-group method and arithmetic averages

(UPGMA) was used to impose structure to the association matrix. Other strategies employed were the space dilation favouring even-sized groups, and ordination by principal co-ordinate analysis. Separate classifications were carried out on edaphic and climatic attributes, resulting in 5 soil groups and 8 homoclimes respectively.

The soil groups ranged from relatively infertile acidic soils to the least acid soils with high fertility. The homoclimes ranged from coastal sites with high rainfall, low temperature and low radiation to inland sites with medium to low rainfall and higher summer temperatures, resulting in an overall drier climate. The climatic factors appeared to have a clearer effect on the performance of karri than the edaphic factors, bearing in mind that by restricting the sampling to regenerated karri stands the edaphically more favourable sites would have been selected. The less favourable sites in the region, carrying jarrah, were covered by Streleins's study.

Because of concern about the influence of plant development (succession) on the relative importance of the species within the plots, all plant data was recorded in binary form, presumably as just presence or absence. The community types were defined using agglomerative hierarchical cluster analysis, employing the Czekanowski coefficient. As in the case of the environmental parameters, an association matrix was imposed using the polythetic agglomerative strategy using unweighted pair-group method and arithmetic averages (UPGMA) was used to impose structure to the association matrix. Also used was the space dilation strategy favouring even-sized groups. Both normal (ecological tolerances) and inverse (species analysis) was carried out using the methodology and terminology of Austin and Belbin (1982). In the case of the species analysis, the TWO-STEP procedure was used to calculate the measure of similarity. Instead of defining the community types by letters as had been done in previous forest site classifications in WA, Inion used the names of prominent retired foresters. He considered the definition of the community by component species as impractical, as a number of species would be needed for each community type.

Inions defined five community groups and subdivided these into thirteen community types. Relationships were sought between community types and environmental variables by ordinating the community types on original environmental parameters. The types were ordinated in three-dimensional space on the basis of precipitation in the driest quarter, radiation in the driest quarter and phosphate content of the soil. The parameters used in the ordination are probably the most significant environmental constraints in the region. The extremes of the three-dimensional continuum were the Harris type of the leached soils in the cool and wet climate of the south coast, and the McNamara type occurring on more fertile soils in drier and hotter inland margin in the north of the species' distribution. Inion *et al.* (1990a and 1990b) also considered the ordination in component space defined from edaphic and climatic variables by Gower's (1971) principal co-ordinate analysis, but did not carry it out.

Inions provided a set of indicator species which covered the continuum. Some of his more marginal types contained some jarrah and thus overlapped with Strelein's classification, providing a link between the two classifications which covered a similar climatic region.

2.28 Wardell-Johnson *et al.* 1989

Although the study by Wardell-Johnson *et al.* (1989) was published slightly earlier, it is discussed after Inion *et al.* (1990a and 1990b) studies because it differs from earlier studies of southern forests not only in methodology but also in objective. Its primary objective is the study of vegetation in a National Park, for the purpose of defining sites with similar floristic composition, with the ultimate aim of protection and management of that vegetation. It shares with Inions studies the taxonomic and computational expertise, in that basically the same personnel was involved. In terms of the area studied and in terms of climatic factors it is little more than a small subset of the area studied by Strelein (1988) and Inion *et al.*(1990a and 1990b), but as it did not confine sampling to a particular forest formation or type, it covered a much wider edaphic and floristic range than either of these studies. In particular it gives much better coverage of the less favourable sites, such as dunes and swamps. A total of 219 sampling sites, covering the whole of the Walpole National Park of 17986 ha, was established in 1985 and 1986. The location of the plots was based on the geomorphological studies of Churchward *et al.* (1988). The plots were large (10m x 10m) quadrats within which the species were recorded on a scale of abundance developed by Havel (1975a), from 1 for rare to 5 for species completely dominating the site. In addition soil description to the depth of 1m was also carried out the structure of the community was described according to Smith's (1972) and Specht's terminology.

The first step in the analysis of the data was the elimination of singletons in order to reduce stochastic variation. As a next step a matrix of pairwise associations between sites was calculated using the Gower (1971) metric, supplemented by Belbin *et al.*'s (1984) programme BIGD to ensure normal distibution of the association measures. As in the case of the Inions *et al.* (1990a and 1990b) studies, an association matrix was imposed on the floristic data using the polythetic agglomerative strategy using unweighted pair-group method and arithmetic averages (UPGMA) was used to impose structure on to the association matrix. The coefficients used were such as to enforce space-dilating strategy and resist the formation of a single large group. The acceptability of the imposed groups was tested by means of Principal Co-ordinate Analysis (PCA). The species analysis, that is the classification of species by sites, was carried out by the procedure TWOSTEP, which defines groups of species with similar ecological tolerances.

The defined groups of species and suites were then merged and presented in a two-way contingency table. Species with poor power of discrimination were excluded from subsequent analysis and species with high site fidelity were identified by discriminant analysis (Fisher 1936) to maximise the separation between community types and provide the basis for the allocation of unclassified sites to defined groups.

On the basis of the above analyses three broad groups, interpretable in terms of landform and drainage characteristic, were then defined, namely poorly drained sites on granitic parent material or fluvial sediments, freely drained sites with good-moisture retention capabilities and sites on deep aeolian sands. To improve resolution twelve groups were also defined at the next level, and the resulting community types were ordinated. The first three axes accounted for 43.8% of the variance. The community types were named by the most characteristic species, by the dominant vegetation structure or by landscape feature. Many of the community types of the first two categories can be related to the classifications of Strelein and Inion, who, however, did not sample the aeolian sands.

Of the 233 species originally used in the analysis, 52 were isolated on the basis of their strong fidelity, for discriminant analysis. It was found that allocation to correct groups did not deteriorate if the data was converted to binary form, which is preferable for field use. Of the 24 sites sampled close to the original samples, 92% were classified to correct community type.

In the hill areas of the Walpole National Park there are sharp ecotones over short distances, and the soil components within the various landforms appear to be stronger determinants than the landforms of the community types, many of which occur in more than one landform unit. In the swamps, the boundaries are more diffuse and the community types tend to be associated with particular landform soil units. The communities on the aeolian sands occur in a very complex pattern and have greater species richness.

The study found a lack of congruence between floristic community types and structural data.

Subsequently Wardell-Johnson commenced study of the forests and woodlands to the north and east of Walpole National Park, and mainly east of the areas surveyed by Strelein (1988) and Inion *et al.* (1990a), though there is a degree of overlap in the west. The region, named by Wardell-Johnson *et al.* (1995) the Tingle Mosaic after three endemic eucalypts, covers an area of 3,700 km2 along the south coast and its hinterland. It is a subset of a larger area covered by Churchward *et al.*'s (1988) landform and soil maps.

The climate in the area is quite diverse, having a gradient in annual rainfall from 750 mm in the northeast to 1400mm in the southwest. The temperatures are higher along the coast in the winter and lower in the summer, than is the case inland.

The study incorporates the floristic data of Wardell-Johnson *et al.* (1989), but additional 441 quadrats (20m x 20m) have been added. The location of the plots was based on Churchward *et al.* (1988) geomorphological maps, with preference being given to areas in existing conservation reserves rather than private property or road reserves containing relatively undisturbed vegetation. All quadrats were marked in permanently and were checked at least twice. Basal area was used as the index of the biomass of the trees. In addition to the floristic data, description was made of the site in terms of climatic variables derived from BIOCLIM, description of the topographic factors such as slope, aspect and occurrence of rock outcrops. The soil parameters determined were the depth to a constraining layer, and substrate of the plot was described in the broad categories of granite, sandstone/siltstone, aeolian sands or none. In addition to the soil profile description obtained from a pit in the centre of the plot fifteen superficial (10 cm depth) samples were collected from 15 locations within the plot, pooled in to five composite samples and analysed for both physical and chemical properties.

The floristic data, containing 857 vascular species on 441 quadrats, was analysed by means of the cluster analysis (Czekanowski metric, UPGMA) and ordination (SSH program of PATN). The process generated five floristic community supergroups, 12 community groups and 44 community types. The supergroups were considered to be sufficiently discontinuous to require separate ordination to get higher resolution of the floristic assemblages within them. The supergroups were described as

Shrubland/woodland
Dune
Swamp and outcrop
Open forest
Tall open forest.

The diagram showing the clustering process was terminated at 44 community types which appear to be well defined, but the floristic data was reported at the level of 12 community groups. All community types were described in terms of their broad climatic and edaphic parameters, and in terms of floristic richness. They ranged from tall open forest of karri and tingle to coastal herblands in terms of height, and from swamps to rock outcrops in terms of site.

Tabulation of the areas covered by the various geomorphic units within the study area was also given, as was a complete ennumeration of species within the study as a whole, and within the twelve community groups. Some of the community groups are too broadly defined and difficult to grasp in terms of indicator species, in particular the group containing wandoo woodland and outcrop, in which there are 11 quite heterogeneous types.

An attempt to relate the community groups to site vegetation types and indicator species groups generated by earlier vegetation studies in the region (Strelein 1988, Inion *et al.* 1990a, Wardell-Johnson *et al.* 1989) has been only partially successful so far, partly because of the heterogeneity of some the community groups for which floristic data has been reported. The open forest (D) and tall open forest (E) communities relate well to forest types described by Strelein and Inion, and one of the dune types (Meerup - B1) relates well to indicator groups defined by Wardell-Johnson *et al.* (1989). It appears to be floristically closer related to community group A4 (Woodland on sandy crests and valley divides) then to the other dune type (Interdune plain and swamp - B2), which has greater affinity to C1 (Peat swamps) and C2 (Saline swamps). The community group C3, which is wrongly labelled as Peat swamps but is really wandoo woodland and outcrops, has a tight group of rock outcrop indicators and another group from wandoo woodlands, but is otherwise too heterogeneous, with plant indicators from the opposite ends of the environmental spectrum. Similarly the first three woodland community groups (A1-3) have less in common with A4 than with the open forest groups D1 and D2, with whom they share a large number of indicators characteristic of the jarrah forest.

It would appear from this that in a large data set the definition of groups cannot be left entirely to computer programs and simple numerical rules. The termination of the clustering process which was appropriate to the forest groups was inappropriate to the more extreme sites. The highest level clustering, at the level of supergroups, appears to have generated only two truly homogeneous groups, those of the open forest and tall open forest.

2.29 Mattiske and Burbidge 1991

Mattiske and Burbidge established a series of permanent sites in the John Forrest National Park and the Red Hill area as part of a wider series of biogeographical studies for the Department of Conservation and Land Management (Mattiske and Burbidge 1991). The latter specific project within the John Forrest National Park and Red Hill area was funded by the Heritage Council of Western Australia.

2.30 Smith 1994

Relatively little was done in the field of vegetation mapping on the Blackwood Plateau until the study by Smith (1994) on Two Rare *Chamelaucium* species. Smith (1994) attempted to use McCutcheon's classification as ecological reference but found that some of the areas in which he was working were more dissected, more fertile than any of the types described by McCutcheon and that the could in fact be better described by Strelein's classification. His thesis is an indication of this type of variation. Smith felt that additional vegetation classification and mapping was needed on the Blackwood Plateau. Smith also surveyed a small conservation reserve near Margaret River township, west of the Blackwood Plateau.

2.31 E.M. Mattiske and Associates, Mattiske Consulting Pty Ltd 1979 to 1996

E.M. Mattiske and Associates and Mattiske Consulting Pty Ltd (1979 to 1996) have carried out extensive vegetation assessments and vegetation mapping projects for a range of mining companies, and in particular Alcoa of Australia Limited and Worsley Alumina Pty Ltd operating in the South-West Forest Region. The data collected includes detailed measurements in established vegetation plots (20m x 20m and 40m x 40m) and extensive vegetation mapping on various grid systems (60m x 120m; 120m x 120m; 200m x 100m). The data collected for a range of common and indicator species on the various grid systems was based on the ranking scale of 1 to 5 (as developed by Havel 1975a) within a 5 metre radius for the understorey species and within a 20m radius for overstorey species. Data has been collected in some 150 or so permanent vegetation plots and at more than 25,000 sites to date for these clients and has been analysed in various ways. Each project area has been mapped at a scale of 1:10,000 using the site-vegetation type system as developed earlier by Havel (1975a and 1975b). In most areas it has been possible to further subdivide the site-vegetation types to another level of definition (for example, the previously broad S site-vegetation type which occurs on well-drained lateritic gravel areas on the mid to upper slopes has been subdivided into ST, SP and SW and the broad G site-vegetation type which occurs on areas associated with shallow soils over granitic outcrops has been subdivided into G1, G2, G3 and G4 for mapping in the eastern areas). This further subdivision has been made on the basis of structural differences (particularly for woodland, shrubland and herbfields on extreme sites such as the G type) and floristic differences (particularly for types which occur on more subtle soil moisture and composition changes). Many of these subdivisions have been critical in operational decisions such as hygiene management for forest diseases. In addition, several new types have been defined and includes the X type which is dominated by *Eucalyptus rudis* (flooded gum) woodland over *Melaleuca incana* (formerly *Melaleuca polygaloides*) and *Acacia saligna* on the fine particle clay soils in the eastern Yarragil and Pindalup valley systems as defined by Churchward and McArthur (1980). The latter reflects the wider coverage of the studies by Mattiske and her team throughout the northern and eastern jarrah forests.

After further negotiations are undertaken these data sets should enable additional checking of the relationships between the site-vegetation types and the proposed expansion to the vegetation complexes and potential higher order mapping systems proposed such as the ecological vegetation systems.

In recent years, further vegetation mapping has been undertaken in the southern coastal areas by Mattiske Consulting Pty Ltd (1996). For example, some of these areas have occurred within Scott National Park. In this Park, Mattiske Consulting Pty Ltd (1996) described a total of 21 plant communities and grouped these into 8 groups ranging from Sedgelands to Open Forest. Many of the species groupings recorded by Mattiske Consulting Pty Ltd are similar to those recorded on coastal plain north of Perth by Havel (1968), but in addition there are many species with southern affinities recorded by Wardell-Johnson *et al.* (1989, 1995). Some of the communities developed on shallow sands over iron pans, were quite unique, with a high proportion of endemics and rare species. Overall the vegetation communities reflected predominance of swampy condition, rather like some of the coastal plains reported by Wardell-Johnson from the vicinity of Walpole.

2.32 Griffin 1992

Somewhat later Griffin (1992) undertook a detailed study of vegetation within the region immediately to the north of System 6, with some degree of geographical overlap. It covered an elongated north-south rectangle from Moora in the north to Chittering in the south. Whilst only the southern third of Griffin's study is relevant to this project, the study is important in that it covers the northern and eastern margin of many species. It also provides a good counter balance to earlier studies of Loneragan (1978). It has a markedly different objective, namely to identify the full range of floristic variation within the region. This region is, on one hand, floristically very rich, but on the other hand, has been strongly affected by agricultural activities over the past century. The survey is thus basically the survey of remnant vegetation. The region has a totally inadequate system of reserves except in the extreme southeast. It overlaps to certain degree with the region studied by Loneragan.

Griffin (1992) sampled quadrats of 100 m^2, which he regarded as releves (plant list), for which he recorded all species by the estimate of the canopy cover based on the Domin-Krajina Cover Abundance Scale (Mueller-Dombois &Ellenberg 1974). He also recorded the vegetation structure in terms of Muir's (1977a and 1977b) classification and the relevant topographic and edaphic information. Altogether he collected 479 releves, scattered in clusters throughout the region, mainly but not exclusively on reserves. These he incorporated into a database, which he analyses by means of a package of programs called PATN (Belbin 1987a and 1987b). He attempted to use the programs for three basic functions:

a) to produce groups of releves according to their species composition, and hence define floristic types
b) to identify differences between vegetation types, to hypothesise about them and to test them
c) to display the results.

The programs used were ASO (similarity measures between releves - rows), FUSE (combination of rows into groups), DEND (display of the progress of fusion), KYST (multi-dimensional ordination program), MST and TWAY (other data display programs). Initially Griffin chose 35 groups of releves which he decided to recognise as distinct vegetation types, with the provision of subdividing these further into sub-types or variants. Ultimately he arrived at 45 groups. In deciding on the groupings, he was influenced constancy and fidelity of the species.

He also attempted to produce an ordination diagram which would summarise the information in few dimensions, but even with 15 vectors the level of "stress" was considered to be excessive and the technique was abandoned because of the extreme heterogeneity of the data.

Instead Griffin displayed the outcome of the analysis in the form of a minimum spanning tree, showing the relationships between the vegetation types. In relating the vegetation types to edaphic and geologic units Griffin found that vegetation is more influenced by geological substrate than by surface soils. There was also a strong relationship with topography, in particular as it reflected the stripping of the plateau by erosion. On the basis of analysis Griffin recognised a number of floristic regions, of which two, namely Bindoon and Julimar, fall within the project area. He tentatively considered them to be part of the Darling District, rather than of the Avon District to the east and north.

Within these two regions, he identified 25 groups, most of which occurred in both regions, but some were specific to Julimar (sand and swamp types) and some to Bindoon (rock outcrop types), which reflects the respective degree of dissection of the two regions. The largest groupings were those identified with woodland dominants (jarrah with 40 releves, wandoo with 85 releves and powderbark wandoo with 32 releves). These correspond broadly to Loneragan's (1978) dominance types, and are broader than Havel's (1975a and 1975b) site-vegetation types. However, the precision of definition is much greater for the numerous sub-types into which the large groups have been subdivided. On the more extreme sites, such as swamps and rock outcrops, Griffin has arrived at much more finely defined groups than those of Havel, complete with their "faithful" species and almost reminiscent of the Zurich-Montpellier (Braun-Blanquet) classification of southern and central Europe. Corresponding sites would not have been sampled by Loneragan.

2.33 Ecologia Environmental Consultants 1994

The central part of the proposed wandoo reserve (Cahill 1984) was, however, subsequently surveyed by Ecologia Environmental Consultants (1994), who established fifty-four (10m x 10m) quadrats and recorded 413 species over an area of 111,630 ha. The area surveyed overlapped with that studied by Loneragan (1978) and partially with that of Havel (1975 a and b). The area surveyed by Trudgen was a subset (3.5%) of it.

The species by site presence/absence matrix was analysed by Bray-Curtis dissimilarity measure for sites, the two-step dissimilarity measure for species and UPGMA clustering routine for both site and species (Belbin 1989). Semi-strong Hybrid Scaling was used to produce an ordination analysis using four dimensions (Belbin 1991). On the basis of the UPGMA clustering six community types were described. Of these, one consisted of one site only. The types were described in terms of the component species, enumerated by structural layers and by description of the average physical site characteristics. The community types can be related through the dominant stratum to Loneragan's sub-formations, and through both dominants and understorey species to Havel's wandoo types (Y, M and L), to the rock outcrop type G and the swamp type AY. One of the types, dominated by Eucalyptus accedens, has no near equivalent among Havel's types, though it does have a close equivalent among Loneragan's sub-formations. Ecologia did not attempt such comparisons, though it reviewed Trudgen's survey and considered the disparity in the number of types defined to Trudgen's use of unbounded sites and opportunistic collecting, as well as inclusion of non-wandoo types.

2.34 Gibson (unpublished)

The most recent study of the southern vegetation is that of Gibson (pers. com), who has done an extensive study of coastal communities along the southwestern coast, comprising 300 sites. The study has generated 30 groups. Some of the groups are geographically compact, others are spread all along the coastline from Meelup to Albany. The study has deliberately avoided the forest vegetation types, considered to have been largely covered by earlier studies. Some of the types described are similar, in broad description, to those described in the Wardell-Johnson studies (Wardell-Johnson *et al.* 1989, 1995).

2.35 Hopkins 1996

Hopkins (1996) and his colleagues have captured the earlier work by Beard for Western Australia in a Geographic Information System and associated Relational Database Management System. All the linework and descriptive detail was captured from the original working drawings, where these were available, or from published maps, all at a scale of 1:250,000. As part of this work there has been a rationalisation of boundaries and groupings for the production of the new 1:3,000,000 vegetation map for the entire State of Western Australia. In preparing a map at this scale the South-West Forest Region has been covered in very broad terms, however this work places the vegetation mapping project in the wider State context and biogeographical context which is relevant for its wider assessment.

3. REVIEW OF HISTORICAL DATA

A review of the historical data was undertaken by the authors and a range of issues arose during this assessment. These are discussed in the following sections.

3.1 Underlying Relationships between the Vegetation Patterns and the Climatic Factors

There appears to be a consistent picture arising between the climatic zones and the patterns of vegetation. To this end as part of this initial phase the possibility of climatic zones was considered by the authors. It appears on this initial review that the climatic criteria affect the vegetation at a sub-regional level (mainly the rainfall, evaporation and seasonal conditions) (see Figure 2 and Table 2).

A total of 6 climatic zones have been developed from the studies by Gentilli (1989); hyper humid; per humid; humid; sub-humid; semi-arid; and arid, see Table 2. It is expected that with further analyses the data presented in Table 2 may be a simplification of the relationships. These will need further validation and testing against the BIOCLIM data and field studies for determining vegetation mapping boundaries and also the higher order mapping ecological vegetation systems and mapping regions within the South-West Forest Region.

Table 2: Summary of Simplified Climatic Zones as developed from the studies by Gentilli (1989)

Climatic Zone	Annual Rainfall	Total Summer Evaporation
Hyper Humid	>1100 mm	<450 mm
Per Humid	>1000 mm	<525 mm
Humid	>1000 mm	<600 mm
Sub Humid	>1000 mm	<675 mm
Semi Arid	>600 mm, < 1000mm	<750 mm
Arid	<600 mm	>750 mm

These six were then divided into 8 climatic regions for testing in the vegetation mapping project; Arid & Semi-Arid Zone of Northern Darling Plateau, Arid & Semi-Arid Zone of Central Darling Plateau, Kojonup Semi-Arid Zone of Eastern Darling Plateau, Arid & Semi-Arid Zone of South Coast Hinterland, Humid & Sub-Humid Zone of Central Darling Plateau, Humid & Sub-Humid Zones of the South Coast Hinterland, Hyper Humid, Per Humid & Humid Zones of Blackwood Plateau, Cape Naturaliste to Cape Leeuwin Horst and Scott Plain and Hyper Humid and Per Humid Zones of the South Coast.

3.2 Underlying Relationships between the Vegetation Patterns and the Soil and Landform Factors

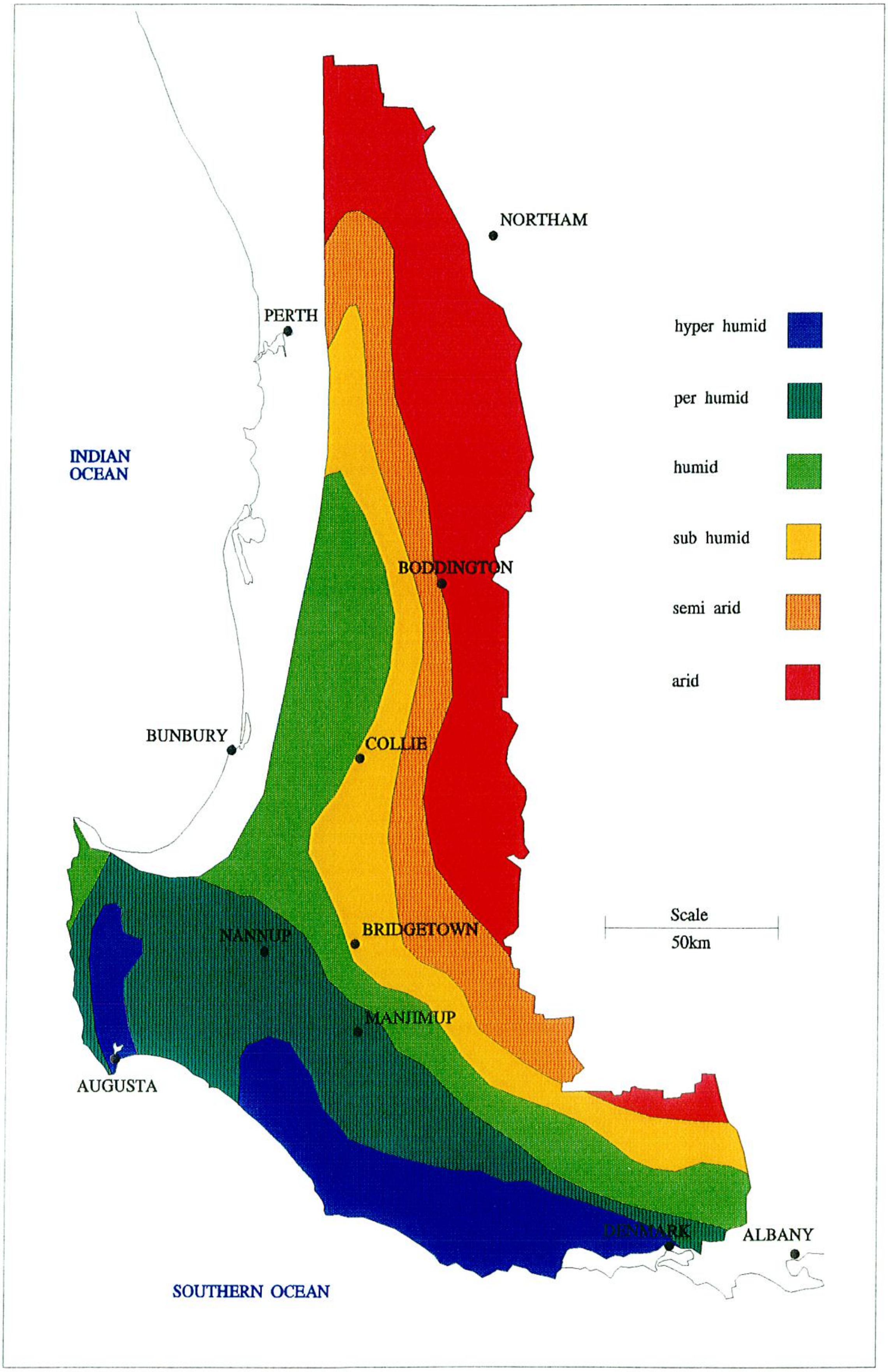
There appears to be a consistent picture arising between the soil and landform factors and the vegetation. To this end as part of this initial phase the possibility of continuing with the concept of vegetation complexes as a means of testing these relationships with soil and landforms with the vegetation has affected the sampling approach. In reviewing historical data there appeared to be a consistent pattern emerging with indicator species reflecting particular soil moisture regimes, physical types of soils, the degree of leaching and position in the landscape. These predictions will require testing in the vegetation mapping project as the data analysed.

It seems feasible that these relationships are present in view of the early observations by settlers on the floristic and structural composition of the forests and through the more extensive detailed studies by a range of authors such as Havel (1975a and 1975b), Strelein (1988), Heddle *et al.* (1980) and E. M. Mattiske and Associates and Mattiske Consulting Pty Ltd on more detailed projects. As a result of this initial overview the sampling regime for the vegetation project should cover as many options as possible in relation to the soil and landform units.

3.3 Overview of Previous Floristic and Vegetation Mapping Projects

The vegetation mapping has been largely regional in scale and has been primarily based on the structural formation level and the dominant tree species. In some recent discussions this has been defined as the "forest type" level. Despite the regional value of this information, which at the time was significant in its contribution to the understanding of the South-West Forest Region of Western Australia, it does not address the inherent diversity of ecosystems within these main forest types. For example, the work of Havel (1975a and b) highlighted the continuum nature of the jarrah forest. Further more detailed studies by Havel (1975b) at Mt Cooke, Ashendon, Leona and Flint survey areas highlighted the inherent variation within the jarrah forest communities.

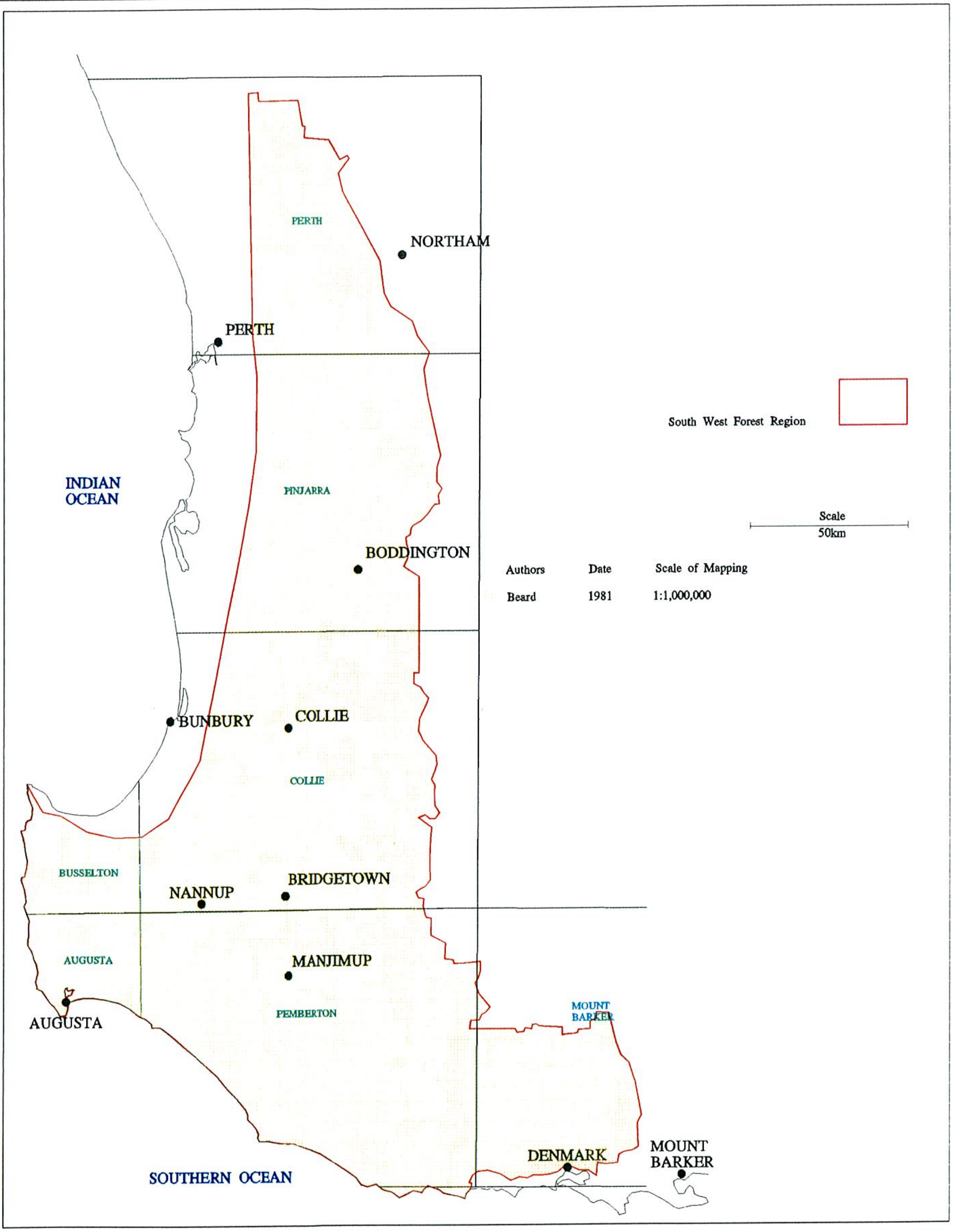
There has been a reluctance to map the vegetation by many authors, possibly due to the complexity of the systems within the South-West Forest Region. Exceptions have included the regional mapping of Beard (1979a, 1979b, 1979c and 1981) and Smith (1972, 1973 and 1974) which were major milestones in the South-West Forest Region (Figures 3a to 3f). In addition, the mapping by Heddle *et al.* (1980) achieved a finer scale of differentiation within the northern jarrah forest by the use of the vegetation complexes which linked the more detailed studies of Havel (1975a and 1975b) and the soil and landform mapping by Churchward and McArthur (1980).



CLIMATIC ZONES OF SOUTH WEST FOREST REGION OF WESTERN AUSTRALIA

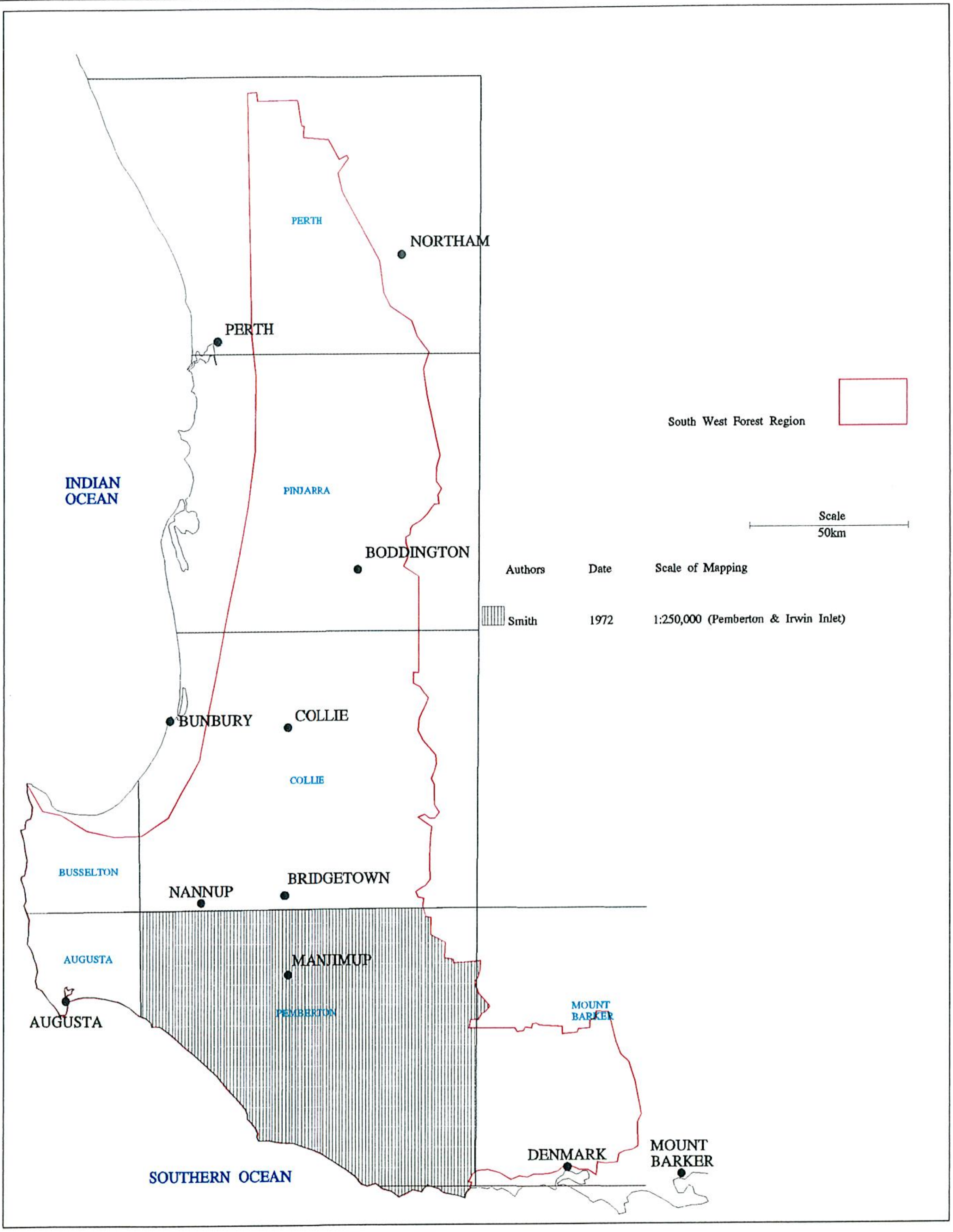
(developed from GENTILLI 1989)

FIGURE 2



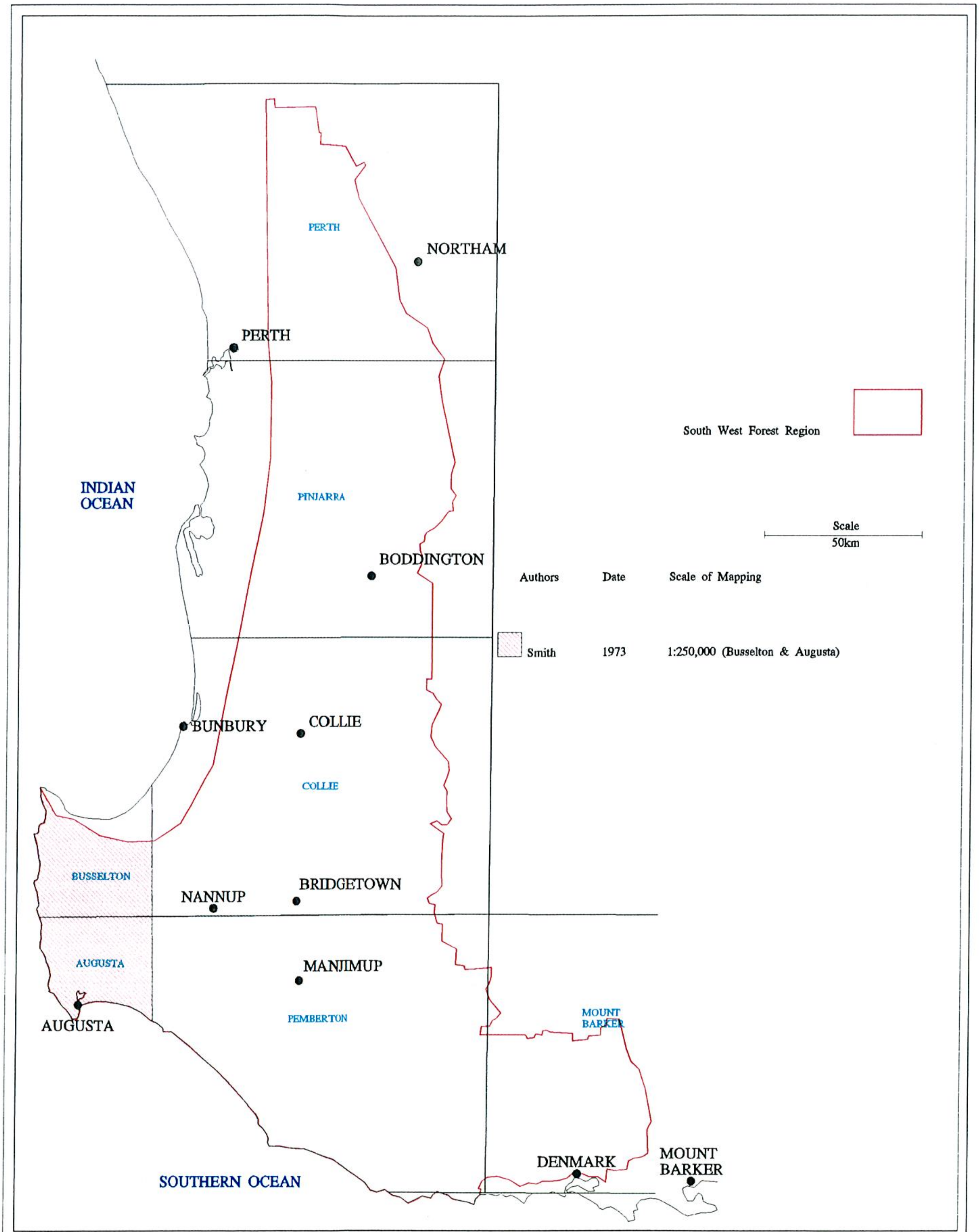
HISTORICAL REGIONAL VEGETATION MAPPING FOR SOUTH WEST FOREST REGION OF WESTERN AUSTRALIA

FIGURE 3 A



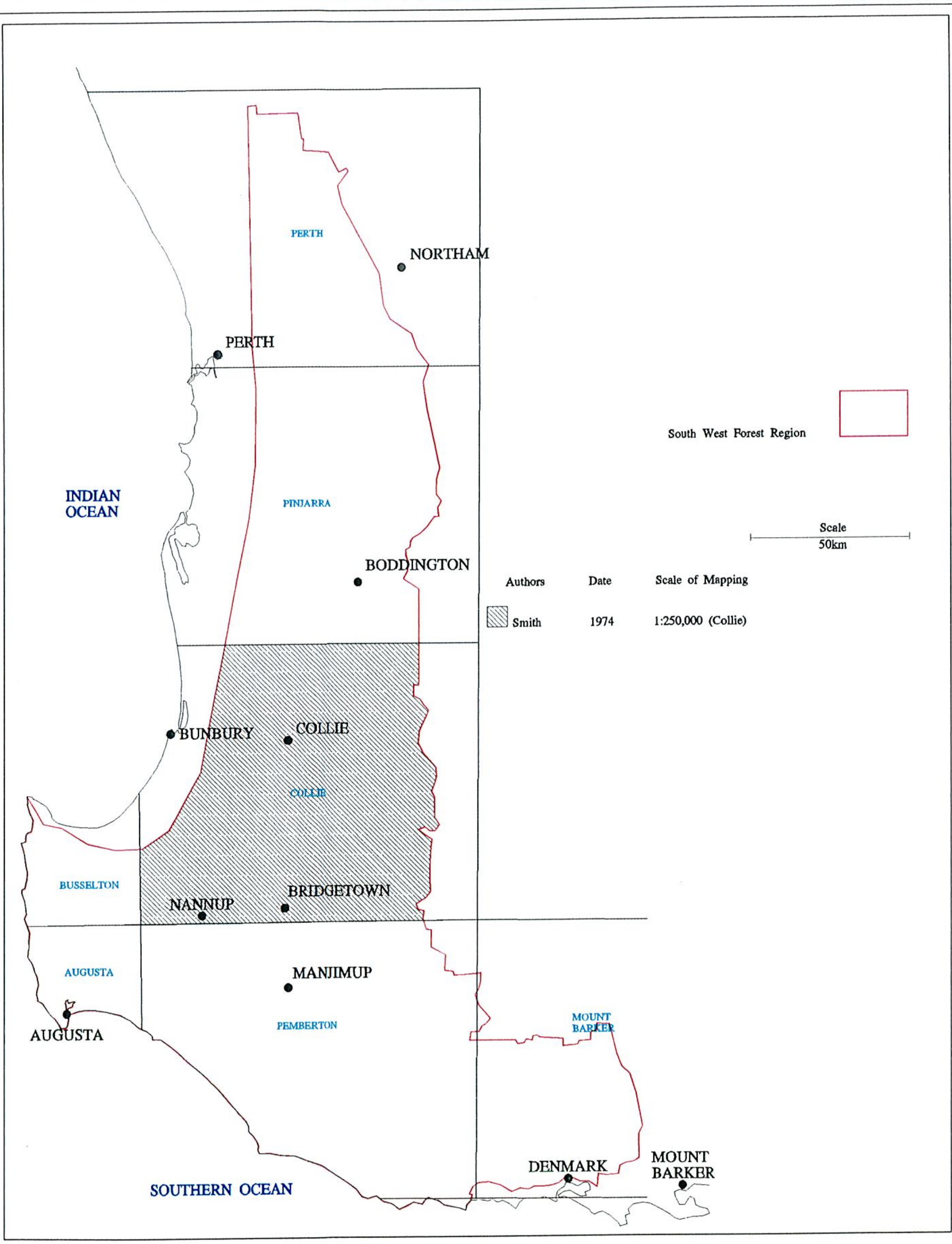
HISTORICAL REGIONAL VEGETATION MAPPING FOR SOUTH WEST FOREST REGION OF WESTERN AUSTRALIA

FIGURE 3 B



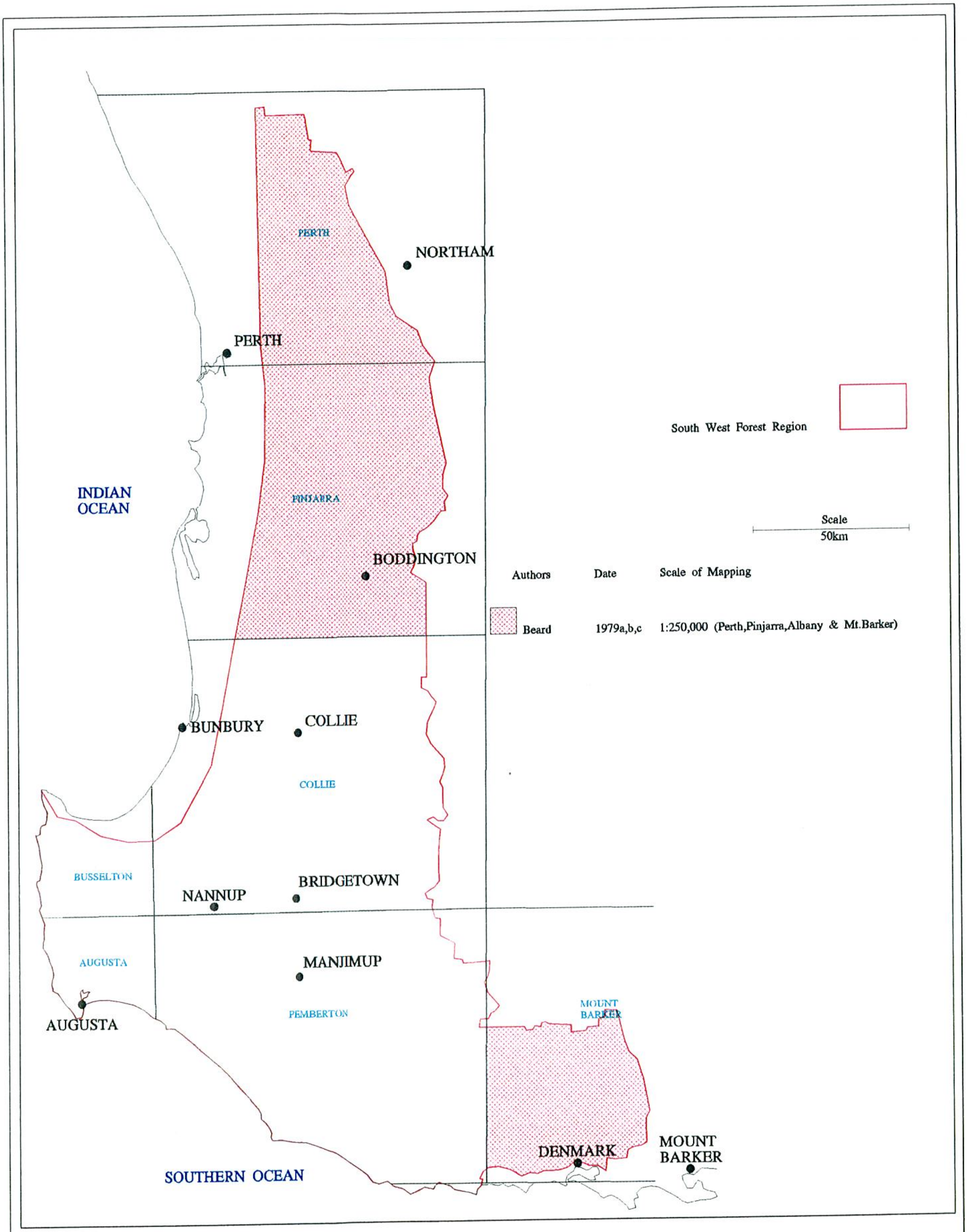
HISTORICAL REGIONAL VEGETATION MAPPING FOR SOUTH WEST FOREST REGION OF WESTERN AUSTRALIA

FIGURE 3 C



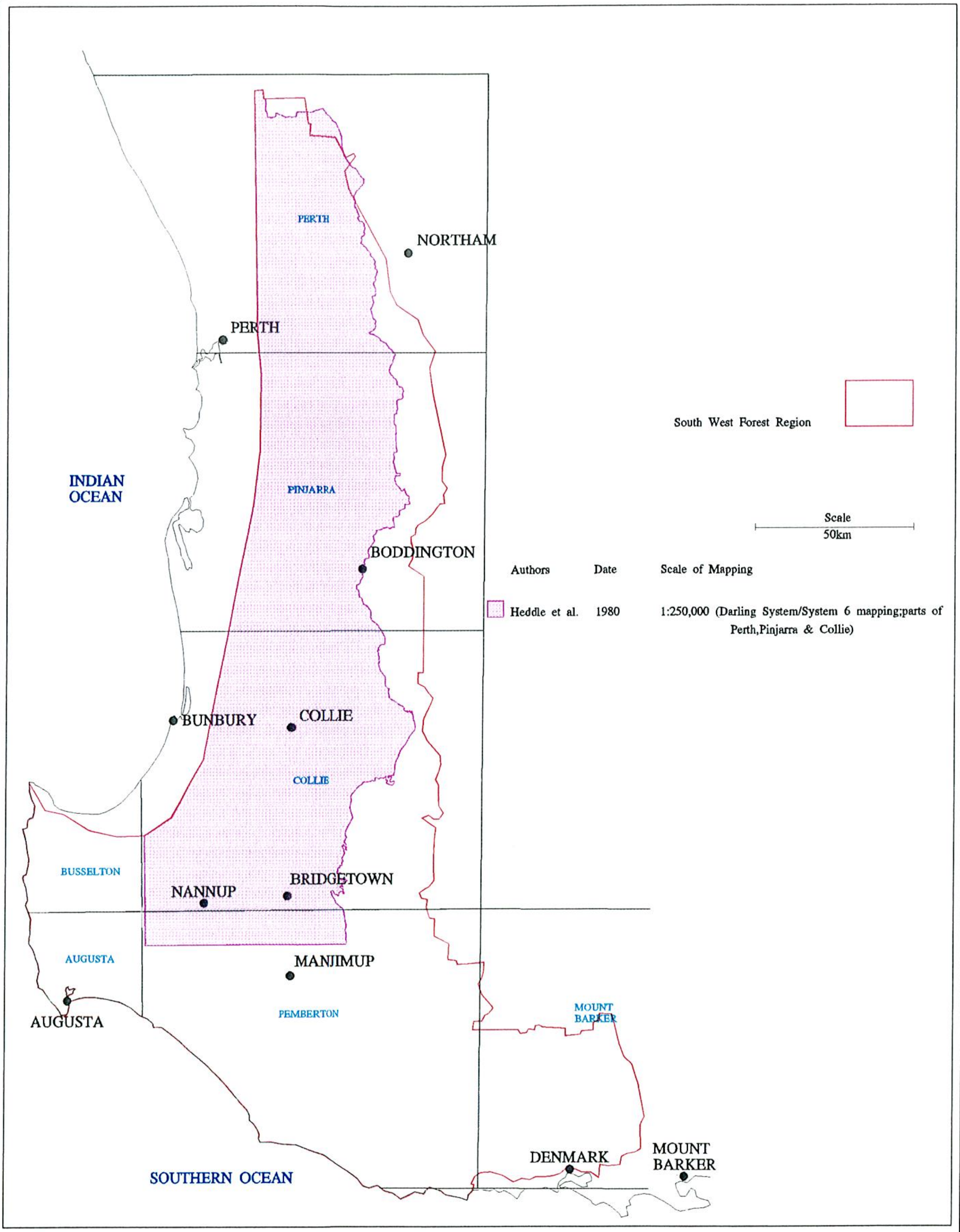
HISTORICAL REGIONAL VEGETATION MAPPING FOR SOUTH WEST FOREST REGION OF WESTERN AUSTRALIA

FIGURE 3 D



HISTORICAL REGIONAL VEGETATION MAPPING FOR SOUTH WEST FOREST REGION OF WESTERN AUSTRALIA

FIGURE 3 E



HISTORICAL REGIONAL VEGETATION MAPPING FOR SOUTH WEST FOREST REGION OF WESTERN AUSTRALIA

FIGURE 3F

In many of the studies undertaken in the South-West Forest Region there has been a reliance on floristic classifications (Figure 4). As indicated by this Figure there are substantial gaps in the knowledge of the floristic composition of the forested areas between Busselton and Augusta (in the largely cleared areas inland from the coastal studies by Gibson (unpublished)), in the areas between Collie and Manjimup and eastwards and then in the areas north of Denmark in the south-east forested areas. This latter maps illustrates some of the major gaps in information within the South-West Forest Region.

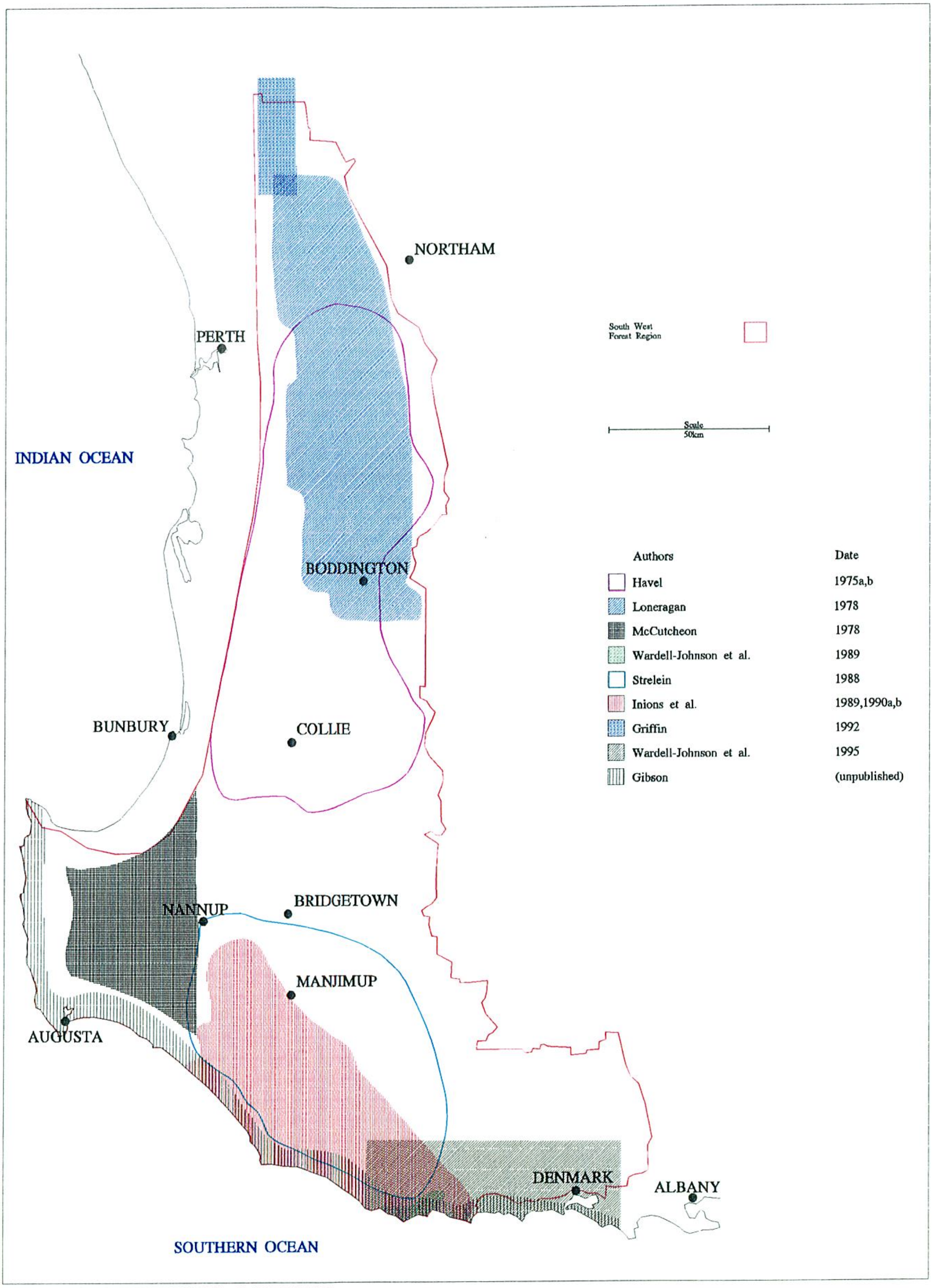
The latter gaps are further exemplified in Figure 5 which illustrates the main coverage of detailed and localised mapping at the site-vegetation type level (at 1:10,000). Several other smaller areas have been mapped; however these were localised and too small to present on this scale. In view the time scale required to map the South-West Forest Region at a detailed scale of 1:10,000 a system which reflects another level or levels of complexity are required in the vegetation mapping projects.

3.4 Data Base Issues

In reviewing the availability of historical data several key issues have arisen which have led to some additional smaller concurrent projects being developed, namely:

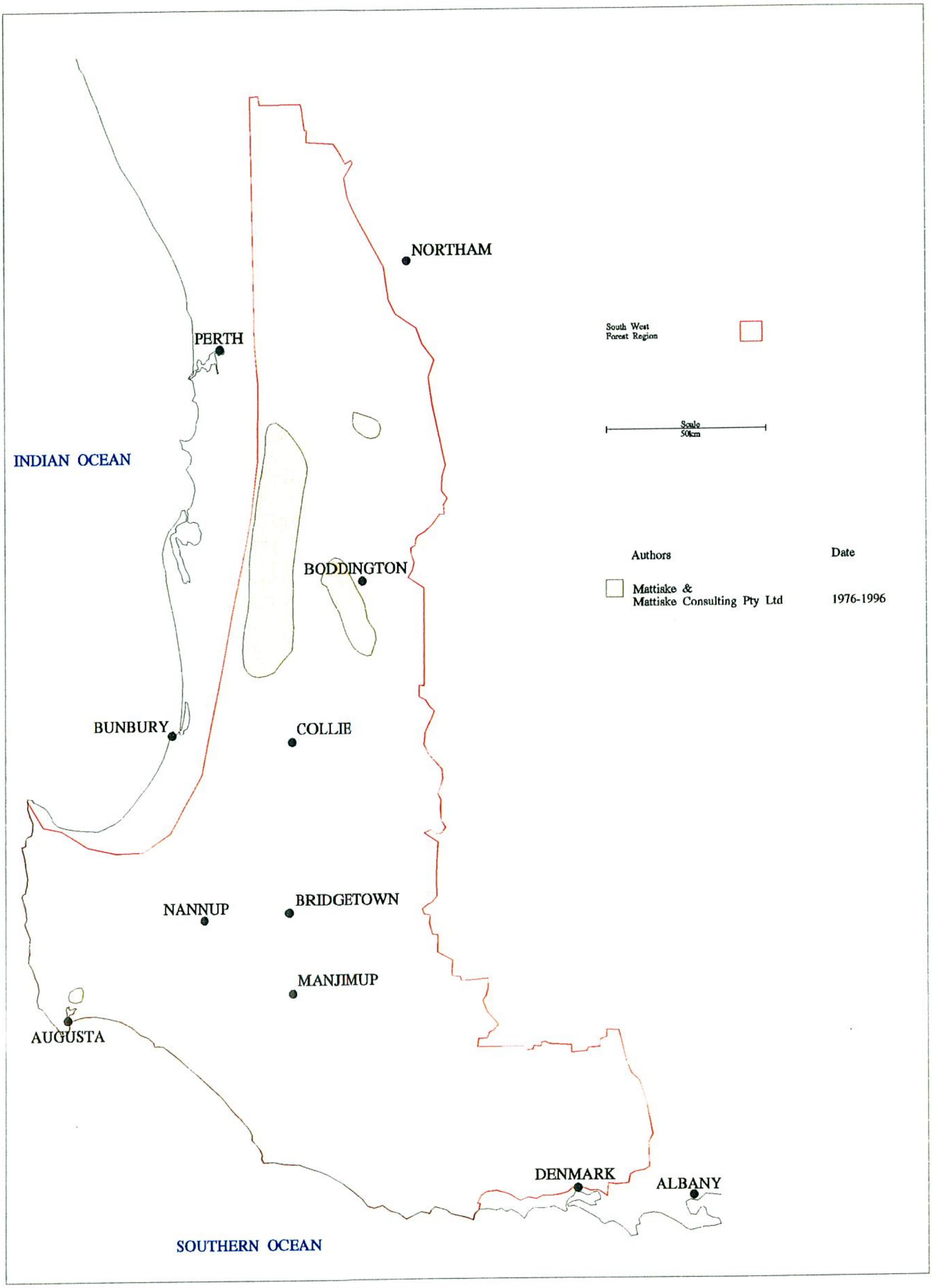
- The data base needs for the vegetation project in the South-West Forest Region are complicated by the high coverage in selected specific areas and large gaps in several areas (East of Manjimup, the south-west corner between Augusta and Busselton, the Blackwood Plateau or Donnybrook Sunklands, the south-eastern forested areas near Denmark and the eastern fringes of the northern forest areas), Figures 4 and 5. This variation will necessitate various levels of gap analyses. In areas where no historical data has been sourced the gap analysis is obvious and the use of the DAM tool kit is not warranted. In other areas the DAM tool kit will be required to further test these gaps in the vegetation mapping project. The degree of these gaps will be further refined after the point data has been integrated and summarised in the coming months by the vegetation mapping project team. Essentially two main types of gaps occur in the data set:
    - The first gap relates to the deficiencies in the spatial spread of the data sets, and
    - The second gap relates to the areas which have already been covered but which require infill sampling.

- The species on many of the historical data sets are no longer valid. This has necessitated a validation through WAHERB, SEDIT and more specifically the State Herbarium records a check on voucher specimen changes. In many instances the species in the historical data sets were not vouchered and then the knowledge of the vegetation mapping team and taxonomists in the State has had to be utilised. The latter has led to two levels of data quality in the historical data (vouchered and un-vouchered).



SUMMARY OF KEY FLORISTICAL CLASSIFICATION
PROJECTS FOR THE SOUTH WEST FOREST
REGION OF WESTERN AUSTRALIA

FIGURE 4



SUMMARY OF SITE VEGETATION TYPE
MAPPING PROGRESS FOR THE SOUTH WEST
FOREST REGION OF WESTERN AUSTRALIA

FIGURE 5

- Many of the original vegetation classification systems have been lost or mislaid and only parts of the work area available (original data, data analyses, publications, digital data sets), Table 3. In all cases, with the exception of the work by the vegetation consultants team this has led to extra data entry and or data formatting. In recognising the latter it must be recognised that many of the data sets have been outdated by more sophisticated data retrieval systems and storage.

- The point locations of many of the data sets need re-checking with a GPS, as the original work was carried out using 1:50,000 maps and distances from road junctures and or features. The latter has led to substantial re-working of the historical point data sets to allow their use in the vegetation mapping project.

- The various historical data sets have collected different data sets, for example some have only collected site location by species data while others have collected site location, site parameters and species data. These differences will require rationalisation during the vegetation project as they will affect what data analyses can be undertaken.

- The various authors have undertaken a variety of analyses on the different data sets and this will require rationalisation after the historical and new data sets have been integrated during the vegetation mapping project.

- The vegetation mapping polygonal data sets have been produced for different publications. Most of the relevant sets of data are still available in either digital or hard copy formats which can be re-adapted and analysed for the vegetation project. Foremost amongst these is the System 6 mapping by Heddle *et al.* (1980). As Mattiske (nee Heddle) is the primary author on this project the majority of the original drawings were held in her office. The remainder (three 1:50,000 map sheets), which had been lent at various times to other researchers have been re-located and a complete set of the original drawings for the System 6 area are available for re-interpretation at the scale of 1:50,000.

- The digital polygon landform and soil mapping data is part of another project under this Regional Forest Agreement. Consequently, despite the range of authors who have worked on this area, the coverage should be completed during this project. As part of this project all this data (both in the draft and final stages) are to be made available to the vegetation mapping consultants.

- Substantial sets of the data collected in the South-West Forest Region are held by various Companies and authors and some of the data has not been released for the vegetation project.

All of these data base issues will need addressing during the vegetation project. In reviewing the historical data sets one of the main benefits which should come from the vegetation project is the integrated data set which should assist all researchers in the South-West Forest Region in the future. The extent of the data base that results from the vegetation mapping project will depend on extensive negotiation with various authors and owners of the data sets.

Table 3: Summary of Data Availability from Previous Authors (Floristic and Vegetation Classifications)

Authors	Hard Copies Raw Data	Hard Copies Maps	Digital Raw Data	Data Analysis	Interpretations	Publications
Diels	N/A	A	N/A	N/A	A	P
Early Floristic Mapping	N/A	A	N/A	N/A	A	P
Early Vegetation Mapping	N/A	A	N/A	N/A	A	P
Forests - API	N/A	A (CALM)	A (CALM)	N/A	A	UP
Holland 1953	N/A	N/A	N/A	N/A	A	P
Williams 1932, 1945	N/A	N/A	N/A	N/A	A	P
Williams 1955 Sochava and Korchagin 1970	N/A	N/A	N/A	N/A	A	P
Speck 1958	N/A	N/A	N/A	N/A	A	P
Lange 1960	N/A	N/A	N/A	N/A	A	P
Churchill 1961, 1968	N/A	N/A	N/A	N/A	A	P
Specht 1970	N/A	N/A	N/A	N/A	A	P
Smith 1972, 1973, 1974	N/A	A	N/A	N/A	A	P
Havel 1968, 1975a, 1975b	Part Some Lost in Archiving (CALM)	A	N/A	A	A	P
McArthur and Clifton 1975	N/A	A	A	A	A	P
Mattiske 1976	A	A	A	A	A	UP

Table 3: Summary of Data Availability from Previous Authors (Floristic and Vegetation Classifications)

Authors	Hard Copies Raw Data	Hard Copies Maps	Digital Raw Data	Data Analysis	Interpretations	Publications
Loneragan 1978	A (author)	N/A	N/A	A	A	P
McCutcheon 1978 and 1980	A (author)	N/A	N/A	A	A	P
Beard 1979a, 1979b, 1979c and 1981	N/A	A	N/A	N/A	A	P
Bettenay *et al.* 1980	N/A	A	N/A	N/A	A	P
Heddle 1979 and Heddle *et al.* 1980	A	A	N/A	A	A	P
Christensen 1980	A	A	N/A	A	A	P
Trudgen 1984	A (author)	A	N/A	N/A	A	P
Geomorphological Mapping	N/A	N/A	Part A	N/A	A	P
Dieback Mapping (CALM)	A (CALM)	A	A (CALM)	N/A	A	UP
Havel Land Consultants 1987	A	N/A	A	A	A	P
Strelein 1988	A (author)	N/A	N/A	A	A	P
Inions *et al.* 1989, 1990a, 1990b	A (author)	N/A	N/A	A	A	P
Wardell-Johnson *et al.* 1989	A	N/A	A (required reworking)	A (required reworking)	A	UP

Table 3: Summary of Data Availability from Previous Authors (Floristic and Vegetation Classifications)

Authors	Hard Copies Raw Data	Hard Copies Maps	Digital Raw Data	Data Analysis	Interpretations	Publications
Mattiske and Burbidge 1991	A	N/A	A	A	A	P
E M Mattiske and Associates and Mattiske Consulting Pty Ltd 1979 to 1996	A (subject to Client approval for release)	A (subject to Client approval for release)	A	A	A	UP (Client ownership)
Griffin 1992	A (author)	A	A	A	A	P
Ecologia Environmental Consultants 1994	A (author)	N/A	A	A	A	P
Gibson (unpublished)	A (author)	N/A	A	A	A (in prep. still)	UP (in preparation still)
Hopkins 1996	N/A	A (in prep.)	A (in prep.)	N/A	A	UP (in preparation)

4. CONCEPTUAL MODEL OF PROPOSED VEGETATION MAPPING TECHNIQUES

This project has enabled a review of the main data bases available for vegetation classifications in the South-West Forest Region of Western Australia. The authors have attempted to integrate the previous vegetation classification systems and have proposed a methodology for the second phase of this project associated with defining the vegetation at a range of scales in the South-West Forest Region of Western Australia. The key basis to this methodology is the linkages between the geology, geomorphology, soils and landforms and climatic factors as underlying causal determinants of the resulting native vegetation cover in the South-West Forest Region, Figures 2 and 6. Havel and Mattiske have developed the relationships between the factors to design a vegetation classification system that integrates all the previous relevant vegetation classification systems and vegetation mapping studies in the region (Figure 6). This conceptual model of relationships will require field testing and data analysis in the vegetation mapping phase of the regional forest assessment process.

On the basis of the example cited for the northern jarrah forest it is possible to link the five layers from the groupings of the indicator species of Havel (1975a and 1975b) through to the broad structural formations as utilised by Beard (1979a, 1979b and 1979c) and Smith (1972, 1973 and 1974). This five layer conceptual model is based on the underlying determining landforms, soils and climate which determine the resultant vegetation. The data presented in Figure 6 has been based primarily on the northern jarrah forest. Essentially in developing the relationships between the broader structural formations and the more detailed vegetation complexes and site-vegetation types it has been necessary to rely on:

- the groupings of the keystone or indicator species (which reflect local specific site conditions - BROFEM - BROad FErtile Moist soils; SANLEA - SANdy LEAched soils) (Figure 6 illustrates the groupings which occur within the one site-vegetation type - B for the northern jarrah forest).

- the site-vegetation types (which reflect the vegetation which are dependent on specific site conditions) (Figure 6 illustrates some of the site-vegetation types which occur on the Swamp vegetation complex), and

- the vegetation complexes (which by their very definition reflect the inherent site parameters and vegetation) (Figure 6 illustrates a few of the northern forest vegetation complexes),

- the ecological vegetation systems (which reflect a higher order interaction of the landforms, soils, hydrology and vegetation) (Figure 6 illustrates a few of the proposed northern forest ecological vegetation systems),

- the structural formations; woodlands, shrublands and herblands at one end of the spectrum which reflect water deficient sites; open forests; tall open forests; and woodlands, shrublands and sedgelands at the water surplus sites and the coastline at the other end of the spectrum.

This conceptual model is presented for the linkages between the grouping of indicator species as defined by Havel (1975a) to one of the site-vegetation types (B as defined by Havel 1975a), to the occurrence in the vegetation complex (the Swamp complex as defined by Heddle *et al.* 1980a), to an ecological vegetation system which is primarily determined by its position in the landscape with a non-responsive to climatic conditions, and to the structural formations of woodlands and shrublands (linkage with Beard 1979a, 1979b, 1979c and 1981 and Smith 1972, 1973, 1974).

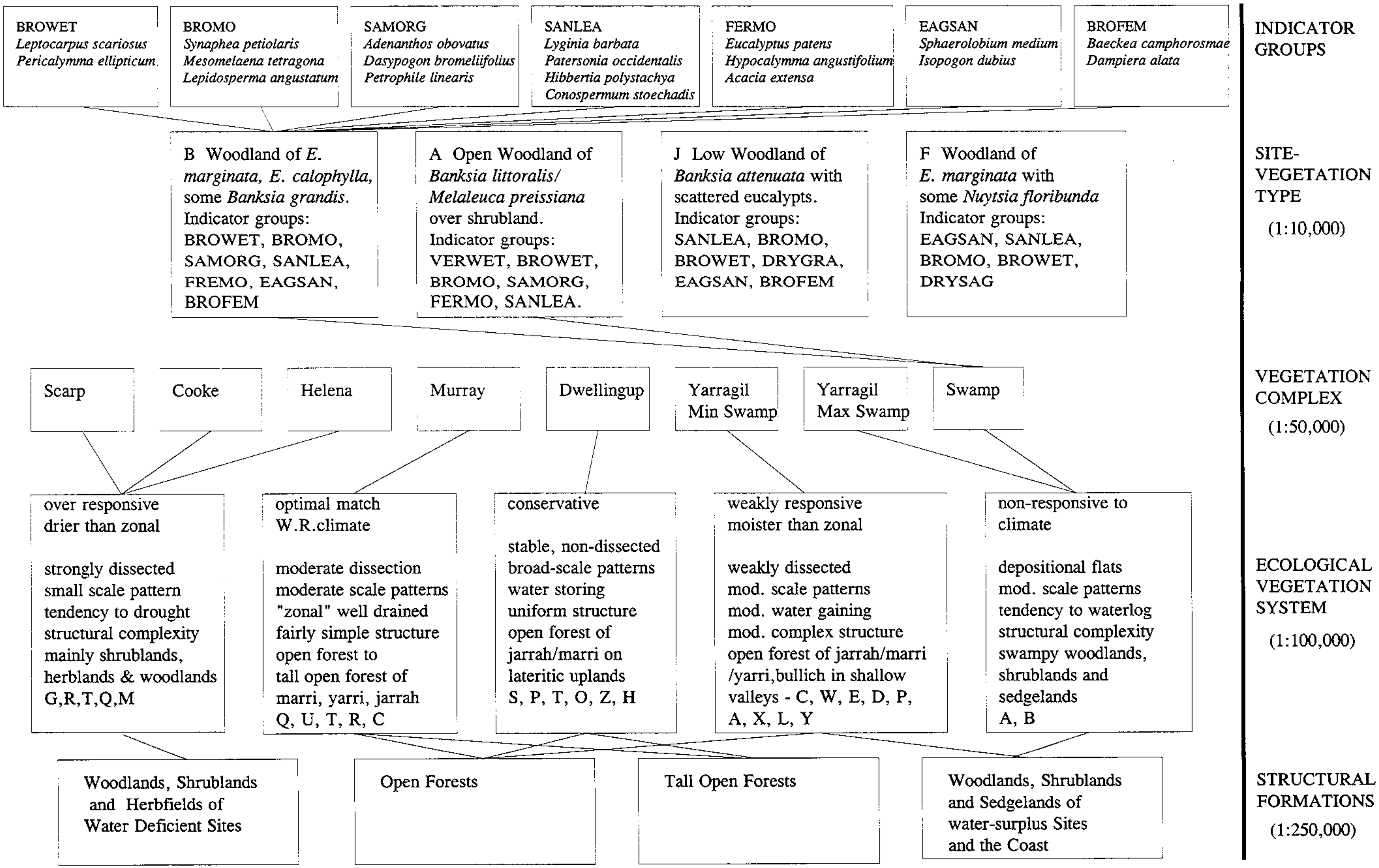
Figure 6 presents a very simplified example of the complex nature of the forest systems. As an example of the complexity, the linkages presented have taken one extreme group of indicator groups that relate to one site-vegetation type which occurs in one complex which is a small component of one ecological vegetation system which supports a range of structural formations which at times are regularly less than a hectare in size. The vegetation project will need to address all these relationships.

Preliminary design work for the southern and central areas appears to hold validity in this approach presented as the key determining factors are reflected in the resultant vegetation. For example, many of the indicators defined in the indicator species layer can be utilised on similar environments irrespective of their geographical location, Figure 6.

There were marked differences in the vegetation classification systems, which was at times accentuated by their respective methodologies. Despite differences in data analyses it has been possible to integrate the detailed work of Havel (1968, 1975a, 1975b), Strelein (1988), McCutcheon (1978 and 1980), Inions *et al.* (1989, 1990a, 1990b), Wardell-Johnson *et al.* (1989) and E.M. Mattiske and Associates and Mattiske Consulting Pty Ltd (1979 - 1996) into an edaphic net, covering the range of climatic zones as developed from the work of Gentilli (1989).

These linkages presented in Figure 6 and as designed for the other forest areas will require further testing and validation during the vegetation mapping project. In view of the degree of complexity this report has concentrated on the northern jarrah forest example, although the design phase for the various regions, which are based on climatic criteria, has also been commenced for other areas within the South-West Forest Region.

Figure 6: Diagrammatic Representation of Relationships between Vegetation Mapping Layers



5. DESIGN OF VEGETATION MAPPING PROGRAMME

5.1 Computer Hardware Issues

There is an apparent need to rationalise hardware in order to accommodate the data audit model (DAM) tool-kit and data bases needed for the integration of information from the Unix based ARC/INFO system used by the Commonwealth agencies. To this end, the vegetation project has required a rationalisation and an alignment of equipment used by the consultant and by the Department of Conservation and Land Management.

5.2 Computer Software Issues

Because of the number of different formats presented used by the historical data sets and the current levels of software used by the different agencies, there has been a need to coordinate the software used by the vegetation mapping consultant and the Department of Conservation and Land Management. Fortunately, both groups rely upon the Windows environment, and thus it will be relatively easy to exchange data in a variety of formats, including DBF, MS-Access, Paradox, Excel, Quattro-Pro and DXF formats.

Following discussions with officers in the Commonwealth and State agencies the software issues become a more difficult issue at the historical data integration phase and the data auditing phase. These issues are being addressed early by all researchers involved with the vegetation mapping project.

WAHERB, SEDIT and HERBIE software will be required as a means of standardising taxon identifications and plant specimen processing with current data bases held by the Department of Conservation and Land Management.

5.3 Database Needs for the South-West

During the vegetation mapping project there will be a need to integrate the following data sets for the South-West Forest Region of Western Australia:

- the digital BIOCLIM data from ERIN for the South-West Forest Region (available now),

- the digital data for the soil and landform mapping units (various authors being re-mapped and integrated by Agriculture Western Australia) (draft available now for the vast majority of the project area),

- the topographical and drainage data for the South-West Forest Region (Department of Land Administration) (available now),

- the base cadastral, roads and ownership data for the South-West Forest Region (Department of Conservation and Land Management) (available now),

- the clearing data sets held by the Department of Conservation and Land Management (available now, although being updated),

- the base and interpreted data for the various vegetation classification systems developed in the South-West Forest Region (in various data formats now for some projects; others will need negotiation with owners and authors of datasets),

- the previous vegetation mapping data for the System 6 areas (Heddle *et al.* 1980a).

- the new polygon and point data sets collected for the vegetation mapping project (available now; although needs digitising for 1:50,000 scale interpretation), and

- the new additional data sets collected during the proposed field work program.

5.4 Proposed Field Methodologies

All data sets will be defined in terms of types of data, currency of data, availability of data, format of data and quality of data. A reliability index has been developed for both the data sets and the standard of vegetation mapping (5.5.2).

Although the level of data is high there is an uneven spread of the data and this will require rationalisation in the second phase of the vegetation studies associated with the Regional Forest Agreement. The areas with low levels of data collection will require more intensive site studies in the vegetation mapping project and a method for selecting sampling regimes is proposed in the following text.

Essentially there will be three levels of additional data collection:

- establishment of permanent Vegetation Plots (recording all species present and their respective height and percentage foliage cover in a 10m x 10m plot). Current estimates of additional plots that can be established within the time frame are in the order of 800 to 1000 plots. The ability to achieve this target will depend of accessibility of sites, the degree of clearing in some areas and the time frame allowed for field studies (October to February),

- if time permits recordings along transects to review relationships of previous soil, landform and vegetation relationships as defined by previous authors in the South-West Forest Region, and

- observations will be carried out along roads and tracks to check boundaries of the vegetation mapping units against underlying landform and soil mapping units.

The emphasis for the new data collection should be placed on the 10m x 10m plots in view of the ability to integrate this sampling with previous similar studies; such as Mattiske and Burbidge (1991) and the extensive grid mapping by E.M. Mattiske and Associates and Mattiske Consulting Pty Ltd utilising site point data (radius of 5m for understorey species and 20m for overstorey).

The procedure for defining the data collection, data collation and mapping needs are summarised in Table 4 and an example of the plot field sheets is presented in Appendix A.

Table 4: Summary of Decision Making Process for Vegetation Mapping Project

Option 1:	**The area is covered by the existing vegetation classification systems and has already been mapped. Only slight modifications to the vegetation maps at 1:50,000 are required (essentially previous System 6 Area)**	
Actions:	Collate all Relevant Historical Data Sets	
	If required undertake Field Work	(plots, transects, opportunistic sites and reconnaissance)
	Incorporate new Field Data	
	Refine Existing Boundaries and Attributes	
	Digitise Maps	
	Edit Maps after Digitising	
Option 2:	**The area is covered by the existing vegetation classification systems and has not been mapped. Detailed field work, data collection and preparation of vegetation maps at 1:50,000 is required (e.g. Strelein - southern jarrah areas, McCutcheon - northern Blackwood Plateau; Wardell-Johnson *et al.* 1989 - southern forest areas)**	
Actions:	Collate all Relevant Historical Data Sets	
	Define Gaps in Information	
	Design Field Sheets for Mapping	(based on historical data)
	Undertake Field Work in Gaps	(plots, transects, opportunistic sites and reconnaissance)
	Incorporate all new Field Data	
	Develop Boundaries and Attributes	
	In disturbed areas, extrapolate	(based on landform and soils, aerial photographs and field studies)
	Digitise Maps & Integrate with Previous Mapping	
	Edit Maps after Digitising	
Option 3:	**The Area is not covered by existing vegetation classification systems and has not been mapped. Detailed field work, data collection and preparation of vegetation maps at 1:50,000 is required (e.g. southern Blackwood Plateau, Horst area between Augusta and Busselton, East of Manjimup)**	
Actions:	Collate all Relevant Historical Data Sets	(in absence of flora and vegetation systems depend more on landform, soils, remnant areas, climatic data)
	Define Gaps in Information	
	Design Field Sheets for Mapping	(based on wider larger regional data from adjacent areas)
	Undertake Field Work in Gaps	(plots initially to develop matrix of species and site parameters)
	Data Analysis of Initial Field Plots	
	Develop Site-vegetation Types	
	Develop and Modify Base Data Sheets	(for transects, opportunistic sites and reconnaissance) and reconnaissance)
	Incorporate all new Field Data	
	Develop Boundaries and Attributes	
	In disturbed areas, extrapolate	(based on landform and soils, aerial photographs and field studies)
	Digitise Maps & Integrate with Previous Mapping	
	Edit Maps after Digitising	

Table 4: Summary of Decision Making Process for Vegetation Mapping Project (continued)

Final Mapping:	**All areas covered will require rationalisation at a scale of 1:100,000 by combining polygons from the 1:50,000 vegetation complex mapping. Modifications to the boundaries will be required.**
Actions:	Refine Existing Boundaries and Attributes Re-attribute the combined Polygons Edit Maps after Digitising and Re-attributing Prepare digital and hard copies of data at 1:250,000 and 1:500,000

5.4.1 Site Selection and Sampling

Sampling numbers will be based on the degree of historical coverage of the respective areas and the reliability of the data sets.

All new sites to be sampled will based on the following criteria:

- Lack of representation of sites in previous historical data sets. To achieve this the location of all historical sites should be addressed in the early phase of the vegetation mapping project.

- All new sites should be selected within the different landform and soil units (wherever this information is available) so that replications of vegetation sampling sites reflect the underlying determining factors such as landform and soils. In the absence of soil and landform data the sites should be selected in extreme locations (upper well drained sites, poorly drained swamps).

- All new sites should occur within each climatic subregion as defined in Figure 2.

- All sites should be in areas which have not been subject to recent fires (area should not have been burnt for at least three years).

- All sites should avoid obvious disease expression areas (unless this option is unavoidable).

- All sites sampled should have minimal disturbance and weed infestations (unless this option is unavoidable in the largely cleared areas and where representation within forested or reserved areas is not feasible). The latter may occur in the largely cleared areas between Augusta and Busselton and east of Manjimup in the agricultural areas.

5.4.2 Sampling Attributes

All sites sampled will be located using either the Latitude/Longitude or the Australian Mapping Grid (AMG) with a Geographical Positioning System (GPS). In areas where the locations have been surveyed and pegged by professional survey teams then the relevant companies AMG pegging system will be used.

All data will be coded for authorship, data recorders, type of data, currency of data, status of data (vouchered, non-vouchered, quality checked), date of data collection, format of data sets, data quality, position accuracy, data completeness (dependent on type of sampling regime and time of sampling in different seasonal conditions).

In the respective levels of new data collection the following data will be collected as time permits in addition to the parameters above:

- Vegetation Plots (10m x 10m) - all vascular plant species present, height of all vascular plant species present, percentage foliage cover of all vascular plant species present.

- Gridded Transect Recordings - abundance ranking of all dominant overstorey species (abundance ranking scale of 0 to 5 as developed in Havel 1975a), abundance ranking of keystone or indicator species (abundance ranking scale of 0 to 5 as developed in Havel 1975a), site parameters (estimated age since fire, number of tree stumps, landform position, soil type, degree of outcropping, disease expression).

- Opportunistic Recording Sites - abundance ranking of all dominant overstorey species (abundance ranking scale of 0 to 5 as developed in Havel 1975a), abundance ranking of keystone or indicator species (abundance ranking scale of 0 to 5 as developed in Havel 1975a), site parameters (estimated age since fire, number of tree stumps, landform position, soil type, degree of outcropping, disease expression).

5.4.3 Data Analyses

After all historical field and interpreted data has been collated and merged onto a data base there is a need to undertake a series of data analyses to determine the merged vegetation classification systems at the regional and local levels. The degree to which this can be undertaken in the time frame will be reliant on the optimisation of field recording sheets (designed to minimise recorder variation) and the metadata base structures (ANZLIC).

A series of clustering and ordination programmes will be utilised by use of the consultant's own software, SYSTAT 6.0 for Windows and PATN on the data at a subregional (e.g. mapping region - Arid and Semi Arid Zone of Northern Darling Plateau) and local (e.g. vegetation complex level - within Dwellingup or Swamp complexes).

The latter will assist in the definition of keystone or indicator species to verify relationships between the various layers of the vegetation mapping.

Consideration will be given to the quality and standards of data at the time of analyses. In general the annuals will not be included at this stage as these species have not consistently been recorded throughout the study site. Further, in view of the differences in the previous sampling regimes there will be at least three main levels of analyses (presence/absence, ranking and foliage cover). All details on the data structures used in the analyses will be summarised on each figure presented in the reporting phase of the vegetation mapping project.

5.5 Mapping Techniques

Vegetation mapping will be undertaken at two levels for the vegetation mapping project for the South-West Forest Region, namely:

- Detailed mapping of vegetation complexes at 1:50,000 for the entire South-West Forest Region of Western Australia. All 1:50,000 maps will be submitted in digital format for the final reporting. Boundaries to be determined on the basis of detailed field studies, previous site-vegetation type mapping at 1:10,000 (where available), topography, landform and soils, climatic regions, API maps, aerial photography and previous publications (e.g. System 6 areas).

- Detailed mapping of ecological vegetation systems at 1:100,000 for the entire South-West Forest Region of Western Australia. All 1:100,000 maps will be submitted in digital format for the final reporting. Boundaries to be determined by combining one or more vegetation complexes. The process of undertaking this merging will be determined region by region and then the attributes assigned to the mapping polygons for the 1;100,000.

- Final presentation maps at 1:250,000 and 1:500,000 to have the same boundaries as the 1:100,000 maps (presentation changes in scale only). All 1:250,000 and 1:500,000 maps will be submitted in digital and hard copy format for the final reporting.

If time permits, selected 1:10,000 mapping should also be undertaken in selected representative areas for interpretation purposes of the relationships between the different scales of mapping.

5.5.1 Definition of Vegetation Mapping Units

The vegetation mapping project will develop a hierarchial system of mapping units to define the mapping units.

The base mapping level for the vegetation project should be the 1:50,000 level of vegetation complexes which should utilise the lower order 1:10,000 vegetation maps for checking boundaries (where available) with the linkage to the sub-groupings of indicator species and site parameters.

The higher order mapping should be undertaken by combining the boundaries from the vegetation complexes at 1:50,000 to the higher order 1:100,000 proposed ecological vegetation system mapping units. In view of the data collection and data collation phases the decision on which vegetation complexes should be combined to form the ecological vegetation system mapping units should be decided within the main subregions as each subregion is completed. The latter decision may be affected by a reliance on different structural and/or floristic criteria which are still being defined for the respective areas. This system of combining the boundaries (and consequently the polygons) will require testing and validation during the initial phases of the vegetation mapping project.

The delineation of vegetation mapping units should be based on the following data:

- Detailed Historical or New Vegetation data sets.

- Topography digital data sets held by the Department of Land Administration.

- Landform and soil mapping (where available) held by Agriculture Western Australia.

- Vegetation mapping units will be defined in a hierarchial coding system (based on the 5 layers as developed in the conceptual model for vegetation mapping).

5.5.2 Proposed Reliability Index

The following Reliability Index is proposed for the vegetation mapping project:

- Very High Reliability - vegetation mapping used topography, landform and soil maps, aerial photographs, API mapping, detailed selective mapping at 1:10,000, detailed vegetation plot data in selected landform and soil mapping units.

- High Reliability - vegetation mapping used topography, landform and soil maps, aerial photographs, API mapping, detailed vegetation plot data in selected landform and soil mapping units.

- Moderate Reliability - vegetation mapping used topography, landform and soil maps, aerial photographs, API mapping, detailed vegetation plot data in some of landform and soil mapping units (lack of plot sampling due to degree of disturbance, reliance on remnant areas as partly cleared).

- Low Reliability - vegetation mapping used topography, landform and soil maps, detailed vegetation plot data in some of landform and soil mapping units (substantial lack of plot sampling due to degree of disturbance, reliance on extrapolating from remnant areas as largely cleared).

6. DISCUSSION

This project has enabled a review of the main data bases available for vegetation classifications in the South-West Forest Region of Western Australia. The authors have attempted to integrate the previous vegetation classification systems and have as a result proposed a methodology for the second phase of this project associated with defining the vegetation at a range of scales in the South-West Forest Region of Western Australia.

The extensive review of the previous literature has highlighted the significance of the geology, geomorphology, soils and landforms and climatic factors in determining the resultant native vegetation cover in the South-West Forest Region. The conceptual model of relationships will require field testing and data analysis in the vegetation mapping phase of the regional forest assessment process.

An example of the potential relationships between the climatic zones, the geomorphological criteria and some of the vegetation elements are summarised in Table 5. This information reflects the complexity of the relationships for a few of the main climatic zones, landscape positions and soil types. The simplified data presented on the vegetation (as defined by the main structural formations and the dominant overstorey species) reflects the complexity of the vegetation in the South-West Forest Region even at the potential mapping units (vegetation complex level).

As illustrated for the northern jarrah forest system it is possible to link the five layers from the groupings of indicator species developed by Havel (1975a) through to the broad structural formations as utilised by Beard (1979a, 1979b and 1979c) and Smith (1972, 1973 and 1974). In reviewing the vegetation classification systems for the southern and central areas the latter approach appears to be valid; although there were marked differences in the vegetation classification systems, which was at times accentuated by their respective methodologies.

The proposed approach is similar to the biogeoclimatic ecosystem classification used in British Colombia by Pojar *et al.* (1987). The recognised units result from a synthesis of vegetation (floristic and structural), climate and soil data. The British Colombia system was also based on a hierarchial method. Therefore the approach proposed in the South-West Forest Region has been used internationally. Other schools of vegetation and land classification adopted a similar approach in Russian and North American areas. On the basis of previous studies such as these this approach appears to provide a powerful integrative and predictive tool; which is foremost in its application in slightly disturbed and or cleared areas. In these latter areas, due to the predictive relationships between landforms, soils and vegetation it is possible to interpret the original cover of native vegetation into cleared and disturbed areas.

In defining the series of site-vegetation types and vegetation complexes there is an inherent reliance on dominant and keystone or indicator floristic species. These species reflect a relationship with particular landforms, soils and climatic factors.

Therefore the proposed vegetation classification and vegetation mapping system is not only a floristic classification, but extends into the definition of vegetation - environmental relationships which has a proven practical value for forest managers. If one then combines the vegetation complexes into a higher order classification system such as the ecological vegetation systems the linkages with the inherent floristic biodiversity is apparent (from the indicator species in the subgroups through the site-vegetation types through the vegetation complexes to the ecological vegetation systems). In defining the ecological vegetation systems, the model adopted for the East Gippsland area was considered (Woodgate *et al.* 1994). The proposed ecological vegetation systems is similar to the ecological vegetation classes as defined by Woodgate *et al.* (1994) as both levels of classification are essentially hierarchial and midway between the broader structural formation level and the more detailed floristic vegetation community. Although the terminology proposed is slightly different the approach for mapping at 1:100,000 is similar in the broad concept. In the proposed system within Western Australia there is a greater reliance on the site-parameters and therefore the keystone species that reflect the floristic component of the vegetation.

The final groupings at the five layers of the vegetation classification systems will be refined as the project progresses; however it is intended to utilise the layers in the systems as follows:

. The groupings (first layer) which reflects the detailed indicator species which are indicative of the site specific parameters (FERMO - fertile Moist soils) at a very site specific level.

. The site-vegetation types (second layer) at 1:10,000 for selected areas, which reflects the detailed relationships between landform, soils and vegetation relationships at a local level.

. The vegetation complexes (third layer) at 1:50,000 for the entire South-West Forest Region, which reflects the main landform, soils and vegetation relationships at a regional level.

. The ecological vegetation systems (fourth layer) at 1:100,000 for the entire South-West Forest Region, which reflects the dominant floristic and structural vegetation components. These systems are the key to determining the main differentiation groups in the geomorphological and ecological sense (within the catena of the landscape the maximum differences occur in the vegetation within the areas which have maximum changes in local soil hydrological conditions in the drier seasons).

. The structural formations (fifth layer) as the overriding generalisation for defining the forest region in the South-West; although this layer avoids the inherent biodiversity, structural and floristic variation in response the local and regional environments. It should be noted that even the jarrah forest needs to be subdivided in relation to the recent subdivision for the jarrah species (Brooker and Hopper 1993) into three subspecies and likewise wandoo needs to be subdivided (Brooker and Hopper 1991). Therefore the earlier studies on the jarrah or wandoo open forest and woodlands are no longer accurate scientifically even at the most simplistic level as they ignore the taxonomic research of Brooker and Hopper (1991 and 1993).

The key to the vegetation mapping project is the data collection, data collation and integration phases. In view of the amount of previous ecological studies in the area and the short time lines which have been imposed on this project there will be a need to optimise this integration by a variety of groups and agencies cooperating.

Table 5: Overview of the Relationships between Climate, Geomorphology and Vegetation

CLIMATIC ZONE	PER HUMID	HUMID	SUB HUMID	SEMI-ARID TO ARID
SOIL TYPE	Rock Outcrops and Skeletal Soils	Rock Outcrops and Skeletal Soils	Rock Outcrops and Skeletal Soils	Rock Outcrops and Skeletal Soils
POSITION IN LANDSCAPE	Upper slopes	Upper slopes	Upper slopes	Upper slopes
LOCATION	Manjimup/ Donnelly River	Willowdale - Collie	Jarrahdale	Bindoon
STRUCTURAL FORMATIONS	Open forest Woodland	Woodland Shrubland Lithic Complex	Woodland Shrubland Lithic Complex	Woodland Lithic Complex
DOMINANT SPECIES	*Eucalyptus calophylla* *Eucalyptus haematoxylon*	*Eucalyptus calophylla* *Eucalyptus haematoxylon* *Eucalyptus laeliae*	*Eucalyptus wandoo* *Eucalyptus laeliae* *Eucalyptus calophylla* *Eucalyptus haemotoxylon*	*Allocasuarina huegeliana* *Eucalyptus wandoo* *Eucalyptus calophylla*
POTENTIAL MAPPING UNITS (Vegetation Complex)	Dickson Donnelly	Darling Scarp Helena	Darling Scarp Helena	Bindoon

CLIMATIC ZONE	PER HUMID	HUMID	SUB HUMID	SEMI-ARID TO ARID
SOIL TYPE	Gradational Earths, Duplex Soils	Gradational Earths, Duplex Soils	Gradational Earths, Duplex Soils	Gradational Earths, Duplex Soils
POSITION IN LANDSCAPE	Mid slopes	Mid slopes	Mid slopes	Mid slopes
LOCATION	Manjimup/ Donnelly River	Willowdale - Collie	Jarrahdale	Bindoon
STRUCTURAL FORMATIONS	Tall open forest	Open forest	Woodland Open forest	Woodland
DOMINANT SPECIES	*Eucalyptus diversicolor* *Eucalyptus calophylla* *Agonis flexuosa*	*Eucalyptus calophylla* *Eucalyptus patens*	*Eucalyptus calophylla* *Eucalyptus patens*	*Eucalyptus wandoo* *Eucalyptus loxophleba* *Acacia acuminata*
POTENTIAL MAPPING UNITS (Vegetation Complex)	Donnelly	Murray	Murray	Bindoon

Table 5: Overview of the Relationships between Climate, Geomorphology and Vegetation

CLIMATIC ZONE	PER HUMID	HUMID	SUB HUMID	SEMI-ARID TO ARID
SOIL TYPE	Alluvium	Alluvium	Alluvium	Alluvium
POSITION IN LANDSCAPE	Valley floor, Lower slopes	Valley floor, Lower slopes	Valley floor, Lower slopes	Valley floor, Lower slopes
LOCATION	Manjimup/ Donnelly River	Willowdale - Collie	Jarrahdale	Bindoon
STRUCTURAL FORMATIONS	Tall open forest	Woodland Open forest	Woodland Open forest	Woodland Shrubland
DOMINANT SPECIES	*Eucalyptus diversicolor* *Eucalyptus calophylla* *Banksia seminuda* *Allocasuarina decussata*	*Eucalyptus patens* *Eucalyptus rudis* *Banksia seminuda*	*Eucalyptus patens* *Eucalyptus rudis* *Melaleuca rhaphiophylla*	*Casuarina obesa* *Eucalyptus rudis* *Melaleuca rhaphiophylla*
POTENTIAL MAPPING UNITS (Vegetation Complex)	Warren	Murray	Murray	Nooning

CLIMATIC ZONE	PER HUMID	HUMID	SUB HUMID	SEMI-ARID TO ARID
SOIL TYPE	Sandy gravels with duricrust outcrops	Sandy gravels with duricrust outcrops	Sandy gravels with duricrust outcrops	Sandy gravels with duricrust outcrops
POSITION IN LANDSCAPE	Upper slopes	Upper slopes	Upper slopes	Upper slopes
LOCATION	Manjimup/ Donnelly River	Willowdale	Jarrahdale	Bindoon
STRUCTURAL FORMATIONS	Tall open forest Open forest	Open forest	Open forest	Woodland
DOMINANT SPECIES	*Eucalyptus marginata ssp. marginata* *Eucalyptyus calophylla* *Banksia grandis* *Persoonia longifolia* *Allocasuarina fraseriana*	*Eucalyptus marginata ssp. marginata* *Eucalyptyus calophylla* *Banksia grandis* *Persoonia longifolia* *Allocasuarina fraseriana*	*Eucalyptus marginata ssp. marginata* *Eucalyptus calophylla* *Banksia grandis* *Persoonia longifolia* *Allocasuarina fraseriana*	*Eucalyptus accedens* *Eucalyptus wandoo* *Eucalyptus calophylla* *Eucalyptus marginata ssp.thalassica*
POTENTIAL MAPPING UNITS (Vegetation Complex)	Bevan	Dwellingup	Dwellingup	Yalanbee

Table 5: Overview of the Relationships between Climate, Geomorphology and Vegetation

CLIMATIC ZONE	PER HUMID	HUMID	SUB HUMID	SEMI-ARID TO ARID
SOIL TYPE	Sandy (infertile)	Sandy (infertile)	Sandy (infertile)	Sandy (infertile)
POSITION IN LANDSCAPE	Lower slopes and broad valleys	Lower slopes and broad valleys	Lower slopes and broad valleys	Lower slopes and broad valleys
LOCATION	Manjimup/ Donnelly River	Willowdale - Collie	Jarrahdale	Bindoon
STRUCTURAL FORMATIONS	Woodland	Woodland	Woodland	Woodland Shrubland
DOMINANT SPECIES	*Banksia ilicifolia* *Xylomelum occidentalis* *Agonis flexuosa*	*Banksia attenuata* *Banksia ilicifolia* *Allocasuarina fraseriana*	*Banksia attenuata* *Allocasuarina fraseriana* *Nuytsia floribunda*	*Banksia attenuata* *Banksia prionotes* *Nuytsia floribunda*
POTENTIAL MAPPING UNITS (Vegetation Complex)	Quagering	Cardiff	Goonaping	Pindalup

CLIMATIC ZONE	PER HUMID	HUMID	SUB HUMID	SEMI-ARID TO ARID
SOIL TYPE	Wet humid podsols	Wet humid podsols	Wet humid podsols	Wet humid podsols
POSITION IN LANDSCAPE	Valley floor	Valley floor	Valley floor	Valley floor
LOCATION	Manjimup/ Donnelly River	Willowdale	Jarrahdale	Bindoon
STRUCTURAL FORMATIONS	Woodland Sedgeland	Woodland Sedgeland	Woodland Sedgeland	Woodland Sedgeland
DOMINANT SPECIES	*Melaleuca preissiana* *Banksia littoralis*	*Melaleuca preissiana* *Banksia littoralis*	*Melaleuca preissiana* *Banksia littoralis*	*Melaleuca preissiana* *Melaleuca viminea* *Banksia littoralis*
POTENTIAL MAPPING UNITS (Vegetation Complex)	Yornup	Muja	Swamp	Swamp

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APPENDIX A: SUMMARY OF FIELD SHEETS

The following field sheets have been developed by E.M.Mattiske and Associates and Mattiske Consulting Pty Ltd and are not to be copied or used without permission of these business operations.

Vegetation Plot Field Sheets

The two pages attached are the field sheets for the 10m x 10m vegetation plots being established is attached.

Mattiske Consulting Pty Ltd

FIELD SHEET - VEGETATION SURVEYS

(beta\wpdocs\admin\mcplform\mcplf17.wpd)

Project:	**Site No:**	**Initials:**
Film No:	**Photo No:**	**Date:** / /

GPS UTM:.......... K/J:.......... ALT:.......... PDOP:..........	**Location** **Notes:**.......... .... **Age Since Last** **Fire:**..........
Topography:.......... Br : R : US : MS : LS : DL : MIC : MAC	**Litter Cover (%)**:.......... **Litter Type**: Logs : Twigs : Leaves
Fauna:..........	**Other**:..........
Outcropping:.......... NUM: MOD: OCC	**Aspect:**.......... N: NW: W: SW: S: SE: E: NE: N/A
Soils: (Ratio 10): Clay : Silt : Sand **Soil Colour:**..........	**Bare Ground (%)**:..........
Pebble Type:.......... Angular : Subangular : Rounded	**Pebble Size**:.......... <1mm: <1cm : <10cm : <20cm : >20cm

Vegetation
Description:..........
....
....

Coll.No.	Species	Ht (cm)	%A	%D

Project:	Site No:			Page:
Coll.No.	Species	Ht (cm)	%A	%D

APPENDIX B: SUMMARY OF METADATA BASE STATEMENTS

The following Metadata Base Statements have been prepared for the data to be used in the vegetation mapping project.

These statements do not include a large range of data which was unavailable.

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: Site-vegetation Types

Custodian Details

Name: Alcoa of Australia Limited
Jurisdiction: Western Australia

Description

Abstract: Havel site-vegetation types have been mapped in areas within Alcoa's 10 year mining regions. The data are used to help plan all mining operations to minimise dieback spread and impact and to also minimise damage to rare and unusual vegetation communities.
Site-vegetation typing is recorded on 1:10000 mapping based on permanent plot and grid data. Attributes include site parameters, floristic structure and condition data.

Search Words:
VEGETATION Floristic Mapping
VEGETATION Mapping

Geographic Extent Names:
Geographic Extent Polygons:
Northern Jarrah Forest, Jarrahdale, Huntly
Hedges and Willowdale Mines

Currency and Status

Beginning Date:	01 Jan 1990	Progress:	In Progress
Ending Date:	Current	Maintenance and Update Frequency:	As Required
Metadata Date:	29 Jan 1997		

Access

Stored Data Format: ARC/INFO point and polygon coverage
Available Format Types:
Digital ARC/INFO export files
Access Conditions: Restricted usage, written application required and subject to licence agreement.

Data Quality

Lineage: Data are recorded on field data sheets and 1:10,000 topographic maps. Coverage is based on 60m x 120m or 120m x 120m grids. The data include presence/absence records of 150 understorey species, key indicator species and relevant site parameters.

Positional Accuracy: Majority of sites located at surveyed and pegged sites based on Alcoa's grid system (based on AMG).

Attribute Accuracy: The major attribute of this dataset is species. Identifications are confirmed using WA Herbarium voucher specimens where required.

Logical Consistency: All results are plotted at 1:10,000 and returned to the mapping consultants for validation GIS point/polygon datasets are topologically consistent.

Completeness: Site-vegetation types are mapped over substantial areas of the 10 year mining region for each mine. Some other limited areas in the region of mining operations have also been mapped.

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: Site-vegetation Types (Continued)

Custodian Details

Name: Alcoa of Australia Limited
Jurisdiction: Western Australia

Contact Information

Organisational Name:	Alcoa of Australia Limited		
Position:	Environmental Manager Mining		
Mail Address:	PO Box 252	State:	WA
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Telephone Number:	09 3165242	Facsimiile Number:	09 3165167
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Organisation Name:	Alcoa of Australia		
Position:	GIS Manager		
Mail Address:	PO Box 252	State:	WA
Mail Address 2:		Country:	Australia
Suburb or Locality:	Applecross	Post Code:	6153
Telephone Number:	09 3165242	Facsimiile Number:	09 3165167
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Additional Metadata

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: Site-vegetation Types

Custodian Details

Name:	Mattiske Consulting Pty Ltd for various Clients including Alcoa of Australia Limited and the Department of Conservation and Land Management
Jurisdiction:	Western Australia

Description

Abstract:	Havel site-vegetation types have been mapped in areas within scattered pockets of the northern, southern and eastern forests for a range of clients. Site-vegetation typing is recorded on 1:10000 mapping based on permanent plot, opportunistic and grid data. Attributes include site parameters, floristic structure and condition data.
Search Words:	VEGETATION Floristic Mapping VEGETATION Mapping
Geographic Extent Names:	
Geographic Extent Polygons:	Northern Jarrah Forest, Southern Jarrah Forest, Eastern Jarrah Forest, Eastern Wandoo Woodlands

Currency and Status

Beginning Date:	01 Jan 1976	Progress:	In Progress
Ending Date:	Current	Maintenance and Update Frequency:	As Required
Metadata Date:	14 Feb 1997		

Access

Stored Data Format:	Quattro Pro, Microsoft Access and ARC/INFO point and polygon coverage
Available Format Types:	Digital spread sheet and ARC/INFO export files
Access Conditions:	Restricted usage, written application required and subject to licence agreement with Clients.

Data Quality

Lineage:	Data are recorded on field data sheets and 1:10,000 topographic maps. Coverage is based on 60m x 120m or 120m x 120m or 200m x 100m grids. The data include presence/absence, ranking records of at least 150 understorey species, key indicator species and relevant site parameters.
Positional Accuracy:	Majority of sites located at surveyed and pegged sites or verified by GPS records.
Attribute Accuracy:	The major attribute of this dataset is species. Identifications are confirmed using WA Herbarium voucher specimens where required.
Logical Consistency:	All results are plotted at 1:10,000 and datasets are topologically consistent.
Completeness:	Site-vegetation types are mapped in sections of the northern, eastern and southern forest areas.

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: Site-vegetation Types (Continued)

Custodian Details

Name:	Mattiske Consulting Pty Ltd for various Clients including Alcoa of Australia Limited and the Department of Conservation and Land Management
Jurisdiction:	Western Australia

Custodian Details

Name:	Various Clients and Organisations
Jurisdiction:	Western Australia

Contact Information

Organisational Name:	Dr Libby Mattiske		
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Additional Metadata

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: Vegetation Monitoring Plots

Custodian Details

Name: Alcoa of Australia Limited
Jurisdiction: Western Australia

Description

Abstract: Permanent vegetation monitoring plots have been established in forest surrounding Alcoa's mines and in the rehabilitation mined areas. The plots are 20m x 20m and cover a range of upland site-vegetation types (P,T,S and combinations) and ages of rehabilitation from 1966 to 1996. They are used to provide comparative measurements of rehabilitation performance.

Search Words:
FLORA Monitoring
VEGETATION Floristic Monitoring

Geographic Extent Names:

Geographic Extent Polygons:
Northern Jarrah Forest mainly around Jarrahdale
Huntly and Willowdale Mines

Currency and Status

Beginning Date:	01 Aug 1981	Progress:	In Progress
Ending Date:	Current	Maintenance and Update Frequency:	Annual
Metadata Date:	29 Jan 1997		

Access

Stored Data Format: ARC/INFO polygon coverage
Available Format Types: Digital GIS export format and SAS database
Access Conditions: Written application required for all unpublished data. Licence agreement may apply.

Data Quality

Lineage: Quadrat Data hardcopy is manually enterred onto computer.
Positional Accuracy: Plots are surveyed using standard surveying techniques.
Attribute Accuracy: Attributes are very accurate and are checked after computer entry.
Logical Consistency: Validation occurs and the GIS coverage is topologically consistent.
Completeness: The permanent plots represent only a small fraction of the total forest area but are considered representative of the type of vegetation mined. Plots in rehabilitation are representative of that year's rehabilitation.

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: Vegetation Monitoring Plots (Continued)

Custodian Details

Name:	Alcoa of Australia Limited
Jurisdiction:	Western Australia

Contact Information

Organisational Name:	Alcoa of Australia Limited		
Position:	Environmental Manager Mining		
Mail Address:	PO Box 252	State:	WA
Mail Address 2:		Country:	Australia
Suburb or Locality:	Applecross	Post Code:	6153
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Email Address:	john.gardner@alcoa.com.au		

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Position:	GIS Manager		
Mail Address:	PO Box 252	State:	WA
Mail Address 2:		Country:	Australia
Suburb or Locality:	Applecross	Post Code:	6153
Telephone Number:	09 3165242	Facsimiile Number:	09 3165167
Email Address:	graham.wake@alcoa.com.au		

Additional Metadata

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: Vegetation Monitoring Plots

Custodian Details

Name: Mattiske Consulting Pty Ltd for various Clients including Alcoa of Australia Limited and the Department of Conservation and Land Management

Jurisdiction: Western Australia

Description

Abstract: Permanent vegetation monitoring plots have been established in northern, southern and eastern forests on behalf of a range of Clients. The plots are 20m x 20m or 40m x 40m and cover a large range of the site-vegetation types.

Search Words:

FLORA Monitoring
VEGETATION Floristic Monitoring

Geographic Extent Names:

Geographic Extent Polygons:

Northern Jarrah Forest, Southern Jarrah Forest
Eastern Jarrah Forest

Currency and Status

Beginning Date: 01 July 1979
Ending Date: Current
Metadata Date: 14 Feb 1997

Progress: In Progress
Maintenance and Update Frequency: Annual

Access

Stored Data Format: Quattro Pro and Microsoft Access and ARC/INFO
Available Format Types: Digital GIS export format
Access Conditions: Written application required for all unpublished data to Clients of Mattiske Consulting Pty Ltd. Licence agreement may apply.

Data Quality

Lineage: Quadrat Data hardcopy is manually enterred onto computer.
Positional Accuracy: Plots are surveyed using standard surveying techniques.
Attribute Accuracy: Attributes including species, heights, cover, numbers, presence/absence and condition are very accurate and are checked after computer entry.
Logical Consistency: Validation occurs and the GIS coverage is topologically consistent.
Completeness: The permanent plots represent only a small fraction of the total forest area but are considered representative of the site-vegetation types.

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: Vegetation Monitoring Plots (Continued)

Custodian Details

Name: Mattiske Consulting Pty Ltd for various Clients including Alcoa of Australia Limited and the Department of Conservation and Land Management
Jurisdiction: Western Australia

Custodian Details

Name: Various Clients and Organisations
Jurisdiction: Western Australia

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Mail Address 2:		Country:	Australia
Suburb or Locality:	Kalamunda	Post Code:	6076
Telephone Number:	09 2571625	Facsimiile Number:	09 2571640
Email Address:	mattiske@wt.com.au		

Additional Metadata

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: South West Western Australia Climate Grids

Custodian Details

Name: Environmental Resources Information Network (ERIN), Commonwealth Department of the Environment, Sports and Territories

Jurisdiction: Australia

Description

Abstract: This data contains climate grids for temperature, precipitation and evaporation. The grids were calculated using the program ANUCLIM (including the Australian climate surfaces) and the South West WA Digital Elevation Model (DEM). The ANUCLIM program and surfaces were supplied by the Centre for Resource and Environmental Studies, Australian National University. The DEM was clipped from the GEODATA National 9 Second DEM for which the Australian Surveying and Land Information Group (AUSLIG) is custodian.

Search Words: Climate and Weather, Temperature, Precipitation and Evaporation

Geographic Extent Names: SW Forest Region, Western Australia

Currency and Status

Beginning Date: 1900
Ending Date: 1980
Data Status: Complete
Maintenance and Update Frequency: As Required
Metadata Statement: 9 Oct 1996

Access

Stored Data Format: Digital - Raster

Available Format Types: Digital - ARC/INFO

Access Conditions: The climate grids supplied to Mattiske Consulting Pty Ltd under licence for the work in relation to the two projects associated with the vegetation projects for the South West Forest Region.

Data Quality

Lineage: Climate Grids were derived using ANUCLIM by interrogating climate surfaces using the National 9 Second DEM. ANUCLIM was used to generate the command file for running BIOCLIM. BIOCLIM was then used to calculate climate grids for temperature, precipitation and evaporation. ARC/INFO grids were then created from the output of BIOCLIM.

Cell Size: 9 seconds (=250m)

Positional Accuracy: Elevation inputs for the 9 seconds DEM were for 1:100,000 scale sources. Major waterbodies and watercourses were from GEODATA TOPO-250k hydrography.

Attribute Accuracy: The climate grids were calculated using the BIOCLIM algorithm that is national and internationally recognised. Climate surfaces are being updated.

Logical Consistency: Some edge matching problems resulting from climate surfaces are apparent in the climate grids.

Completeness: The DEM used to interrogate climate surfaces was the Perth and Albany 1:1 million map sheets of the National 9 second DEM. Climate grids were created for selected temperature, precipitation and evaporation parameters.

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: South West Western Australia Climate Grids (Continued)

Contact Information

Organisational Name:	Department of the Environment, Sports and Territories		
Contact Position:	Scientific Coordinator, Regional Information Section		
Contact Person:	Kate Ord		
Contact Address:	GPO Box 787	State:	ACT
Mail Address 2:		Country:	Australia
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Email Address:	kateo@erin.gov.au		

Additional Metadata

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: South West Western Australia Soil and Landform Maps

Custodian Details

Name: Various Authors, currently being merged by Agriculture Western Australia as another project in the South-West Forest Region Assessment and supplied to the Department of Conservation and Land Management and Mattiske Consulting Pty Ltd for the vegetation mapping project.

Jurisdiction: Western Australia

Description

Abstract: This data contains soil and landform mapping (historical and new data) for the South-West Forest Region.

Search Words: Soils and Landforms

Geographic Extent Names: SW Forest Region, Western Australia

Currency and Status

Beginning Date: 1970
Ending Date: Current
Data Status: Being Completed as part of another project.
Maintenance and Update Frequency: As Required
Metadata Statement: 14 Feb 1997

Access

Stored Data Format: Digital - ARC/INFO
Available Format Types: Digital - ARC/INFO
Access Conditions: The soils and landform polygon data supplied to Mattiske Consulting Pty Ltd for the work in relation to the two projects associated with the vegetation projects for the South West Forest Region.

Data Quality

Lineage: Soil and landform data was derived from a range of authors and part of the contract held by Agriculture Western Australia is to cleanse and rationalise the datasets for then South-West Forest Region.

Positional Accuracy: From 1:50,000 scale sources.

Attribute Accuracy: The soil and landform mapping was undertaken on the basis of extensive field surveys and sampling.

Logical Consistency: Some edge matching problems resulting from differences in detail and authors.

Completeness: The soil and landform mapping currently being completed as part of another project.

Contact Information

Organisational Name: Agriculture Western Australia
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Email Address:
State: WA
Country: Australia
Post Code: 6151
Facsimiile Number:

Additional Metadata

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: South West Western Australia Topography and Drainage Data

Custodian Details

Name: Department of Land Administration and supplied to the Department of Conservation and Land Management.
Jurisdiction: Western Australia

Description

Abstract: This data contains topography and drainage data for the South-West Forest Region.

Search Words:
Topography, Drainage

Geographic Extent Names: SW Forest Region, Western Australia

Currency and Status

Beginning Date: 1900
Ending Date: Current
Data Status: Current
Maintenance and Update Frequency: As Required
Metadata Statement: 14 Feb 1997

Access

Stored Data Format: Digital - ARC/INFO
Available Format Types: Digital - ARC/INFO
Access Conditions: The topography and drainage polygon data supplied to Mattiske Consulting Pty Ltd for the work in relation to the two projects associated with the vegetation projects for the South West Forest Region.

Data Quality

Lineage: Topography and drainage data was derived from data held by the Department of Land Administration.
Positional Accuracy: From 1:50,000 scale sources.
Attribute Accuracy: AUSLIG standards
Logical Consistency: AUSLIG standards
Completeness: Complete for South-West Forest Region.

Contact Information

Organisational Name: Department of Land Administration
Contact Person:
Contact Address: Midland Square State: WA
Mail Address 2: Morrison Road Country: Australia
Suburb or Locality: Midland Post Code: 6056
Telephone Number: 09 273 7046 Facsimile Number:
Email Address:

Additional Metadata

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: South West Western Australia Base Cadastral, Tenure, Clearing and Roads Data

Custodian Details

Name: Department of Conservation and Land Management
Jurisdiction: Australia

Description

Abstract: This data contains cadastral, ownership/tenure, clearing and roads data for the South-West Forest Region.
Search Words: Roads, Tenure

Geographic Extent Names: SW Forest Region, Western Australia

Currency and Status

Beginning Date: 1950
Ending Date: Current
Data Status: Current
Maintenance and Update Frequency: As Required
Metadata Statement: 14 Feb 1997

Access

Stored Data Format: Digital - ARC/INFO
Available Format Types: Digital - ARC/INFO
Access Conditions: The base cadastral, ownership/tenure, clearing and roads polygon data supplied to Mattiske Consulting Pty Ltd for the work in relation to the two projects associated with the vegetation projects for the South West Forest Region.

Data Quality

Lineage: The base data held by Department of Conservation and Land Management.
Positional Accuracy: From 1:50,000 scale sources.
Attribute Accuracy: AUSLIG standards
Logical Consistency: AUSLIG standards
Completeness: Complete for South-West Forest Region.

Contact Information

Organisational Name:	Department of Conservation and Land Management		
Contact Person:	Executive Director - Dr S Shea		
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Email Address:			

Additional Metadata

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: Floristic and Vegetation Data - South-West Forest Region Western Australia

Custodian Details

Name: Various Authors employed by the Department of Conservation and Land Management and the former Forests Department of Western Australia (whilst employed - Havel, Heddle, McCutcheon, Wardell-Johnson, Strelein, Inions and Gibson, Christensen - Ph.D. data)
Jurisdiction: Australia

Description

Abstract: This data contains a vast array of point survey data and vegetation plot data for the South-West Forest Region.
Search Words: Floristic Classifications
Vegetation Mapping
Site-vegetation Types
Flora
Vegetation Monitoring

Geographic Extent Names: SW Forest Region, Western Australia

Currency and Status

Beginning Date: 1960
Ending Date: Current
Data Status: Current
Maintenance and Update Frequency: As Required
Metadata Statement: 14 Feb 1997

Access

Stored Data Format: Various formats, hard copies of field sheets through to Digital format in Excel, Quattro Pro, Microsoft Access and ARC/INFO
Available Format Types: Spreadsheets and Digital - ARC/INFO
Access Conditions: The base data for most authors needs entering from field sheets and then editing and merging.

Data Quality

Lineage: Variable, minimum detailed locations supplied (often in hard copy map form rather than GPS locations), presence/absence data and in most instances ranked data (mostly on scale of 1 to 5 as developed by Havel 1975a). Data held by Department of Conservation and Land Management and authors in various status and availability.
Positional Accuracy: From hard copies of maps supplied by authors.
Attribute Accuracy: Variable, however minimum standards apply.
Logical Consistency: Variable, needs verifying in view of taxonomic changes.
Completeness: Mostly complete, although some subsets of data lost (e.g. some of Havel's raw data.

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: Floristic and Vegetation Data - South-West Forest Region Western Australia

Contact Information

Organisational Name:	Department of Conservation and Land Management		
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Email Address:			

Additional Metadata

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: Floristic and Vegetation Data - Loneragan - Northern Forest Region in South-West Forest Region Western Australia

Custodian Details

Name: Ph.D. data collected by Loneragan 1978 (University of Western Australia Botany Department)
Jurisdiction: Australia

Description

Abstract: This data covers some 122 plots scattered in the northern section of the forests within the South-West Forest Region.
Search Words: Floristic Classifications
Vegetation Mapping
Flora

Geographic Extent Names: SW Forest Region, Western Australia

Currency and Status

Beginning Date: 1960's
Ending Date: 1978
Data Status: Current
Maintenance and Update Frequency: As Required
Metadata Statement: 14 Feb 1997

Access

Stored Data Format: Held by Author.
Available Format Types: Field sheets and spreadsheets
Access Conditions: Written application required for data from author. Licence agreement may apply.

Data Quality

Lineage: Data collected for all tree species in 48m x 48m plots (numbers, basal area) and in 16 - 1m x 1m quadrats for understorey species (frequency and canopy cover in selected central quadrats). Site parameters were also recorded.
Positional Accuracy: Subject to author.
Attribute Accuracy: Accurate in terms of data collected.
Logical Consistency: Will need verifying in view of taxonomic changes.
Completeness: Subject to author releasing data.

Contact Information

Organisational Name:	University of Western Australia - Botany Department		
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Additional Metadata

ANZLIC Core Metadata Elements - Directory Item Report
Vegetation Mapping Project - South-West Forest Region of Western Australia

Title: Floristic and Vegetation Data - Griffin - Northern Forest Region in South-West Forest Region Western Australia

Custodian Details

Name: Data collected by Griffin 1992 for Department of Agriculture Western Australia (published in 1992)

Jurisdiction: Australia

Description

Abstract: This data covers remnant areas in the northern section of the RFA survey area within the South-West Forest Region (Moora to Chittering). 479 sites, quadrats $100m^2$. All species were recorded, including canopy cover. Used Muir system which incorporates layers within vegetation to descrive communities (height and cover).

Search Words: Floristic Classifications
Vegetation Mapping
Flora

Geographic Extent Names: SW Forest Region, Western Australia

Currency and Status

Beginning Date: 1990's
Ending Date: 1992
Data Status: Published
Maintenance and Update Frequency: As Required
Metadata Statement: 14 Feb 1997

Access

Stored Data Format: Held by Author and Department of Agriculture Western Australia (now Agriculture Western Australia).

Available Format Types: Field sheets and spreadsheets, digital format.

Access Conditions: Written application required for data from author. Licence agreement may apply.

Data Quality

Lineage: Data collected for species in 479 sites, quadrats $100m^2$. All species were recorded, including canopy cover and heights. Site parameters were also recorded.

Positional Accuracy: Subject to author.
Attribute Accuracy: Accurate in terms of data collected.
Logical Consistency: Will need verifying in view of taxonomic changes.
Completeness: Subject to author releasing data.

Contact Information

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