Ecology of the forests of south western Australia in relation to climate and landforms

This thesis is presented for the degree of Doctor of Philosophy

by

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I declare that this thesis is my account of my research and contains as its main content work which has not been previously submitted for a degree at any tertiary educational institution.

Jaroslav Joseph Havel
To my wife Betty
ABSTRACT

This thesis sets out to test the hypothesis that the vegetational patterns in the forested region of south western Australia are primarily determined by the interaction of climate and landform.

The region is an area of 4.25 million hectares subject to recent agreement between the Commonwealth of Australia and the state of Western Australia regarding long-term protection and management of forest (Regional Forest Agreement).

The climate of the south western forest region is warm temperate and summer dry, matching Koeppen’s category Cs, usually described as mediterranean.

The dominant geological features of south western Australia are crystalline and sedimentary plateaus and coastal plains. They are subject to a complex process of weathering, denudation and re-deposition, which is the key determinant of landforms and soil patterns. Deep but infertile soils are prevalent.

The dominant vegetation formation of the region is open forest, which reduces to woodland in the drier north and east and increases to tall open forest in the moister south. Floristically the vegetation is very rich, comprising over 3000 vascular plant species. The richness resides in the forest and woodland understorey and in the shrublands, heathlands and sedgelands of edaphically extreme sites. By comparison, the forest overstorey is very simple, only one or two species being often dominant over extensive areas.
The validation of the hypothesis that climate and landforms determine the vegetation patterns in southern Western Australia is carried out in the following stages:

1) review of past studies of vegetation patterns in relation to the underlying environmental factors, relating them to one another in terms of floristics,

2) conversion of landform and climate maps for the region into vegetation maps by means of toposequences, that is gradients of topography, soils and vegetation within individual landform/climate combinations,

3) production of two sets of vegetation maps, namely six maps of vegetation complexes (1:250,000) and one map of vegetation systems (1:500,000),

4) testing the predictive capability of the resulting maps by comparing the occurrences of individual species of trees, shrubs and herbs predicted by map legends, with their records in FloraBase, the geographic information system of the Western Australian Herbarium, and

5) using the outcomes of the above studies to assess the validity of the hypothesis.

Because the above hypothesis is so broad, it will be considered under seven headings:

a) nature of the vegetation patterns (continuum or discrete categories),

b) regional effect of climate and local effect of landform,

c) effect of landforms on soil depth, texture and fertility,

d) joint effect of slope, soil depth and texture on water balance,

e) interactive effect of landform and climate on vegetation patterns,

f) response of individual species to climate and landform, and

g) effect of other factors of environment, such as fire, on vegetation patterns.

The subsidiary hypotheses are defined in Chapter 5.
It is concluded that the vegetation of the region forms a lumpy continuum from the wet south west to the dry north east. Within that broad continuum there are localised continua from waterlogged sites in depressions to drought-prone sites on steep stony slopes. However, the dominant vegetation of the region is open forest on plateau uplands with deep infertile soils.

Although climate and landforms have a strong effect on vegetation patterns, they do not determine all vegetation patterns directly. Some tree species have ranges of occurrence that are too broad for that, and others have ranges that are too restricted.

A more probable explanation is that climate and landforms, together with fire, set the stage on which the interplay of species takes place and determines the structure and composition of the vegetation. An attempt is made to predict the likely effect of climatic changes on vegetation patterns.

The applicability of the methodology developed to the mapping of other regions, especially the adjacent ones, is examined. A review is made of how the products of the study, in particular the maps, are currently being used, and suggestions are made how they could be used in the future.
Acknowledgements

I would like to express my sincere gratitude to my primary supervisor, Associate Professor Bernie Dell of the School of Biological Sciences and Biotechnology, Division of Science and Biotechnology, Murdoch University, for his excellent guidance, advice, encouragement and support throughout the compilation of the thesis. I also wish to thank my co-supervisors, namely Professor Richard Hobbs, Professor of Environmental Science, School of Environmental Science, Division of Science and Engineering, Murdoch University for advice and direction on the compilation of the thesis, and for the review of the draft, and to Dr Stephen Hopper, Director of Kings Park, for advice during the early stages of the writing process, particularly as it added to their already heavy work load. I am very grateful to Dr Elizabeth Mattiske (nee Heddle) of Mattiske Consulting Pty Ltd for opening the opportunity for me to return to vegetation mapping, and to renew our cooperation in this field that goes back for 24 years. I also wish to thank her for making available the facilities and staff of her firm for the compilation of the maps and of the report on which this thesis is based, and for the review of the thesis. I am also grateful to Dr Neil Gibson of the Department of Conservation and Land Management for making available his unpublished study of south coast vegetation, and for reviewing the draft of the thesis.

In the writing of the thesis I was greatly helped by Mrs Janice Barrett in word processing and by Ms Suzanne Rosier in checking of references, and I am very grateful for their assistance. I am also grateful to Dr Eleanor Bennett and Mrs Beverley Koch for advice on changes in botanical nomenclature and on taxonomy in general.
I am very conscious that the thesis, and the associated maps, are the summation of the combined effort of plant ecologists, foresters, botanists, geomorphologists, soil scientists and climatologists over the past half a century. Their contribution are acknowledged in the text and in the reference section. The more recent contributors, on whose publications I have drawn are Mr Jack Bradshaw, Dr Per Christensen, Dr Ted Griffin, Dr Garry Inions, Dr William Loneragan, Mr Graham McCutcheon, Mr Greg Strelein and Dr Graham Wardell-Johnson, I am grateful for their contribution. Whilst in the past I have also contributed at various stages of that process by field studies, surveys, quantitative analyses and published reports, my role in this final stage has been largely that of integrator of information, generator of hypotheses and compiler of toposequences and map legends. I wish to express my gratitude to Dr David Goodall and the late Dr Joseph Gentilli, who were my mentors in quantitative ecology and climatology respectively. Dr John Beard has been an inspiration with his maps of the structure of the vegetation of Western Australia as a whole. I have greatly benefited from long association with Dr Maurice Mulcahy, Mr Max Churchward and Mr Bill McArthur, who introduced me to geomorphology and over the years generated much of the information on landforms, which underlies the maps. I have also benefited from more recent discussions of landforms and soils with Mr Noel Schoknecht. I wish also to acknowledge the many years of faithful and arduous support in the field studies by Mr Roger Edminston in the northern jarrah forest and similar contribution to field studies in southern forests by Mr Tony Annells and Mr Roger Hearne.

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The kind permission by the Subsidiary Rights Manager, Mrs Frances Rothwell, of Elsevier Science, Oxford UK, by the former Executive Director of the Department of Conservation and Land Management WA, Dr Syd Shea, and by the Chief Executive Officer of Environment and Protection, WA, Dr Bryan Jenkins, to use illustrations from the publications of their respective organisations, is gratefully acknowledged.

Closer to home, I wish to acknowledge the challenge and the encouragement given to me by my children Geoffrey, Peter and Kathryn, to write the thesis. I have greatly appreciated the help of my son-in-law, David Devereux, in adjusting to changes in computer technology. I wish to express my gratitude to my wife Betty for her patience in putting up with my obsession with plant ecology.

Finally, I thank God for giving me the strength and clarity of mind to complete the task.
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PUBLICATIONS

The following papers and maps relevant to the research presented here have been published:


Havel, J.J. (1975b). Site vegetation mapping in the northern jarrah forest (Darling Range) II. Location and mapping of site vegetation types. *Forests Department WA, Bulletin 87.*


Two poster papers have been presented at a National Conference:


A paper covering the first three chapters of this thesis is under review:

Chapter 1: Introduction

1.1 Objectives, Description of the Study Area and Methodology

1.1.1 Objectives of the Thesis

This thesis sets out to test the hypothesis that the vegetation patterns in the forests of south western Australia are primarily determined by the interaction of climate and landform. It attempts to do so by first reviewing past studies of vegetation patterns in relation to the underlying environmental factors. As a next step, these relationships are used to convert landform and climate maps into vegetation maps at two scales, namely vegetation complexes (1:250,000) and ecological vegetation systems (1:500,000). In order to construct the maps all landform maps are agglomerated together and all earlier vegetation classifications are related to one another in terms of floristics. The matching of vegetation to landform and climate is carried out by means of toposequences, that is gradients of topography, soils and vegetation within individual landform/climate categories. The process represents a progression from localised objective quantitative studies of simple systems to the more subjective synthesis of the region as a whole.

The predictive capability of the resulting maps is then tested by comparing them against FloraBase, the geographic information system of the Western Australian Herbarium. The recorded occurrences of individual species of trees, shrubs and herbs within the map polygons are examined against their predicted occurrences within the
corresponding map categories. Finally, the outcome of the above studies are used to assess the validity of the hypothesis that climate and landforms determine the vegetation patterns in south western Australia.

1.1.2 Description of the Study Area

The forested region of south western Australia described here is the area of 4.25 million hectares subject to the recent Regional Forest Agreement between the Commonwealth of Australia and the State of Western Australia, which addressed the management of the forests and the comprehensiveness and adequacy of reservations.

Essentially it consists of the main forested region in the south western corner of Western Australia, bounded in the south by the Southern Ocean, in the west by the Swan Coastal Plain and the Indian Ocean and in the east by the wheatbelt. Whereas the bulk of this region consists of various categories of crown (publicly owned) land, such as State Forest, National Parks and Nature Reserves, the neighbouring Swan Coastal Plain and wheatbelt are largely alienated and cleared.

The RFA region is located between latitudes 31°S and 35°S, and between longitudes 115°E and 118°E. Figure 1.1 shows the RFA boundaries and the main population centres of the region (RFA 1998b).

The forested region corresponds closely to, but is not fully identical to two Interim Biogeographical Regions of Australia (IBRA) defined by the Environment Australia
Figure 1.1 - Map of the area covered by the Regional Forest Agreement (RFA 1998 b)
for the National Reserve System, namely Jarrah and Warren (Thackway and Cresswell 1995) (Figure 1.2). It also corresponds to, but does not exactly match, the Systems 1 (south west), 2 (western south coast) and 6 (Darling) defined by the Department of Conservation and Environment WA (1976, 1983) in the preceding round of reserve definitions, except that the Swan Coastal Plain is excised. It also corresponds to Beard’s (1981a) Darling Botanical District, except that the Drummond sub-district, consisting of the Swan Coastal Plain, is excluded. There is also a partial correspondence to Hopper’s (1992) High Rainfall Zone and a close correspondence to the South West Forest Region of Bradshaw et al. (1997). The wheatbelt referred to in this and subsequent sections largely corresponds to Beard’s (1980) Avon Botanical District and Hopper’s (1992) Transitional Rainfall Zone.

Climate

The climate of the south western forest region is warm temperate (coldest month below 18° C) and summer dry (driest summer months receiving less than 1/3 as much rain as the wettest winter month). This puts it into Köppen’s (1936) category Cs, usually described as mediterranean (Gentilli 1989). The duration of the rainy season varies from 5 months in the north east to 9 months in the south. The median annual rainfall ranges from 500 mm in the north east to 1400 mm in the south of the region. The rainfall is offset by strong summer evaporation (December to February), which ranges from 800 mm in the north east down to 400 mm in the south. The climate is very conducive to fires, which together with the summer drought have strongly influenced the vegetation patterns (Gentilli 1989). A more detailed description of the climate is given in 2.3.1.
Figure 1.2 - Biogeographic regions of the area covered by the Regional Forest Agreement
Geology and Geomorphology

The dominant geological feature of the forested region of south western Australia is the Darling Scarp, which extends from the north of the region to its southern limit near the Southern Ocean (Biggs et al. 1980). It is the surface expression of the Darling Fault, that is a massive normal fault that separates the crystalline rocks of the Yilgarn Block to the east from the sedimentary rocks of the Perth Basin to the west. The Yilgarn Block forms a stable shield composed of linear belts of Archean metamorphic rocks (sedimentary and volcanic) with large granitic intrusions. Its surface expression is the Darling Plateau, which within the forested region is 200-320 m high and moderately dissected. The less dissected remnants of the plateau are capped by laterite. Granitic and metamorphic monadnocks protrude locally above the plateau, reaching heights of 500 to 600 m. There are Phanerozoic sedimentary deposits in basins and depressions within the plateau, the largest of which is the Collie-Wilga-Boyup group.

The Perth Basin is a deep trough filled with Phanerozoic sediments up to 15 km deep, consisting mainly of sandstones, but with interbedded siltstones, shales, clay and chalk, largely of marine origin. Its surface expressions are the Swan Coastal Plain, the Dandaragan Plateau in the northwest, the Blackwood Plateau in the south west and the Scott Coastal Plain along the southern coast. The two plateaus are capped by sand and laterite.
In the south, the Yilgarn Block abuts on to the Albany-Fraser Orogen, which is a belt of metamorphic rocks such as migmatite and gneiss, intruded by granitic batholiths. This belt, which has a west-northwest orientation, slopes southwards toward the Southern Ocean and is also referred to as the Ravensthorpe Ramp. The Pinjarra Orogen to the west of the Yilgarn Block is mainly exposed as the Leeuwin Complex of granites, gneisses and metamorphics, which is located west of the Blackwood Plateau and borders the Indian Ocean. The bulk of the coast consists of Tamala limestone and of unconsolidated sands in the form of parabolic dunes. Behind the dunes are low-lying unconsolidated coastal plain deposits.

The land surface of most of the region has been subject to a complex process of weathering, denudation and redeposition, which is still on-going, and is the key determinant of landform and soil patterns (Churchward and McArthur 1980). Overall, the vertical differentiation is relatively mild. The geology of the region is described in more detail in 2.3.2 and geomorphology in 2.3.3.

**Vegetation**

The dominant vegetation formation of the region is open forest, which reduces to woodland in the drier north east and increases to tall open forest in the moister south. The understorey consists mainly of sclerophyllous shrubs and perennial herbs. The height of the vegetation is further reduced on the more extreme sites, such as rock outcrops (shrublands, herbfields, lichens), dunes (shrubland and heath) and swamps (shrublands and sedgelands). However, compared to other regions with mediterranean
climate such as southern Europe, northern Africa, western Asia, the Cape Province of South Africa, central Chile and southern California, the vegetation is taller (Diels 1906), possibly because of the predominance of deep soils capable of storing the high winter rainfall to offset the equally high summer evapotranspiration.

Floristically the vegetation is very rich, comprising over 3000 species (RFA 1998a). The richness resides in the forest and woodland understorey, in the shrublands, heathlands and sedgelands. The forest overstorey is by comparison very simple, often comprising only one or two species of eucalypts. There is a high degree of endemism (Bell and Heddle 1989; Hopper et al. 1992). Many of the endemic species have narrow ranges or disjunct populations. The flora of the entire south west, including the coastal plains, northern sandplains and wheatbelt is even richer, being estimated at 8000 species (Hopper 1992). The vegetation, in particular its floristics and ecology, is the subject of the remaining chapters, in particular chapters 2, 3, 4 and 5.

The vegetation of the south western forest region (Jarrah and Warren bioregions) is relatively well preserved compared with the neighbouring areas, namely the Swan Coastal Plain to the west and the wheatbelt to the east, which have been largely altered by agricultural development. Majority of the forest region is in public ownership, in the form of State Forest, National Parks and Regional Parks and Nature Reserves. There are localised foci of alienation, clearing and agricultural development around the main population centres within the region, listed here from North to South: Toodyay, Mundaring, Jarrahdale, Dwellingup, Collie, Donnybrook, Bridgetown, Nannup, Margaret River, Manjimup, Mt Barker, Pemberton and Denmark. These are
shown in Figure 1.1. Much of the State Forest has been subject to one or more phases of logging, and there has been a considerable impact of the dieback disease caused by the introduced fungus *Phytophthora cinnamomi*. A small but significant proportion of the northern third has been subject to surface mining for bauxite, coal and gold. However, there are sufficient remnants of the original vegetation to make it possible to reconstruct the original vegetation patterns.

The proposed series of maps is envisaged as bridging the gap between Beard’s (1981a) 1:1,000,000 series and Beard’s (1979a,b,c) and Smith’s (1972,1973,1974) 1:250 000 series of Vegetation Survey of Western Australia, which are primarily based on vegetation structure, and the various localised vegetation classifications of the forested region in which floristics of the vegetation pays a greater role (Havel 1975a,b; Loneragan 1978; Christensen 1980; Strelein 1988; Inions *et al.* 1990a,b; Wardell-Johnson *et al.* 1989,1995; Griffin 1992; Gibson *et al.* 1994).

1.1.3 Methodology

In attempting to bring the various earlier classifications together, consideration was given to similar tasks being undertaken in other Australian states. The Tasmanian project, which was by then completed, focused on dominance classification of extant vegetation (RFA 1977b), which was appropriate given the floristic and structural diversity of the forest overstorey. This reflects the greater topographic and edaphic diversity of that compact state. The Victorian project (RFA 1997a, 1998c) also used the dominance classification, for similar reasons as the Tasmanian project, but in
addition also described the nature of the understorey and the underlying environmental conditions. It also extrapolated from existing vegetation back to the pre-1750 vegetation through expert opinion on linkage between vegetation and the underlying environmental factors. Neither project had to face the main obstacles of vegetation mapping in Western Australia, that is structurally and floristically uniform overstorey over much of the forest region, and major gaps between the areas covered by past classifications and mapping. Consequently no methodology for dealing with gaps and with integration of divergent classifications could be transferred from the Eastern States to Western Australia.

For this reason, attention was turned to North American sources. The need to map extensive areas of forested lands with limited resources, particularly in Canada, has resulted in the development of an approach that utilises climate and landforms to establish a broad framework, into which the more detailed vegetation classifications are fitted (Mueller-Dombois 1965; Bajzak and Roberts 1996; Banner et al. 1996; Matson and Power 1996; Pojar et al. 1987; Rowe 1996; Smith and Carpenter 1996). These sources provided ideas and methods for the integration of the past classification into a unified system that could be used as a basis for the mapping of forests of south western Australia.

The final approach adopted was similar to that used by Heddle et al. (1980) for the mapping of the northern part of the Jarrah bioregion, with the important difference that it was based on the integration of several landform and vegetation classifications, rather than a single vegetation classification and a uniform set of landform maps. It
also had the benefit of a major review of forest climates by Gentilli (1989) and climatic zonation was consequently given greater consideration. This was essential given the wider range of climates in this project.

The resulting maps overcame the problem of the structural and floristic uniformity of the overstorey by focusing on the floristic diversity of the understorey and its linkage to the underlying landforms and climate. Whereas the understorey vegetation could only be mapped directly at fine scales of 1:10,000 to 1:25,000 using intensive and costly fieldwork, the landforms, which could be mapped from aerial photographs, provided the means of mapping extensive forest areas in considerable detail yet at reasonable cost. This approach was further facilitated by the availability of landform maps for the bulk of the project area and on-going landform mapping aimed at filling in residual gaps.

In this project, the geomorphologic maps covering the two bioregions are converted into maps of vegetation complexes by using climatic data and outputs of localised quantitative vegetation studies. The annual median rainfall discounted by summer (December to February) evaporation is used as the key broad scale determinant of vegetation patterns. Within the climatic zones thus generated, the moisture balance was considered to be further modified by landforms, ranging from steep slopes with shallow soils, which have no capacity to store winter rainfall toward summer transpiration, to depressions with prolonged water accretion or to deep soils capable of storing the bulk of the incoming rainfall. Landforms are also considered to be the determinants of fertility, the extremes of the range being loamy soils freshly
developed over basic crystalline rock and highly leached sands that have been through more than one cycle of soil formation. The information contained in published reports was complimented by the establishment of 1200 permanent plots, located so as to eliminate gaps in coverage by previous studies. The aim of the additional sampling was to cover all possible combinations of landform and climate. The plots were located by Geographical Positioning System (GPS), and all vascular plant species, as well site parameters, were recorded. This was further augmented by recording of toposequences based on reconnaissance, particularly on those landforms impacted strongly by agricultural activities.

The resulting maps at the scale of 1:250,000 (Appendix 3.4) are then combined into a single map of ecological vegetation systems at the scale of 1:500,000 (Appendix 3.5).

The maps attempt to depict the vegetation prior to the European settlement, which commenced in 1830’s, so as to provide a basis on which the comprehensiveness and adequacy of conservation of the original vegetation can be assessed.

1.2 Review of Past Ecological Classification and Mapping

There are several potential approaches to the review of ecological classification and mapping of vegetation in south western Australia, but none is entirely satisfactory. For instance, a review based on methodology has to overcome the problem that many of the past ecologists used more than one method in their attempt to classify or map
vegetation of the region. A review based on the objectives of these studies encounters similar difficulties, in that often the studies have had multiple objectives, or the objectives have changed in the course of the study because of changing economic and political conditions. Even a sequential historical review has to overcome the problem of researchers contributing to this field of study on several separate occasions over several decades, with different objectives and methodologies. Mapping of vegetation, which requires considerable resources, has had a particularly uneven progress. The political motivation for it, and the resulting financial backing, have been so episodic that bursts of intensive effort have been separated by decades of inactivity. The approach adopted in this chapter is a historical one, describing what work has been done by whom, how and where. The detailed outcomes of these studies are dealt with in relevant chapters, in sections dealing with choice of methodology (2.2), with continuity between the various studies (2.4), with relationship between vegetation and the environment (3.3) and with the mapping process (3.4 & 3.5).

**Early Floristic Mapping**

Gentilli (1979a,b) 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 the Moore River to the 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, *Corymbia 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, cited by Gentilli 1979b; Sievers 1895, cited by Gentilli 1979b). This earlier tradition of floristic maps of dominant forest species was continued by Ednie-Brown (1896, 1899 both cited by Gentilli 1979b), Lane-Poole (1920, cited by Gentilli 1979b) 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 *Eucalyptus marginata* (Brooker and Hopper 1993) and *Eucalyptus wandoo* (Brooker and Hopper 1991).

The first vegetation map of the south west, in the narrow sense of structure and function of the vegetation rather than its floristic composition, was that of Schimper (1898, cited by Gentilli 1979b), who coined the term sclerophyllous woodland.

**Diels 1906**

Although the botanical collections and descriptions in south western Australia date back to the earliest period of European settlement, such as, Drummond's systematic collections in the 1830s, the first major attempt to classify and map the vegetation was that of Diels (1906) in his classic Die Pflanzenwelt von West Australien südlich des Wendeskreises - The Plant World of Extra Tropical Western Australia.
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 a 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. 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 Anarthria, Conostylyis, Dasypogon, Kingia, Lyginia, Nuytsia, Phlebocarya and Synaphea and as first-class endemics, that is without any relations outside, and Andersonia, Calothamnus, Desmoclados, Diplolaena, Hypocalymma, Platytheca and Tremandra, and 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 northern portion of 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. It does, however, also contain some swampy alluvium and sands. Jarrah is used as the characteristic species. The north east portion of the area falls marginally into Diels' Avon District, and the south east portion equally marginally into the Stirling District. The southern portion of the survey area fall into the Warren District, which is quite varied edaphically. It does, however, have higher overall rainfall than the other districts and its characteristic species is karri.

Other Early Vegetation Mapping

Several authors contributed to the vegetation mapping in the south west region during the period 1906 to 1940. Hardy (1911, cited by Gentilli 1979b) defined the forest areas as "winter rain forest" which recognised the potential role of climate conditions in determining forest boundaries.

Gardner's (1923a,b) description was little more than a brief summary of Diels' work in English. It was followed by a vegetation map in 1928 (cited by Gentilli 1979b).

Geisler (1930, cited by Gentilli 1979b) included the dominant floristic element in each plant formation and his accuracy on the dominant species reflects 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 for the south west the scheme of classification was essentially that of Diels. The jarrah forest was mentioned only briefly, with no additional information.

Prescott's (1931, cited by Gentilli 1979b) vegetation map is well known, although it did not differ substantially from the earlier map of Gardner (1928, cited by Gentilli 1979b). 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".

**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 is 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. The observations in the first survey were done with painstaking detail, 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 20 m 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: Corymbia calophylla, Eucalyptus wandoow, Eucalyptus marginata and Eucalyptus patens (yarri).

**Forests Department WA - 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,b,c) and Heddle et al. (1980), 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 with characteristic structural features can be identified on the aerial photographs, for example karri and rock sheoak (*Allocasuarina huegeliana*).
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 is, from jarrah through wandoo and marri to flooded gum (*Eucalyptus rudis*). Relatively few associated species were named. 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.

Williams 1955

Williams’s map in 1955 (cited by Gentilli 1979b), followed on from the earlier studies of Wood (1950) and was based on strictly structural characteristics. Since William’s work, a series of maps have been produced for Australia including Cochrane (1967, cited by Gentilli 1979b), Moore (1970, cited by Gentilli 1979b) and later Carnahan (1976).

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 were
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.

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* and *Corymbia 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-C. 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-C. calophylla* and the tall, temperate woodland of *E. wandoo-C. 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.

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.

**Lange 1960**

Lange (1960) related climatic and edaphic factors to distribution of tree species in the Narrogin district. Although much of his study area was east of the Jarrah bioregion, many of the tree species studied by him do occur within the survey area, and their distribution in a drier climate throws considerable light on their site requirements. 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.
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*, *Corymbia calophylla* and *Eucalyptus diversicolor*. 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 *Corymbia 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.

Specht 1970

Specht (1970) developed a new system of vegetation mapping for Australia based on projective foliage cover and height of the tallest stratum. As 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).
Smith 1972, 1973 and 1974

Smith (1972, 1973, 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, for the Department of Agriculture WA under the auspices of the Western Australian Vegetation Survey Committee. 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 1965 to 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. Subdivisions of the structural formations on the basis of plant associations are indicated by means of symbols. The maps were published at the scale of 1:250,000. The definition of structural formations was clearest along the coast line, where vegetation varies from herbland to forest. It was moderately clear along the southern periphery of the jarrah open forest, where it is intermixed with karri tall open forest, and along its eastern periphery where it gives way to wandoo woodland. In the central forest belt, jarrah open forest was mapped over the bulk of the area because of the lack of structural differentiation.
The location and coverage of the studies described from this point on is shown in Figure 1.3 on page 71.

**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 just 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 vegetation and soil moisture regimes, are relevant to three of the districts 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 an applied ecological project, in which understanding of the vegetational patterns was not the end in itself, but only a means to an ecologically based land management system. Initially the study was undertaken as a basis for land classification for plantation forestry. Its initial aim was to use vegetation to predict site productivity, because the 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 (1965) and the clearly defined biogeocenosis concepts of Sukachev and Dylis (1954), that worked for the European vegetation strongly modified and fragmented by millennia of human impact, were of limited use in south western 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. Attention was therefore turned to other European approaches to vegetation classification, such as the vegetation-based site classification system of Cajander (1926) in Finland and Ilvessalo (1929) in North America. The concept of a continuum of forest types, based on the composition of the understorey, was more applicable to the situation within the forest systems of the south west. 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. This simple, subjective methodology was inadequate to deal with the complex and species-rich vegetation of the South West Forest Region of Western Australia.

Attention turned to more objective methodologies for dealing with continua, such as that of Pogrebnyak (1955), namely the ordination (edaphic net) developed for the forest-steppe transition in Ukraine. A similar method to that of Pogrebnyak’s approach was also used successfully in the United States of America by Whittaker (1956). It proved effective 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 laborious.

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 guidance and help a system was developed that has been used over the next twenty years for 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 40 m x 10 m, within each of which were nested two shrub sub-plots of 4 m x 4 m (metric equivalent of 13 ft x 13 ft). 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 (0-1 and 1-2 m), were analysed in the laboratory for soil reaction and the percentages of iron and organic matter, suspected
to be the chief determinants of moisture and nutrient holding capacity of the sands. Because of the limitation of the programme the shrub data had to be reduced to thirty species of moderate to high frequency. Uncommon and very common species were omitted. The output of the principal component analysis identified the degree of the leaching of the soil, expressed as percentage of iron, as the key determinant of vegetation patterns. The second key determinant was moisture availability.

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 the 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 40 m x 40 m, containing eight 4 m x 4 m 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 content for a full year. Subsequently they were resumed on a yearly basis as part of an 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 on a regular triennial basis. Combined with annual reassessment of the vegetation data they provide one of the longest studies of vegetation dynamics in Australia, from 1965 to 2000 (Havel 1968; Heddle 1980; Mattiske Consulting Pty Ltd 1995). The
study had influence beyond its original narrow objective of site classification for plantations.

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 nodal in a multidimensional continuum, not narrowly defined plant associations of the European classification systems.

Many of the indicator species have re-emerged 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.

Before the results of the studies were published, the workability of the system was tested by extensive field surveys covering 3307 ha in five localities within the northern Swan Coastal Plain. The differences due to fertility, which are reflected in the composition of the shrub stratum, were more difficult to map, requiring ground surveys. The differences due to water availability, which are reflected in the composition and structure of the tree overstorey, were detectable on aerial photos. It was found that it was 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 the late sixties, Havel turned his attention to the northern jarrah forest (Havel 1975a,b). The initial objective of this study 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 1989a). Economic developments such the expansion of 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 a sound ecological base for conservation and multiple purpose management. As the area to be classified and mapped was much more extensive (732,600 ha compared with 51,030 ha) and diverse (in terms of geology and climate) than the coastal study, changes in methodology also became
necessary. Fortunately, the developments in computer technology and quantitative ecology were equally rapid. The sampling comprised 320 plots of 40 m x 40 m, each containing 16 quadrats (subplots) of 1 m x 1 m. Total enumeration of all trees in terms of basal area was carried out 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 the 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 to define ecologically equivalent or at least similar sites.

The program was also used to test the discriminatory capacity of any species, by observing how tightly or loosely the occurrences of a species were clustered 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 nodal in a four-dimensional continuum, not tight plant associations. They were indexed by letters of the alphabet for convenience in field mapping, as the definition by the names of several indicator species would be too cumbersome. Two further site-vegetation types were added subsequently.
The study of the ecology of the northern jarrah forest is described in full in Appendices 1.1 and 1.2.

Alternative methods of classifications were also used, namely the monothetic divisive classification, using the programs DIVINF and DIVINFRE (Lance and Williams 1968), and the agglomerative polythetic classification using the program CLASS (Lance and Williams 1967). 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 at 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 of 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 a 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.
McArthur and Clifton 1975

In the southern half of the study area, a broadscale account of climate, 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 soil studies in light of the new nomenclature of Northcote et al. (1967), 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 south west, 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 based on any formal analysis of quantitative samples, it was 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 although the climatic gradients across the area were influencing the vegetation, the single most significant factor in determining the vegetation was the soil. The authors defined the main vegetation characteristics in relation to the soil associations (Balbarrup, Perup, Nyamup, Pemberton, Boorara, Chudalup, Blackwater, Quagering, Meerup, Yeagerup, Carey, Coolyarbup and d'Entrecasteaux). There was a recognition that there were subsets of vegetation units within these soil associations, that largely reflect subtle soil and soil moisture changes.

Loneragan 1978

Concurrently and parallel with the work of Havel, but independent of him, Loneragan (1978) studied the interface between forests of jarrah and woodlands of wandoo. The two studies had much in common: both took the earlier work of Speck (1958) as a starting point and 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 north eastern 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's 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 south western 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 questions 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 50 m from any well-defined stream bed, which automatically eliminated the moist end of the vegetation continuum.

Ultimately Loneragan selected 122 sample plots. The data collected by Loneragan was comparable to that of Havel (1975a), in that trees were recorded on 48 m x 48 m plots in terms of numbers and basal area, and shrubs and herbs were recorded on sixteen 1 m x 1 m 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 observations 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 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. No *Melaleuca preissiana, Banksia littoralis, Banksia attenuata* or *Allocasuarina huegeliana*, which are typical of these sites, were included in the test.

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 (*Eucalyptus accedens*) (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 species were present in significant proportions. In T4, jarrah was accompanied by all other species, both the eucalypt co-dominants and non-eucalypt 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 species 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 south west. 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.

Ordination of the tree data by means of PCA omitted species of low frequency, namely *Eucalyptus patens*, *Acacia acuminata* and *Acacia saligna* (previously *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 and marri occurred in 91 stands, wandoo in 55 stands and powderbark wandoo 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 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’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 to 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.

**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. 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 a potential indicator of site quality, as done earlier by Havel (1968) 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 (1975a), though his plots were circular (20 m radius for trees and 10 m radius for shrubs and herbs). The recording was confined to 72 common species of the region, recorded on an abundance scale. The data were 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 Swan 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 site-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 site-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 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 site-vegetation types. The indicator groups formed were designed specifically to assist in soil surveys. The six site-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.

The value of the study to this thesis is that it 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.
Beard 1979a, 1979b, 1979c and 1981a

Vegetation mapping on structural basis, initiated by Smith (1972,1973,1974) was taken up by Beard (1979a,b,c) who mapped the remaining regions of the south west (Perth, Pinjarra and Albany & Mt. Barker) at 1:100,000, published them at 1:250,000 scale and then combined his maps and those of Smith (1972,1973,1974) into the Swan Vegetation Map at 1:1,000,000 (Beard 1981a). In the explanatory notes, Beard went beyond structural vegetation mapping and discussed natural regions, climate, geology, geomorphology and human influences, as well as vegetation plant formation, vegetation series and vegetation system level. He also explored possible 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 criteria.

Bettenay et al. 1980

Bettenay et al. (1980) carried out a description of the experimental catchments in the Collie Area. The vegetation was mapped by using the method described by Havel
(1975a,b), who delineated 21 distinct site-vegetation types in the northern jarrah forest. In small areas, such as the Collie catchments, it was possible to increase the number of types by mapping variants of the types using a combination of coding letters, which are relevant to the area. In addition to the plant species used by Havel a reconnaissance of the catchments was made, and any plant species which showed promise as an indicator of a particular site-vegetation type 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. Aerial photo interpretation was used for checking the boundaries.

**Heddie 1979 and Heddie et al. 1980**

Heddie (1979) and Heddie et al. (1980) extended the interpretation of vegetation patterns in relation landforms and climate into 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 Heddie et al. (1980) relied on the previous studies in the area and in particular the detailed site-vegetation type work of Havel (1975a,b), the Aerial Photographic Interpretation (API) mapping by the Forests Department, the topographic data held by the Department of Land Administration WA, the landform and soil mapping of Churchward and
McArthur (1980) and, the structural vegetation mapping by Smith (1974) for the Collie area. The studies by Beard (1979a,b) were being developed concurrently with those of Heddle et al. (1980) and therefore the essentially structural formation mapping of Beard was not available to Heddle et al. (1980) at the time of the mapping.

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

The mapping by Heddle et al. (1980) depicted the original plant cover and attempted to describe the relationship of the site-vegetation types to the underlying landforms and soils and climatic patterns. All mapping was undertaken at scales of 1:25,000 and 1:50,000.

During the mapping project detailed field work was undertaken in selected areas and broad reconnaissance work was undertaken over the extensive road and track system throughout the project area.

Christensen 1980

In the late 1970’s, Christensen (1980) undertook a range of studies on two marsupials (Bettongia penicillata and Macropus eugenii) in the Perup forest area, east of
Manjimup. Although the prime purpose of this study was to investigate the vertebrate fauna species, detailed recordings were undertaken on the vegetation and fauna habitats.

In the vegetation component of his study, he followed closely the methodology of Havel (1975a). Frequency on a scale of 1-5 was recorded for 73 common and indicator species on 149 circular plots of 20 m radius. The data analysis by means of principal component analysis was carried out to the stage of ordination of the species and the plots on the first four axes. He did not define site-vegetation types or indicator groups.

**Congdon 1981**

Congdon (1981) described the vegetational zonation in the marshes at the mouth of Blackwood River, from *Sarcocornia* spp. marsh near the mouth, through sedgelands of *Juncus krausii* and *Baumea juncea* and shrublands of *Viminaria juncea* to woodland of *Melaleuca cuticularis* further inland. The zonation varied according to the configuration of the land, and distance from the rivermouth. The narrowness of the zones (less than 500 m) would make it difficult to map them at the 1:250,000 scale.

**Heddle and Marchant 1983**

Heddle and Marchant (1983) described the vegetation of the Darling Scarp primarily in terms of structure, that is as open forest, woodland, low open woodland, heath and
herblands. However, they also provided a list of components for each structural
category.

Trudgen 1984

Trudgen (1984) carried out a survey of the Westdale-Dobaderry group of reserves
located on the north eastern perimeter of the south west forest region. The reserves
cover a wide range of 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 the nomenclature of Havel (1975a,b),
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. A 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 a scale of 1:40,000, followed by an 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 laborious identification of the “faithful” species.
Trudgen’s report and the earlier published studies (Havel 1975a,b) were used by The Campaign for Native Forests (Cahill 1984) to put forward a proposal for a very large wandoo reserve of 111,630 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.

**Site-vegetation Type Mapping for Assessment of Dieback Disease Risk**

After Havel (1975b,1979) demonstrated the relationship between site-vegetation types and the occurrence of the dieback disease caused by *Phytophthora cinnamomum*, 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 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 types 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,b) which is considered to be the best predictor of the highly susceptible (P, SP) and less susceptible sites (ST, T).

Shearer and Tippett (1989) 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
development of the disease to the floristic composition of the particular site-vegetation types, in
particular the proportion of species from the highly susceptible families, such as the
Proteaceae and Euphorbiaceae.

Havel Land Consultants 1987

Havel Land Consultants (1987) 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 the OMNIS programme and the
impact determined by specifying the level of inundation for the varying engineering
options. The observations were carried out along transect lines at 50 m 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, i.e. 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 of
Havel (1975a), in which there was a bias towards the upland surfaces of the Darling Plateau.

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 the 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 summarised in the form of Minimum Spanning Trees and Linkage Dendrograms.

**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 followed the methodology of Havel (1975a) closely. 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 of 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 the Reciprocal Averaging program RECAV (Hill 1973), which proved of limited use because it tended to 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 construct a four dimensional model of the location of the various species within the component space.

Using the four-dimensional models, Strelein defined a set of site 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 describe the silvicultural characteristics of these types, such as basal area stocking and presence of regeneration.
The chief value of this study is the meticulous way in which Strelein tested a very wide range of indicator species, both in terms of 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 types defined by Strelein bear considerable similarity to Havel’s northern site-vegetation sites and even are identified with the same letters of the alphabet. 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. There are some types which bear no 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 determine what part of the landscape the site-types occupy and how extensive they are. Before leaving the field, Strelein did, however, attempt to relate his site 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 the jarrah forest, two of his types contain a small proportion of karri and provide an overlap with and link to the corresponding study of the karri forests by Inions et al. (1990a,b). Its also links up with the
classification of the southern coastal plain by Wardell-Johnson et al. (1989), which overlaps with it in the extreme south east.

**Inions et al. 1990a and 1990b**

The studies of Inions et al. (1990a,b) mark the beginning of a new era in the methodology of vegetation classification in south western Australia. In a sense Inions' 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 stands 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, Inions et al. sampled 204 plots distributed over the main range of karri from south of Nannup to Irwin Inlet east of Walpole.

Inions' 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 homoclines, respectively.

The soil groups ranged from relatively infertile acidic soils to the least acid soils with high fertility. The homoclines ranged from coastal sites with high rainfall, low summer 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 (1988) 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. 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, Inions used the names of prominent foresters and numbers. 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 et al. defined five community groups, subdivided these into thirteen community types, and 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.

Wardell-Johnson et al. 1989 and 1995

Although the study by Wardell-Johnson et al. (1989) was published slightly earlier, it is discussed after Inions et al. (1990a,b) 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 the Inions et al. studies, the taxonomic and computational expertise, in that basically the same personnel were 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 Inions et al. (1990a,b), 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 (10 m x 10 m) 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 1 m was also carried out. The structure of the community was described according to Smith’s (1972) and Specht’s (1970) terminologies.

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 distribution of the association measures. As in the case of the Inions et al. (1990a,b) studies, an association matrix was
imposed on the floristic data using the polythetic agglomerative strategy using an 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.

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

Subsequently Wardell-Johnson et al. (1995) commenced study of the forests and woodlands to the north and east of Walpole National Park, mainly east of the areas
surveyed by Strelein (1988) and Inions et al. (1990a), though there is a degree of overlap. 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 north east to 1400 mm in the south west. The temperatures are higher along the coast in the winter and lower in the summer, than is the case inland.

The study incorporated the floristic data of Wardell-Johnson et al. (1989), but an additional 441 plots (20 m x 20 m) have been added. The location of the plots was based on Churchward et al.'s (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 plots 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 (Czakanowski 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 enumeration of species within the study as a whole,
and within the twelve community groups. Some of the community groups are too broadly defined, in particular the group containing wandoo woodland and outcrop, which consists of 11 quite heterogeneous types.

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 for 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.

Mattiske and Burbidge 1991

A series of permanent vegetation plots from the John Forrest National Park was described by Mattiske and Burbidge (1991). The plots spanned the interface between the mildly sloping lateritic uplands of the Darling Plateau and the steep face of the Darling Scarp. In terms of structure the plots ranged from herb fields through heath and woodland to open forest. There was a parallel gradient of floristic composition. The data were presented in the form of a species/site matrix for 16 plots with 25 quadrats each. Each plot was considered to be representative of a different ecological setting.

The most recent study of the Darling Scarp vegetation is that of Markey (1997), which has come to notice too late to be incorporated into the mapping process. It could be
used to refine the definition of vegetation on the Darling Scarp and Ridge Hill landforms.

Smith 1994

Relatively little additional work was done in the field of vegetation studies on the Blackwood Plateau until the study by Smith (1994) of two rare Chamelaucium species. Smith attempted to use McCutcheon’s (1980) classification as ecological reference, but found that some of the areas in which he was working were more dissected and more fertile than any of the types described by McCutcheon. They could, in fact, be better described by Strelein’s (1988) classification of the adjacent crystalline Darling Plateau. 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.


Mattiske, E.M. and Associates (1979-1994) and Mattiske Consulting Pty Ltd (1994-2000) have carried out extensive vegetation assessments and vegetation mapping projects for a range of mining companies, 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 (20 m x 20 m and 40 m x 40 m) and extensive vegetation mapping on various grid systems (60 m x
120 m; 120 m x 120 m; 200 m x 100 m). 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 20 m radius for overstorey species. Data have been collected in some 150 permanent vegetation plots and at more than 25,000 mapping sites to date and have 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,b). In most areas it has been possible to further subdivide the site-vegetation types to a higher 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 with 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 a woodland of *Eucalyptus rudis* over *Melaleuca incana* var. *incana* (formerly *Melaleuca polygaloides*) and *Acacia saligna* on the fine particle clay soils in the eastern Yarragal 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. Some of the studies have been published under the name of the clients, such as Worsley Alumina Pty Ltd (1985, 1999).

In recent years, further vegetation mapping has been undertaken in the southern coastal areas. For example, within Scott National 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 the 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 endangered species. Overall the vegetation communities reflected predominance of swampy condition, rather like the coastal plains reported by Wardell-Johnson from the vicinity of Walpole, although local differences were noted in the shallow ferricrete soils.

**Griffin 1992**

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 (Julimar and Bindoon districts) is relevant to this project, the study is important in that it covers the northern and eastern margin of many species. It has as its objective, to identify the full range of floristic
variation within the region which 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 south east. It overlaps to a certain degree with the region studied by Loneragan (1978).

Griffin (1992) sampled quadrats of 100 m², which he regarded as relevés (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 and Ellenberg 1974). He also recorded the vegetation structure in terms of Muir’s (1977a,b) classification and the relevant topographic and edaphic information. Altogether he collected 479 relevés, scattered in clusters throughout the region, mainly but not exclusively on reserves. These he incorporated into a database, which he analysed by means of a package of programs called PATN (Belbin 1987a,b). He used the programs for three basic functions:

a) to produce groups of relevés according to their species composition, and hence define floristic types,

b) to identify differences between types, to hypothesise about them and to test them, and

c) to display the results.

The programs used were ASO (similarity measures between relevés - rows), FUSE (combination of rows into groups), DEND (display of the progress of fusion), KYST (multi-dimensional ordination program), and MST and TWAY (data display
programs). Initially Griffin chose 35 groups of relevés 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 by 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.

Within the area covered by the RFA study, he identified 25 groups, most of which occurred in both Julimar and Bindoon districts, but some were specific to Julimar (sand and swamp types) and some to Bindoon (rock outcrop types). The largest groupings were those identified with woodland dominants (jarrah with 40 relevés, wandoo with 85 relevés and powderbark wandoo with 32 relevés). These correspond broadly to Loneragan’s (1978) dominance types, and are broader than Havel’s (1975a,b) 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 1965) classification
of southern and central Europe. Corresponding sites would not have been sampled by Loneragan.

Ecologia Environmental Consultants 1994

The central part of the proposed wandoo reserve (Cahill 1984) was surveyed by Ecologia Environmental Consultants (1994), who established fifty-four (10 m x 10 m) 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,b). The area surveyed by Trudgen (1984) 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 1990a). 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 site-vegetation 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.

Gibson et al. 1994

Gibson et al. (1994) carried out a floristic survey of the southern Swan Coastal Plain, which is marginally included in the periphery of the RFA project area. The purpose of the survey was to provide a more detailed knowledge of the conservation status of species and communities in remnant vegetation in the highly modified landscape. The survey involved the establishment of 509 quadrats (10 m x 10 m), largely located in remnant vegetation on publicly owned (Crown) land, which were intended to cover the geographical, geomorphological and floristic variation of Crown lands. All vascular plants were recorded, as well as information on slope aspect, vegetation structure and condition.

The classification process for sites utilised the Czeckanowski coefficient and "unweighted pair-group mean average" (UPGMA) fusion method (Sneath and Sokal 1973). Species were classified into groups according to their occurrence on the same sites by using the TWOSTEP similarity algorithm (Austin and Belbin 1982) followed by UPGMA fusion. In addition semi-strong hybrid (ssh) ordination of the site data was used to explore spatial relationships between groups and to relate the groups to environmental factors.
The nomenclature used is based solely on floristic composition, and comprises 4 supergroups, which reflect landscape scale pattern, and 30 community types. The data pool contained 1485 species of flowering plants, of which 172 were weeds. Of the 1313 native taxa, at least 130 were as yet undescribed. The study also explored endemism, geographic range of taxa and rarity. Many of the species were recorded only once (singletons) and were not utilised in the analysis.

Gibson personal communication

The most recent study of the southern vegetation is that of Gibson\(^1\) (personal communication), who has done an extensive study of plant communities along the south western coast, comprising 300 sites. It was carried out to provide regional ecological overview of sand mining proposals. It utilised B-C, UPGMA methodology for both normal and inverse analysis. 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 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). The early stages of the analysis have been made available for this study, and are utilised in subsequent chapters.

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Department of Conservation and Land Management WA, Woodvale
Hopkins et al. in press

Hopkins et al. (in press) have captured the earlier work by Beard in 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 at a scale of 1:1000,000, 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 RFA vegetation mapping project in the wider State context and biogeographical context which is relevant for its wider assessment.

Worsley Alumina Pty Ltd 1981, 1985 and 1999

Worsley Alumina Pty Ltd has financed a number of vegetation studies in the areas mined by them. The studies were primarily located in the catchment of the Murray River and its tributaries near the eastern boundary of the Jarrah Bioregion, midway between its northern and southern extremities. There is also extension towards south west of the Jarrah Bioregion along an overland conveyor to the refinery. The initial studies, Phase One Flora and Fauna Studies (Worsley Alumina Pty Ltd & Dames and Moore 1981) primarily amounted to mapping of vegetation.
In Phase Two (Worsley Alumina Pty Ltd 1985) this initial work was expanded in order to improve floristic information and definition of plant communities and to supplement it with phenological and plant dynamics information for rehabilitation after mining. The Phase Two studies involved 84 plots of 40 m x 40 m dimension, for which the following parameters were obtained: height, basal area and number of tree stems for the plot as a whole and foliage cover of understorey species on four 5 m x 5 m quadrats located at the corners of the plot. Several quantitative analyses were carried out, including Carlson Clustering, Minimum Spanning Tree and Principal Axes Ordination of plots (Q-mode) and Association Analysis, Minimum Spanning Tree, Pearson Correlation and Factor Analysis of species (R-mode).

The dendrogram summarising Carlson Clustering separated the jarrah forest from the high rainfall refinery site and conveyor corridor from the jarrah forest from the lower rainfall mining area, and from the wandoo woodland and heaths. The jarrah forest / woodland from the lower rainfall was further subdivided, mainly on topographical position and soils, as were the heaths. The Minimum Spanning Tree for jarrah forest woodland in the low rainfall zone subdivided this large group primarily on topographical position and soil texture.

The Principal Axes Ordination separated the heath plots from the rest and, apart from minor overlap, also separated high and low rainfall jarrah forest and woodland from each other.
The constellation diagram of associated plant species in the jarrah communities delineated several species groups, some of which resemble Havel’s (1975a) indicator groups, such as *Persoonia longifolia* and *Banksia grandis* (Havel’s GRAMED) and *Leucopogon capitellatus, Macrozamia riedlei* and *Phyllanthus calycinus* (Havel’s FREGRA).

The constellation diagram of associated species of the wandoo woodland and heath communities delineated some species groups not identified by Havel, such as *Leucopogon capitellatus, Calothamnus quadrifidus, Dodonaea ceratocarpa, Astroloma epacridis, Grevillea bipinnatifida, Trymalium ledifolium, Acacia alata* and *Hypocalymma angustifolium*, from heath on shallow soils of upper slopes and ridges. Ultimately six jarrah community types, three heath types, one wandoo and one rock sheoak type were delineated in terms of the component species, topographical position and soil, such as:

19JSd - open forest of *Eucalyptus marginata* and *Corymbia calophylla* with second storey of *Banksia grandis, Allocasuarina fraseriana* and *Dryandra sessilis* on gravelly soils overlying shallow rocks on ridges and upper slopes. Indicator species were *Stylidium dichotomum, Clematis pubescens, Acacia celastrifolia, Senecio leucoglossus* and *Xanthosia atkinsoniana*. The type was identified as eastern variant of Havel’s (1975a) type S.

A matrix of species / plots was developed and the project area was mapped at the scale of 1:10,000. This was reduced to 1:20,000 for publication.
Subsequently, Worsley Alumina Pty Ltd (1999) carried out a vegetation survey of a new project (gold mine), located west of the alumina mine. In this case, detailed sampling of eight 40 m x 40 m plots was combined with a vegetation survey on a 50 m x 100 m grid published at the scale of 1:33,000. Greater emphasis was placed on relating the vegetation to landforms and vegetation complexes (Heddle et al. 1980). The site-vegetation types were defined in terms of Havel (1975a,b) nomenclature, with reference to nomenclature used in earlier Worsley Alumina Pty Ltd studies, eg. ST (formerly coded as 19JSd). The site-vegetation types were again described in terms of overstorey and second storey trees, and those understorey species considered to have indicator value. New types, not adequately covered by Havel, were defined for the more extreme sites (AX riparian woodland and G3 and G4 heaths on shallow soils).

The areas covered by the studies described above are shown in Figure 1.3. The coverage of the RFA project is uneven and incomplete.

Semeniuk et al. 1990 and Semeniuk Research Group 1997

Semeniuk et al. (1990) proposed a classification of wetland vegetation which appears to operate at scale too fine for the RFA project, except for those wetlands described as macro and megascale. Semeniuk (1997) extended the study of wetlands to the Warren bioregion from Augusta to Walpole and northward to Lakes Muir and Unicup.
They mapped the wetlands at the scale of 1:25,000 and in the process identified additional categories to those described for the Darling System (Semeniuk 1988), particularly wetlands on hillslopes. They assessed the wetlands in the southern part of the Warren Bioregion to comprise 35% of the total area. It has not been possible to fully utilise the information, partly because the scale of mapping was too detailed for mapping at bioregion scale, but also because by the time their work was published the RFA mapping process had already commenced.

Burbidge et al. 1996

Burbidge et al. (1996) surveyed and mapped the Boonaring Nature Reserve on the Dandaragan Plateau immediately to the north west of the RFA project area. They defined ten vegetation associations, ranging from marri forest through jarrah – marri woodlands and banksia low woodlands to heathland (kwongan). These contained 573 taxa of vascular plants, including many that are rare or uncommon. The detail is finer than what can be utilised in the mapping of vegetation complexes at 1:250,000.

Bradshaw et al. 1997

The south west forest region has been mapped at the scale of 1:250,000 by Bradshaw et al. (1997). Although the maps are primarily based on aerial photo interpretation (API), the mapping process also involved ground surveys to refine the definition of the composition of the overstorey. The mapping units are defined as forest associations and are primarily described in terms of the height, density and
composition of the overstorey. The maps of forest associations are supplemented by a map of the height of the tallest stratum at 1:650,000 and by a map of karri distribution prior to European settlement at 1:350,000. The map of original karri distribution is the only one of the set that covers privately owned land, the others being restricted to publicly owned land. The maps of the forest associations are described in greater detail in 3.5.5.

**Gibson and Keighery in press**

Gibson and Keighery (in press) surveyed the Byenup – Muir reserve system straddling the south eastern periphery of the RFA project area from the point of view of flora conservation. The study was not available in time to influence the mapping.

### 1.3 Conclusion

The review of past vegetation studies within the south west forest region has shown that the only ones giving full coverage of the region are those describing the structure, and to a lesser degree the composition, of the dominant stratum.

The numerous studies dealing with the floristic composition of entire vegetation communities are localised, and generally differ in the methodology of sampling and data analysis. They can be jointly viewed as a process of successive approximations. Whilst there is considerable degree of geographical overlap between the various localised studies, there also sub-regions which largely or completely lack coverage.
Chapter 2: Review of Methodology for Mapping at the Bioregion Scale, Description of Key Environmental Factors and Evaluation of the Continuity of Earlier Vegetation Classifications

2.1 Introduction

The review of past attempts at classifying and mapping the vegetation of the forest region (Jarrah and Warren bioregions) concluded that these represent a process of successive approximations which is as yet incomplete in terms of coverage (Chapter 1). In the northern third of the region, maps already exist that combine vegetation structure and composition with underlying factors of the environment, in particular climate and landform (Heddle et al. 1980). However, in the southern two thirds of the region there are only several separate classifications built on different objectives and methodologies. In addition, the southern two thirds are climatically, geomorphologically and ecologically more complex. The climate is influenced by two oceans rather than one and landforms include several separate plateaus and coastal plains. As a result, the vegetation is also more complex, ranging from sedgelands and heath to tall open forest. A whole new set of species is added to the northern set, and some of the northern species are absent in the south. The mapping approach formerly used in the northern third, therefore, cannot be automatically taken as being the most appropriate methodology for the mapping of the whole region.
The objective of this chapter, therefore, is the exploration of the options available for the generation of an overall regional map. One of the aspects of this exploration is a search for other mapping systems at a bioregion level, and examination of these systems as to their effectiveness and objectivity. Other aspects to be explored include the methodology of linking vegetation to underlying environmental factors, and whether additional factors need to be examined beside landform and climate.

2.2 Review of Methodology for Mapping at the Bioregion Scale

As the first step in the exploration, the approaches adopted for mapping of forested regions of Victoria and Tasmania for the Regional Forest Agreement were examined. Although the objectives are identical to those in Western Australia, that is, the provision of a sound basis for the reservation of old growth forests, there is no ready transferability of methodology between states.

In Tasmania, there is a high degree of edaphic and topographic diversity and an equally high degree of the floristic diversity of the dominant tree stratum, as compared to south western Australia. These features made the dominance classification the logical choice for vegetation mapping in that state (RFA 1997b). Its applicability to south western Australia is limited due to the fact that topography is relatively subdued, edaphic differences subtle and extensive areas are dominated by just one or two overstorey species.
The Ecological Vegetation Classes used in the Victorian process (RFA 1997a, 1998c) incorporate in their definition not only the description of the vegetation structure (forest, woodland, shrubland, heath), but also the nature of the understorey (heathy woodland, grassy woodland) and the underlying environmental conditions (montane dry woodland, floodplain, riparian woodland). The definitions also recognise the fact that at the scale of mapping adopted (1:250,000) the diversity may be such as to make the mapping of homogeneous categories impossible, and consequently many of the categories are described as mosaics or complexes of two or more vegetation types (rocky outcrop shrubland/herbland mosaic, valley grassy forest/box ironbark forest complex). The Ecological Vegetation Classes may consist of two or more Floristic Vegetation Communities, and both categories are, wherever possible, defined by reference to the original ecological studies, such as “Limestone Box Forest (Woodgate et al. 1994)”.

A further aspect of the Victorian RFA process is that the vegetation is mapped at two timeframes: extant vegetation and pre-1750 vegetation. The latter was compiled by extrapolation from the former, with reference to land systems and geology and using expert opinion on the influence of landform, soil, climate and hydrology on the development of Ecological Vegetation Complexes.

From many aspects, the Victorian approach appears to be more applicable to south western Australia than the Tasmanian approach, though there are some differences. For instance, Victorian forests have greater floristic and structural diversity of overstorey than those of south western Australia. In addition, because Victoria is
smaller in area and has denser population than Western Australia, the gaps in coverage by past ecological studies are fewer and smaller. Consequently, it has been easier to compensate for the gaps.

The greater availability and continuity of earlier vegetation classification and mapping has enabled the Victorian process to build maps directly from available information. In the local (WA) context, that approach is hindered by the localised nature of the existing classifications and maps, and by the considerable gaps between them that need to be filled. Some conceptual basis is needed for linking the various classifications, and for converting them into maps.

At first sight, other regions of the world with comparable climate would seem to be the most likely sources of such concept and methodology. However, the best known of these, the Mediterranean region of southern Europe, northern Africa and western Asia, mostly contain vegetation fragmented by thousands of years of cultivation and grazing. The methodology that has been developed there, and is currently in use there, the Braun-Blanquet systematic classification of plant communities, has had only a limited use in the south western forest region (Bridgewater 1981) because it is better suited for classifying discrete parcels of relatively homogeneous anthropogenic vegetation.

Two other regions with comparable climate, southern California and central Chile, have markedly different geomorphic patterns of steep mountains, caused by tectonic instability. In California, Whittaker (1960) successfully used gradient analysis to deal
with the steep altitudinal gradients of vegetational change that occur under these conditions. In south western Australia such steep gradients do not occur, because the dominant landforms are mildly sloping plateaus. Synecological studies of Chilean forests (Armesto et al. 1997) have as yet not reached the stage where they could serve as a prototype for WA. In any case, except in the coastal range, the tectonic instability is even more acute than in California. It is only in South Africa’s Cape Province that comparable conditions of tectonic stability, extensive mild landforms with infertile soils and floristically rich vegetation are found. The vegetation classification in South Africa is primarily based on structure (von Breitenbach 1974), comparable with the mapping of Smith (1972,1973,1974) and Beard (1979a,b,c,1981a) in Western Australia. Although description of the floristic composition is given, there is no transferable up-to-date methodology. In addition, the dominant vegetation formation of the Cape Province is fynbos (heathland), not woodland or forest.

Search of the northern American literature proved more rewarding. The objective of sustainable forest management, which northern America shares with Australia, has generated a search for appropriate methodology for forest classification and mapping. It has been addressed at the both conceptual and methodological levels.

2.2.1 Conceptual Basis of Vegetation Mapping at the Bioregion Scale

At the conceptual level, Banner et al. (1996) perceive ecosystem classification as providing the taxonomic framework for describing ecological units in terms of their nature and pattern, and ecosystem mapping as the means of depicting their spatial
distribution. Rowe (1996) views classification and mapping as synergistic. He sees the chief benefit of combining classification and mapping to be the obligation to consider all parts of the terrain. When classification is carried out separately, the difficult transitional and abnormal units are often left out. The boundaries between vegetation units express the map maker’s hypotheses that important compositional and functional differences lie on either side of the boundary. The patterns on the vegetation map are underlain by patterns of landform and drainage, which are less subject to short term disturbances by such factors as fire, insect, wind or human activity, than vegetation. This means that consideration of ecosystems without their abiotic components, which control the reception and transformation of energy and moisture, is suboptimal.

This is also the view of Matson and Power (1996) who consider trees to be the ultimate integrators of environmental influences and thus the representatives of the environment. Ecological land classification is considered by Sims et al. (1996) to be a combination of art and science that deals with definition, recognition and representation of ecosystems across gradients of space and time. In their view, vegetation maps must be underpinned by testable and well defined hypotheses. On the other hand, the boundaries defining map polygons may at times be wide and fuzzy rather than sharp.

On a somewhat more applied side, Smith and Carpenter (1996) weigh up the two alternative approaches to ecological classification and mapping, namely the bottom-up approach from lower to higher ecological units, and the top-down approach from higher to lower units. The bottom-up approach is seen as more repetitive and
inductive, the top-down approach as more direct and deductive. Though Smith and Carpenter (1996) do not deal with the implication of the two approaches, the bottom-up approach is more suitable for dealing with vegetation continua, whereas the top-down approach is better suited for dealing with discrete categories. The need for flexibility in mapping is also advocated by Bedward et al. (1992), who are concerned with the utility of maps. They consider this to be determined by the balance between the scale of the map and the choice of attributes, both of which should be chosen so as to maximise the information content of the map.

The concepts employed in mapping at the bioregion level are thus quite diverse, but there appears to be an agreement that mapping is best carried out in conjunction with classification and that the two are synergistic and interactive. A vegetation map needs to be underlain by an understanding of the relationships between vegetation and the underlying environmental factors, and a framework needs to be established within which the two components of the ecosystem can be related to one another. It is common for such a framework to be hierarchical, though a rigid factorial hierarchy is probably less appropriate than a nested one. What components of vegetation and what factors of the environment can be related to each other is dependent on the scale of the map being constructed.

2.2.2 Methods Employed In Mapping at the Bioregion Scale

At the methodological level, there is considerable discussion on the relationship between appropriate methodology and scale of mapping. The relationship between the
two and mapping terminology is addressed by Bajzak and Roberts (1996) who examined the range from ecoregion (1:1,000,000 to 1:3,000,000) through ecodistricts (1:50,000 to 1:250,000) down to ecosite (1:10,000 to 1:50,000). Along this range, the size of the area that can be mapped decreases and homogeneity of the map polygons increases. Similar concepts, but different terminology, were used by Matson and Power (1996). Their hierarchy was climate, landform and soil in descending order.

Mac Nally and Quinn (1998) were concerned that sampling employed by ecologists is often decided upon by convention rather than upon consideration of the ecological processes. The consideration of scale also leads to consideration of appropriate methodology. At the finer level of resolution, toposquence can be used to integrate vegetation and soils with the landscape (Roberts et al. 1996). The use of edaphic information was considered by Roberts et al. (1996) as essential to definition of the ecological position of the forest stands. Whatever the methodology, it is useful to build in a validation process. Matson and Power (1996) considered the strength of the site / species relationship as a measure of the success of the methodology to isolate factors that control the distribution of ecosystems. The closest matches to the perceived needs in south western Australia, in terms of both concepts and methodology, are with the studies of Pajar et al. (1987) in British Columbia and Mueller-Dombois (1965) in Manitoba.

The match with Pajar et al. (1987) arises out of the common objective of bringing together earlier maps and classifications for a large region as basis for forest management. In terms of terrain, vegetation, climate and soils there is not a great deal
of similarity. Pojar et al. (1987) utilise the methodology developed by Krajina (1960), which in turn is derived from the Braun-Blanquet (1965) methodology, though it also incorporates other European and North American schools of ecological thought. The principal concept is that the proper subject of vegetation studies is the biogeocoenose or ecosystem, defined as the sum of vegetation, animals and abiotic factors of the environment (climate, soil moisture and soil nutrients). Other concepts in the classification scheme are that regional, long-term climate is the fundamental determinant of the nature of terrestrial ecosystems, and that beside the climatic climax there are other climaxes such as edaphic, topoedaphic, zootic and fire climaxes. A particular emphasis is put on the principle of equivalence, namely that sites with same or equivalent properties have the same vegetation potential.

The factors of the physical environment are not always physically measured but are rated according to scales considered to reflect the biological effect of these factors. For instance, the soil moisture regime, defined as the average amount of soil water annually available for evapotranspiration by vascular plants, is rated on a scale from very xeric (0) to hydric (8), which is developed by synthesis of soil properties and indicator plants. Similarly, the soil nutrient regime is defined as the amount of essential nutrients available to vascular plants in the long term, which is a measure that is difficult to determine quantitatively because it is influenced by many other factors of the environment. For routine work a scale of five classes (A-B), derived by subjective synthesis of soil properties and indicator plants, is used. In the case of British Columbia, an attempt was made to relate measurable properties of the soil, such as pH, C/N, total N and SEB (sum of exchangeable Ca, K and Mg) to floristic
composition and productivity of forest stands. The soil moisture and soil nutrient scales are combined into an edatopic grid, a concept first developed by Pogrebnyak (1930). In the scheme of Pojar et al. (1987), the edatopic grid is a 9x5 matrix. Pogrebnyak’s concept of edatopic grid has been used locally by Havel (1968).

In Pojar et al. (1987), the climate rating scheme is not simply based on measurement of climatic data, which often are not available or are difficult to define and measure, but on the zonal ecosystem concept and on observation of the vegetation. A zonal ecosystem is one in which the integrated influence of climate on the vegetation and the soil is most strongly expressed, that is one with intermediate light, heat, soil moisture and soil nutrients. This is interpreted as mid- to upper slope position, gentle to moderate slope and moderately deep to deep loamy soil without an impeding horizon.

It is in the description and classification of vegetation of Pojar et al. (1987) that the classification scheme is closest to that of Braun-Blanquet (1965), namely in the hierarchy of categories (class, order, alliance, association, sub-association), formal nomenclature (endings such as -etea, -etalia, -ion, -etum and -etosum), the use of diagnostic plant species (character, differential, companion and accidental) and analysis by means of diagnostic tables.

It is not proposed to go into details of this as the applicability of Braun-Blanquet (1965) to Australian conditions has already been tested by Bridgewater (1981), who concluded that the acceptance of some of its features, such as the nomenclature, is
unlikely, but that the system has merits that have not been given adequate recognition.

The positive aspects of the Braun-Blanquet system identified by Bridgewater were:

a) the products of the process are efficient mapping units,

b) it has a low technology requirement,

c) it is a polythetic process in which all species are used to produce the classification,

d) the species remain untransformed at the end of the process, and

e) the final classification has a high predictive value if the autecology of the component species is known.

The chief problem in applying the approach of Pojar et al. (1987) locally is that the hundreds of person-years already invested in forest synecology in British Columbia cannot be matched. The homogeneity of vegetation types described in British Columbia goes against some significant studies in Western Australia, such as those of Loneragan (1978) and Churchill (1961,1968), which suggest that the vegetation of southwestern Australia forms a continuum. In addition, British Columbia has a much greater topographic range, and yet is floristically much poorer than southwestern Australia.

In addition to the methodology of Pojar et al. (1987), which is mainly used at a fine scale, a coarser scale mapping is also used in British Columbia (Banner et al. 1996). It combines the biogeoclimatic ecosystem classification and ecoregion classification. It utilizes ecoregions and biogeoclimatic zones to stratify the region into broad units that are physiographically and climatically homogeneous. Within this broad framework,
permanent landscape units are then delineated on the basis of terrain features. Within these are nested ecosystem units, derived from the site series of the biogeoclimatic ecosystem classification. The concept of zonal site, that is the site with intermediate moisture and nutrient conditions and thus best reflecting the regional climate, which is central to the biogeoclimatic classification, is retained. The ecosystem units are the lowest level mapping individuals, which reflect the moisture and nutrient regimes and the climax vegetation potential of the site. Provision is made for recognition of more detailed variation in topography and soils, by means of site modifiers. There is also provision for variation in stand development with time in structural stage and seral association modifiers.

It is significant that whereas ecoregion units are mapped at the relatively small scales of 1:250,000 to 1:2,000,000, the detailed site- or ecosystem mapping is normally carried out at the much larger scales of 1:5,000 to 1:10,000. It is the latter maps that are primarily used in forest management. Intermediate ecosystem (habitat) maps at scales of 1:10,000 to 1:50,000 have also been produced for research and planning purposes.

The differences between the situation in south western Australia and British Columbia in environmental framework, such as steepness of topography and high rainfall, are absent in Mueller-Dombois's (1965) classification of forests in south eastern Manitoba. That state shares with south western Australia the subdued topography, lower rainfall and gradual edaphic catenas in which water regimes play a key part. The key feature of Mueller-Dombois's studies is the development of the concept of an
ecological series, which he defines as a group of two or more habitats along a transect, which differ from one another in different intensities of a major environmental control factor. Another important concept developed by Mueller-Dombois and Ellenberg (1974) is that soil water regimes are, in the long term, imprinted in the soil profiles in such ways as the degree of leaching, the deposition of additional nutrients, the incorporation of humus and the development of gley horizons and fragipans, so that soil moisture regimes and nutrient regimes tend to be mutually correlated. This combination is then reflected in the vegetation patterns. Also relevant is Mueller-Dombois' finding that under such conditions the understorey species reflect the water regimes qualitatively by their presence or absence, whereas the overstorey trees tend to respond more quantitatively, in terms of growth rates. Understorey species can thus be used as indicators of the site conditions. This parallels local observations by Havel (1968, 1975a).

In summary, there are several important methodological principles that need to be considered in the compilation of vegetation maps. The first of these is that methodology must match the scale of the map, as that determines what detail can be mapped. A validation process needs to be built into map compilation. Secondly, it is desirable to nest smaller units into larger ones, such as vegetation into climate and landform, but the nesting need not be strongly hierarchical. If the factors of physical environment cannot be fully measured, they may be inferred and rated on the basis of known relationship to vegetation parameters. A concept of zonal ecosystem is useful in such a case. In regions of subdued topography the relationship between vegetation,
soil and landform can be expressed or illustrated as an ecological series or toposequence.

2.2.3 The Nature of Vegetation in South Western Australia – Continuum or a Set of Discrete Categories

Perhaps the most important issue that has to be decided upon is what is the nature of the vegetation of south western Australia – is it composed of discrete categories, or is it a continuum? The answer to this, if it can be found, will influence the approach to the integration of the earlier vegetation classifications in the region and to developing the model for mapping the vegetation. The continuum-discrete categories debate becomes periodically topical. Recently Walter and Paterson (1994) questioned the validity of ecological community classification on the grounds that palaeontological evidence points to individualistic concept of communities. Their view was challenged by Andersen (1995) who considered the essence of ecology to be the definition of communities in terms of current species distributions and interactions, and the integration of the roles of both biotic and abiotic factors influencing species distribution. He considered it as generally accepted that different species within a community often respond differently to climatic variables, so that present association does not guarantee past association. The issue is not whether or not competition exists, but its relative importance as one of several potential factors, and the conditions under which it is important. In the case of plants, Andersen (1995) considers competition in the context of stress (factors limiting productivity) and disturbance (factors removing biomass). He describes as simplistic, the view that species are optimally adapted to
their environment, as species are often most abundant outside their optimum environment due to interaction with other species.

It is an issue that had to be addressed by those who attempted to classify or map the vegetation in the past. Turning to Western Australia, the early studies (Diels 1906; Gardner 1923a,b) tended to be based on the assumption that vegetation is divisible into discrete categories. Even so, Diels introduced the concept of swamp complex for vegetation not divisible at the scale that he was working at.

The first detailed studies, those of Williams (1932, 1945) defined associations and consociations, which again imply divisibility. The areas mapped by Williams were by local standards strongly dissected and the mapping was done in fine detail, which would favour the detection of discrete categories, yet Williams concluded that the units were too heterogeneous to be described as associations in the narrow sense.

In his survey of the northern part of the Jarrah bioregion and its northern neighbours, Speck (1958) described three formations, 24 subformations and 62 associations using Beadle and Costin’s (1952) terminology. He rejected Diel’s (1906) swamp complex concept, but one of his illustrations, that of a xerosere originating from a granitic outcrop, depicted a continuum from lichens to forest. Vegetation continuity was also implied in the arrangement of his associations into a climatic series along a gradient of decreasing rainfall. For broadscale description of the region he employed the land system concept of Christian and Stewart (1953), which implies recurrent patterns of landforms and vegetation.
Lange (1960) considered the 500 mm isohyet to be a significant marker for the distribution of tree species on the Darling Plateau in the Narrogin district, which is midway along the eastern boundary of the Jarrah bioregion. The tree species dominant east of it had mainly inland distribution patterns, whereas those dominant west of it had mainly coastal distribution patterns. However, he also identified a group of tree species that straddled the 500 mm isohyet and overlapped the distribution ranges of the first two groups.

Churchill (1961) considered the vegetation of south western Australia to be a continuum primarily determined by rainfall, in which each species occupied a distinct segment. However, Havel (1975a) found that the individual species could be grouped, on the basis of the distribution maps provided by Churchill, into small groups of species with similar distribution patterns, but the groups did form a continuum based on climate.

Furthermore, Havel (1968) found principal component analysis (factor analysis) of Goodall (1954) and Pogrebnyak’s (1955) edaphic net, both of which are best suited for dealing with a continuum, to be the most useful methods for the study of coastal plain vegetation. Havel (1975a) used methods applicable to both continuum and discrete categories to study the vegetation of the northern jarrah forest, and found the principal component analysis, which implies continuum, more useful than the monothetic divisive association analysis (Williams and Lambert 1961; Lance and Williams 1968) which implies discrete categories. The polythetic agglomerative
analysis (Lance and Williams 1967) gave outcomes that were more comparable to those of principal component analysis than the outcomes of the divisive monothetic analysis. Havel found it necessary to use species with proven responsiveness to mathematically derived components to divide the multi-dimensional vegetation continuum subjectively into segments that could be mapped.

Loneragan (1978) specifically set out to establish whether the vegetation of the Darling Plateau could be objectively subdivided by statistical methods. His study area overlapped partially with that of Havel, and straddled one of the strongest environmental and floristic gradients in the Jarrah bioregion, between the jarrah forest and wandoo woodland. By using principal component analysis and correlation analysis he was able to relate the tree data to rainfall and silt and clay fraction of the soil. He was also able to group the tree data into identifiable clusters using Goodall’s Probabilistic Similarity Index (PSI). Loneragan’s analysis of the understorey (shrub and herb stratum) was much less conclusive, probably because it was based on the 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 to 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 independently of each other. Given that his analysis was more objective than that of Havel (1975a), it indicates that the vegetation of the Jarrah bioregion is closer to a continuum than to a set of discrete categories. By using less common species with greater discriminatory power, Havel was able to divide that continuum into meaningful segments. Neither author was able to define discrete ecological groupings.

Christensen (1980), McCutcheon (1980) and Strelein (1988), who utilised the same methodology as Havel (1975a) in different portions of the southern jarrah forest (Warren bioregion), also described continua rather than discrete categories. However, by emphasizing species with proven responsiveness to the environment Strelein was able to break up the continuum into meaningful segments, many of which were quite similar to those derived by Havel.

Most of the more recent ecological studies of south western forests (Inions et al. 1990a,b; Wardell-Johnson et al. 1989,1995) have used the polythetic agglomerative strategy with unweighted pair-group and arithmetic averages (UPGMA) in combination with ordination of the resulting site groups by principal component analysis. Although the categories are defined more objectively by this means than in the case of the earlier studies, they unmistakably form multi-dimensional continua with considerable overlap of characteristic species. This is particularly apparent in Inions et al. (1990b) study of the regenerated karri stands, where the floristically derived site groups are ordinated on three environmental criteria (phosphorus in the
soil A-horizon, precipitation and radiation in the driest quarter of the year) to give one major trend from infertile soils in a moist and cool coastal climate to fertile soils in a warm and dry inland climate.

Semeniuk (1997) also defined four wetland communities arranged in a continuum, from community 1 with *Melaleuca preissiana* overstorey and understorey of *Acacia hastulata, Astartea aff. fascicularis, Beaufortia sparsa, Calothamnus lateralis* and *Hakea ceratophylla*, to community 4 in which the overstorey incorporates besides *Melaleuca preissiana* also *Nuysia floribunda, Eucalyptus marginata* subsp. *marginata* and *Banksia ilicifolia* with understorey of *Adenanthes obovatus*, *Hakea sulcata, Homalospermum firmum* and *Hypocalymma strictum*. In the Muir − Unicup wetland systems they associated *Eucalyptus occidentalis* with clay-flooded swamps and reeds and *Melaleuca preissiana* with sand-floored swamps, with *Melaleuca cuticularis* occurring on both.

In light of these findings, a lumpy multi-dimensional continuum, divisible by use of responsive species into workable segments, appears to be a reasonable model to adopt for the description of the combined Jarrah and Warren bioregions. At this scale of description and mapping, the key environmental factors, climate and landforms, can be used to provide a framework within which the segments of the vegetation continuum can be mapped.
2.3 Description of Key Environmental Factors

In light of the conclusions reached in the preceding sections, namely that under local conditions the most informative map is likely to be the one that describes floristic details of the vegetation within a framework based on interaction between climate and landform, it is important to examine these two environmental factors in more detail.

2.3.1 Climate

There have been many attempts at defining those key features of the climate of south western Australia which determine the vegetation patterns. There is some reference to climate in every mapping and classification scheme, as well as several stand-alone discussions of the climate-vegetation interaction (Chapter 1).

A strong north-south and east-west pattern in the distribution of individual species, was described by Churchill (1961). These ranged from those confined to the humid south, such as *Eucalyptus diversicolor, Allocasuarina decussata, Chorilaena quercifolia* and *Agonis juniperina*, to those only entering the forested region along its northern and eastern margin, such as *Eucalyptus astringens* and *E. accedens*. He also illustrated wide differences in the climatic range of species, such as the narrow range of the species described above compared with the very broad range of others, such as *Nuytsia floribunda, Banksia attenuata, Macrozamia riedlei* and *Melaleuca preissiana*, which occur throughout the forested region and beyond whenever suitable edaphic conditions are present.
The effect of climate on vegetation was studied by Havel (1975b) by field surveys of a set of sub-catchments spanning the full climatic range of the northern jarrah forest, from 600 to 1300 mm of annual rainfall. Climate was found to be a strong determinant of broad changes in structure and composition of vegetation, particularly on the valley slopes. In addition to the main east-west gradient in vegetation, which parallels a strong rainfall gradient, Havel also observed a north east-south west gradient which was more difficult to explain in terms of the climatic criteria then available. He also observed that the line of high monadnocks that rises above the plateau, and has a north westerly orientation, appears to be exercising an influence on tree distribution patterns, in that the trees with a south western centre of distribution do not occur east of it.

The analysis of the climatic patterns for the region as a whole in relation to vegetation was carried out by Beard (1981a). He described the dominant role of high-pressure anticyclones in generating dry summer conditions and the dominant role of low pressure cyclones in generating a relatively high and reliable rainfall in winter. He also pointed out that there are two rainfall gradients in the region, related to the south and west coasts, respectively. Of these, the former is sharper and stronger as it is associated with the principal rain-bearing winds, the westerlies. It is accentuated by the uplift caused by the Darling Scarp, so that high rainfall is experienced about 10 km east of the Scarp as far north as Jarrahdale, just south east of Perth. This rainfall is strongly concentrated in the winter season. By contrast the gradient associated with the south coast is due to onshore southerly winds, and in magnitude is much less. It is,
however, also much less seasonal. In the south of the forest region the two gradients overlap and give rise to a much longer rainy season, and consequently less intense and shorter drought. This is reflected in the number of months without rain, in that Perth and Albany, occurring at the north west and the south east of the forested region respectively, have comparable annual rainfall of 800-900 mm, but whereas Albany has only one month with lowest monthly rainfall of 0 mm, Perth has six such months.

Beard (1981a) also referred to the differences between the coastal localities (no frosts at Perth and Albany) and inland localities, where winter night frosts are relatively common. The difference in temperature regimes of coastal and inland localities was also observed by Churchward et al. (1988), who noted that in the southern half of the region there was a downward gradient in temperatures from the coast inland in the winter, and an upward gradient in summer. This adds up to a much greater temperature range inland than on the coast. A similar temperature gradient was also observed for the karri region by Inions et al. (1990a).

Beard's main preoccupation was with climatic indices. He considered that under local conditions both Koeppen's (1936) and Thornthwaite's (1931, 1948) classifications do not reflect the vegetational patterns well, and preferred the Bagnouls and Gaussen's (1957) ombrothermic diagram based on the formula $r = 2t$, (where $r$ is the mean monthly rainfall in mm and $t$ is the mean monthly temperature in °C). Any month not meeting this criterion is considered to be dry. In his adaptation of the system to the south west region he recognizes four climatic types based on the number of dry months:
a) moderate mediterranean of 3-4 dry months, covering the southern half of the forest region,

b) dry mediterranean of 5-6 dry months, covering the northern half of the forest region,

c) extra dry mediterranean of 7-8 dry months, which just touches the forest region in the dry northeast, and

d) semi-desert mediterranean of 9-11 dry months, which occurs completely outside the forest region.

A further refinement was sought by Beard (1981a) by dividing the zones defined by Bagnouls and Gauussen's (1957) formula into eastern and western sectors. The entire forest region considered in this study falls into the western sector. He also examined the effective rainfall formula of Vollprecht and Walker (1957), in which effective rain per month is defined as \( r = 0.54 \times e^{0.7} \). This formula defines the karri region as having over eight months of effective rainfall, as compared with less than 6 months for the northeastern wandoo woodlands. The chief limitation of the formula appears to be that a considerable proportion of the southern coast between Albany and Ravensthorpe, down to an average annual rainfall of 500 mm, much of which does not support forest, comes up as climatically superior to tall open forest north of Manjimup. There appears to be an overcompensation for the cooler climate and longer
wet season along the south coast. Much the same appears to be also true of the Bagnouls and Gaussen's (1957) formula.

Beard (1981a) gave considerable consideration to past climates, chiefly drawing on the studies of Churchill (1961, 1968). These studies indicated series of climates alternatively drier and wetter than the present climate. The current climatic patterns are considered to have persisted over the past 5000 years. The occurrence of outliers of the tree species outside their current range is attributed to these climatic changes.

The most detailed analysis of climate associated with vegetation study is that of Inions et al. (1990a), who analysed seventeen climatic measures (variants of temperature, precipitation, radiation, evaporation and rain days, generally for the year as a whole and for the wettest and driest quarters) from the karri region by polythetic agglomerative clustering techniques and by principal component analysis. He derived three major and eight minor homoclimes. The three main homoclimes represented a high rainfall western portion, a warm medium to low rainfall inland portion and a cool, high rainfall south-coastal portion of the species distribution respectively. Subdivision of these to the eight minor homoclimes improved the definition. Unfortunately, comparable studies are not available for the bulk of the forested region.

The most relevant analysis of the climate of the south western forest appears to be that of Gentilli (1989). Its coverage is virtually identical to the RFA area, in that it does not just cover the main jarrah forest but includes the karri forest and western wandoo
woodlands as well. It analyses the climatic components in great depth and puts forward a diagram relating annual rainfall and summer evaporation to the occurrence of the main forest types, which matches field observations better than any of the schemes discussed above. It also relates the climate of the south west to worldwide climatic classifications.

The inadequate distribution of weather stations within the forest region was supplemented by calculations. It was found that rainfall could be best interpolated by regression on the basis of latitude, distance from the sea and altitude. Gentilli (1989) saw the 635 median isohyet as the eastern margin of the jarrah forest and the 900-1200 mm belt as its optimum. However, the rainfall exceeds the optimum in a relatively narrow zone 10-12 km east of the Darling Scarp, which causes a three hundred metre uplift of the westerly airmasses. It also exceeds 1200 mm in the proximity to the southern coast.

The characteristics of the climate of the south western region are that it is a warm temperate (coldest month below 18°C) and summer dry (driest summer months receiving less than 1/3 as much rain as the wettest winter month). This puts it into Köeppen’s (1936) category Cs, usually described as mediterranean. Köeppen subdivided this into categories a and b according to whether the average temperature of the hottest month is above or below 22°C. Locally, that divides the south western region along the line from Bunbury to Katanning.
Koeppen's classification was considered by Gentilli (1989) to be inadequate, in that the Cs category goes northwards beyond the occurrence of the jarrah forest. He attributes that to the failure to give adequate consideration to the duration of the wet season, which within the south west forest region varies from 5 months in the north east to 9 months in the south. For that reason, Creutzburg's (1950, cited by Gentilli 1972) and Bagnoulls and Gausen's (1957) classifications, which take this into consideration, give a better match.

However, even these classifications are suboptimal for the south western region, with its considerable latitudinal spread and strong winds and high temperatures. For that region Thornthwaite's (1931) classification which incorporates the concept of precipitation effectiveness \[ PE = 1.65 \left( \frac{r}{t+12.2} \right)^{1.11} \] which utilises monthly rainfall (r) and monthly temperature (t), seems more appropriate. In Thornthwaite's classification, forest is considered to need annual Precipitation Effectiveness between 64 and 128. Gentilli (1972) refined Thornthwaite's classification by the introduction of climatic subdivisions, whereby the jarrah forest (B – humid) is distinguished from jarrah woodland (C – subhumid).

A further refinement was brought in by introducing the concept of summer stress, to take into account the particularly strong summer drought lasting 4-7 months, which is characteristic of south-western Australia. Gentilli (1989) found that the duration of the drought was influenced by latitude, in that northern localities tended to have a more severe drought. There was also an influence of topography, that is, whether a locality is exposed to rain-bearing winds or cut off from them by higher ground. He also found
that the lack of rain in one month can be mollified by rain in preceding or following months. A further significant factor was solar radiation, and its interception by cloudiness, the latter factor being stronger in the south.

Gentilli also described a gradient in temperature, the average daily maxima for February ranging from 33°C in the north at Upper Swan to 27.6°C at Manjimup in the south. Neither Gentilli (1989) nor Churchill (1968) considered temperature to be a very significant direct factor in forest distribution.

According to Gentilli (1989), not only the magnitude of the rain, but also its timing is important. The heaviest rain events tend to contribute relatively more to run-off than to soil storage and vegetation than less intensive ones. Similarly there is a difference between late winter rains, which fall on saturated soil, and autumn rains, which fall on unsaturated soil.

Gentilli (1989) considered that climatic classification for forests should take account of both the favourable factor (rainfall) and the severely limiting factor (summer stress). He analysed water balance between rainfall and evaporation at the beginning and end of the rainy seasons and used it to divide the forest region into a number of categories, ranging from perarid at the northeastern margin of the forest at York to hyperhumid in the south at Pemberton and Denmark.

His most effective definition of climate suitable for forest growth was the plotting of median annual rainfall against total summer evaporation (December to February) and
fitting the various localities in the south west within that framework. The main karri forest occurrence was delimited by summer evaporation of less than 500 mm and annual median rainfall of more than 1000 mm, though relicts of karri occur at lower rainfall down to 700 mm. The dominance of jarrah was best expressed between the above criteria and summer evaporation of less than 750 mm and annual rainfall of more than 800 mm. In a more stressful climatic environment of summer evaporation exceeding 750 mm and median rainfall dropping below 800 mm, the forest reduces to woodland. Below median rainfall of 600 mm, jarrah occurs only as small outliers. The climatic factors, considered by Gentilli to be of key importance, are incorporated into Havel and Mattiske's (1998) map of vegetation systems (Appendix 3.9).

Gentilli (1989) also related climate to fire behaviour, which is a very powerful ecological factor in the region, in that, apart from offshore islands, no part of the south western region is exempt from periodic fire occurrence. Gentilli examined the occurrence of thunder days, which are the chief natural cause of ignition. He related the occurrence of thunder days to the formation of a line of instability, associated with a barometric trough offshore, and considered the danger to be greatest when the land inland from the trough was hot and fuels dry. The rise of the fast, moisture-laden westerly airstreams over the Darling Scarp contributes to the instability, and the sudden changes in wind direction associated with the passage of the barometric trough accentuate the danger. Yet another factor contributing to the severity of fires in the region are the anticyclones which dominate the summer weather pattern. Associated with them are the strong easterly winds, which in summer are both hot and dry as they enter the forest region from the dry inland. The worst conditions arise when a series
of days with hot and dry northeasterly winds is followed by a trough, so that risk of
ignition is high and the high temperatures and dry fuels are conducive to extreme fires
(Gentilli 1989).

With the accent on the dry and hot summers as determinants of the vegetation
dynamics, there has been insufficient attention to the obverse side of the coin, namely
that in winter the relatively high and reliable rainfall is not balanced by evaporative
and transpirative demand. This therefore means that in winter the vegetation also has
to cope with water surplus in the root zone, unless the topographic position and the
soil texture and structure are conducive to rapid drainage. The potential for
waterlogging exists throughout the project area, but in the northern half it is reduced
by the strong east-west topographic gradient generated by the Darling Scarp. The belt
close to the Darling Scarp is generally well-drained as streams are deeply incised. It is
only further inland, in the headwaters of streams, where valleys are shallowly incised,
with broad flat floors and mild gradients, that waterlogging becomes more prevalent.
However, it is in the southern half that the scope for waterlogging is maximised. Here
the Darling Scarp is less prominent and the Ravensthorpe Ramp consists of belts of
weakly sloping shelves separated by belts of hills composed of igneous rock. The
shelves are generally poorly drained. The maximum scope for waterlogging is along
the south coast, where high dune systems deflect the streams toward a few estuaries,
so that much of the coastal plain behind the dunes is poorly drained.
2.3.2 Geology

The dominant geological feature of the forested region of south western Australia is the Darling Scarp, a major tectonic feature, which extends from the north of the region to its southern limit near the Southern Ocean (Biggs et al. 1980). In Figure 2.1 its surface expression is the Darling Fault, which is a massive normal fault which separates the crystalline rocks of the Yilgarn Block to the east from the sedimentary rocks of the Perth Basin to the west. In the subsequent text, the rock categories shown in Figure 2.1 are referred to by numbers in brackets.

The Yilgarn Block forms a stable shield composed of linear belts of Archean metamorphic rocks (sedimentary and volcanic) with large granitic intrusions (5). The Archean rocks, which have a northwesterly lithological and structural trend, determine the major grain of the country. There are some minor areas of metamorphosed sediments assigned to Proterozoic along its western margin and some Phanerozoic sediments in depressions within the shield. The shield extends eastwards beyond the inland boundary of the forested region. The Archean rocks include granitic rocks (granite, quartz monzonite, granodiorite and adamellite) in the form of large batholiths; gneisses, migmatises, metasediments, acid and basic volcanics, quartzite, schist in the form of metamorphic belts and dolerite dykes in the form of sheetlike intrusions (Biggs et al. 1980). The main occurrence of metamorphic rocks, derived from both acid (9) and basic (10) volcanics, is near Boddington.
Figure 2.1 - Geologic features of the area covered by the Regional Forest Agreement
The Permian sediments in the depressions within the Archean shield (8) consist of conglomerate, sandstone, siltstone, shale and seams of sub-bituminous coal. They are entirely overlain by Tertiary sediments. Extensive fluviolacustrine deposits assigned to Eocene (11) overlie the Archean shield near Boyup Brook and Manjimup and a more restricted area of sediments (3, 8) occurs near the Darling Scarp, such as sandstone at Donnybrook and conglomerate at Kirup.

The Perth basin is a deep trough filled with Phanerozoic sediments up to 15 km deep. The Permian and Cretaceous rocks within it comprise mainly sandstones, but interbedded with them are siltstones, shales, clay and chalk, mainly of marine origin (3). They only outcrop in the northwest of the region, on the dissected portions of the Dandaragan Plateau, and in the south west, on the dissected portions of the Blackwood Plateau. These two plateaus are capped by sand and laterite and are separated from the Swan Coastal Plain by scarp-like features of marine origin, referred to as Gingin and Whicher Scarp respectively. The Blackwood Plateau merges at its southern margin into the Scott Coastal Plain, which is low-lying and swampy. On the coastal plains the Cretaceous deposits are covered by Cainozoic deposits of conglomerate, sandstone, clay and sand (4). The sands have varying proportion of calcium, often in form of shell segments, ranging from very high near the coastline to very low away from the coastline. The proportion of calcium is interpreted as a reflection of the degree of leaching. Those that have a very high proportion of calcium and are consolidated are referred to as calcarenite or Tamala limestone. There are also
lake, swamp and estuary deposits within the plains, composed of clay, sand, peat, gypsum and diatomaceous earths.

Within the Blackwood Plateau there are outcrops of Bunbury Basalt in the dissection by the Blackwood River and its tributaries. The basalt also outcrops on the coast of the Indian Ocean at Bunbury, and on the coast of the Southern Ocean at Black Point. It is considered to be a basalt flow that infilled pre-existing valleys, and is limited in extent (Biggs et al. 1980).

In the west region the Blackwood Plateau abuts on to the Leeuwin-Naturalist Ridge, a block of Proterozoic basic, ultrabasic, gneissic and granitic rocks (1, 2) in the form of a relatively narrow, undulating plateau, described in some publications as the Margaret River Plateau. At its western edge, near the shore of the Indian Ocean, it is overlain by a strip of Tamala limestone, which in turn is partially overlaid by unconsolidated dunes (4).

South of Manjimup the Yilgarn Plateau abuts on to the Albany-Fraser Orogen, which is a belt of metamorphic rocks such as migmatite and gneiss, intruded by granitic batholiths (2). Further to the south is a complex of Proterozoic granites and gneisses (6) and metasedimentary rocks (7), which slopes southwards toward the Southern Ocean and is also referred to as the Ravensthorpe Ramp. The low-lying portions of the Ramp are infilled with Eocene deposits and form swampy plains. The plains drop from 160 m a.s.l. in the north almost to sea level near the south coast. The batholiths mostly rise more than 100 m above the intervening plains, but some, like Mt
Lindesay, are much taller. In the south east of the forested region the Ravensthorpe Ramp is partially covered by a superficial deposit referred to as the Pallinup Siltstone, which slopes from 180 m a.s.l. inland to 40 m near the coast. There are outcrops of the granitic and gneissic rocks (6) within the South Coast Plain, but the bulk of the coast consists of Tamala limestone and of unconsolidated sands in the form of parabolic dunes (4). Behind the dunes are low-lying unconsolidated coastal plain deposits (4) of the type already described above for the Swan Coastal Plain, but the proportion of peaty deposits is higher here than on the Swan Coastal Plain. There are also sedimentary deposits on the higher part of the landscape, mostly in the form of grey sands with pebbles and grits, whose origin is under discussion (Churchward et al. 1988).

The land surface of most of the region has been subject to a complex process of weathering, denudation and redeposition. Of particular importance is the formation of deeply weathered mantle over both crystalline and sedimentary country rocks, which tends to have an upper horizon of sesquioxides in form of nodules and crusts, and is underlain by mottled and pallid zones of kaolinised country rock, and ultimately, sometimes as deep as 50 meters, by unweathered rock. This profile is described as laterite (Stephens 1946), and is particularly common on upland surfaces. Within valleys and on scarps it has been removed, to varying degree, by the process of erosion. This process, which is still on-going, is the key determinant of landforms and soil patterns.
2.3.3 Geomorphology

Geomorphic mapping 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). The early work was on a continental scale, and thus serves a framework for this study, rather than an aid to mapping. The whole of this project falls within Jutson's (1934) Southwest (Swanland) physiographic division, which extends beyond the project area both to the north and the east. It falls into just two of Clarke's (1926) natural regions, Perth and Darling.

More detailed geomorphologic mapping, on a scale relevant to this project, began in the agricultural areas (Mulcahy and Kingston 1961). It was then introduced into the forested areas by Mulcahy et al. (1972), first into the Helena catchment in the northeast of the project area. It was at this stage that the linkages between geomorphology and plant ecology begun to be developed through mapping of vegetation over a range of geomorphic units by Havel (1975b). A linkage between geomorphology and land use was established for the Wungong catchment through the
cooperation of a geomorphologist and a forester (Churchward and Batini 1975). On occasions, the forest ecologists drew attention to landforms which, on basis of vegetation studies, warranted a new landform category, such as the Cooke landform (Havel 1975b). The geomorphologic mapping was then extended southward by McArthur et al. (1977) to the Murray catchment, again as a basis for a joint land use planning project. A separate study of geomorphology was carried out by Finkl (1976) in the Blackwood catchment in the centre of the current project area. Bettenay et al. (1980) surveyed the geomorphology, hydrology and plant ecology of a series of subcatchments of the Collie River.

All the above studies were combined by Churchward and McArthur (1980) to cover the entire forested region north of the Blackwood River (System 6 Region), and the set of three maps developed by them was utilised by Heddle et al. (1980) to map vegetation of the region for the purpose of delineating national parks and nature reserves. Churchward and McArthur (1980) considered the slope of the land and the nature of the soils as determinants, on one hand, of the landform-soils units that they were mapping, and on the other hand, of the way that the land could be used. They used five of the geomorphological provinces, namely:

- the Darling Plateau of Precambrian crystalline rocks
- the Swan Coastal plain of aeolian and fluviatile sediments
- the Dandaragan Plateau of Mesozoic sediments
- the Blackwood Plateau of Mesozoic sediments
- and the Collie basin of Permian and younger sediments

as the major subdivisions of System 6 region that they were mapping.
They recognised that with the exception of the Swan Coastal Plain, these provinces were covered by a mantle of weathered rock, often as deep as 50 m, the upper horizons of which are frequently ferruginous and bauxitic and are referred to as the lateritic profile. They observed that the mantle was subject to erosional modification which exposed the weathered and unweathered materials and that the product of the erosion were distributed downslope. This gave rise to predictable soil patterns, determined by the degree of removal of the weathered mantle. Generally, the upland interfluves are still mantled by the laterite. The valley slopes carry catenas of soils determined by their steepness and by the geological nature of the substrate.

In as much that Churchward and McArthur’s (1980) maps are the basis of vegetation mapping of the Jarrah bioregion, an example of their hierarchy of landforms is appropriate.

Churchward and McArthur (1980) subdivided the largest of these provinces, the Darling Plateau, into:

- Lateritic Uplands
- Minor Valleys
- Major Valleys including Slopes and Floors
- Major Valley Floors and
- Major Valley Slopes and Scarps.

These subdivisions were not actually mapped, nor given any generic name.
The lateritic uplands were subdivided into three mapping units. Churchward and McArthur (1980) considered their mapping units, based on aerial photographs and contour base maps of between 1:25 000 and 1:50 000, to be approximately equivalent to soil associations. The units were given names of the locality in which the particular landform was best expressed:

- **Dwellingup** – extensive uplands with coarse gravels in the west and northwest
- **Yalanbee** - extensive uplands with fine gravels in the east and northeast
- **Hester** – residual narrow crests in the south.

Similarly, the valleys were subdivided according to the degree of dissection. The detailed subdivision of the geomorphological provinces of Churchward and McArthur (1980) is given in Appendix 2.1.

In as much as some of the above landforms are subject to inundation and waterlogging, Semeniuk's (1987) classification of wetlands of the Darling System is relevant to this study. It cannot be utilised directly, as there is no geographic overlap between the Regional Forest Agreement area and the examples given as illustration of the classification. However, the concepts embodied in the classification, such as the cross-sectional shape of the wetland (basin, channel, flat) and the degree of inundation and waterlogging, are useful in relating vegetation to landform. The terms particularly relevant are sumpland (seasonally inundated basin), dampland (seasonally waterlogged basin), flood plain (seasonally inundated flat) and palusplain (seasonally waterlogged flat). For instance, the Nooning landform (No) fits largely into the floodplain and palusplain categories, whereas the Swamp landform (S) fits into the sumpland and dampland categories.
Semeniuk (1987) also distinguishes between fresh and saline wetlands, and between fluctuating and stable salinity. Generally the north eastern wetlands, such as Wannamal (Wn) tend to be saline, whereas the south western ones, such as Scott Coastal Plain (Swd), are fresh.

In the southern half of the project area, a broadscale linkage between soils and vegetation was first described by McArthur and Clifton (1975) for the Pemberton district as an aid to land use planning. Basically they first reviewed past soil studies in light of the nomenclature of Northcote et al. (1967), and then defined the dominant soil types within the region. They mapped several subdistricts arranged in a continuum from the uplands of the Darling Plateau in the north, through the dissection of the plateau toward the south west, 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 the component soil types. They also looked at the relationship between these soil types and the vegetation that they carried.

Some of the concepts developed by them were a starting point for subsequent more detailed studies. Their work was subsequently expanded by Churchward et al. (1988) to cover the bulk of the south coast and its hinterland from Northcliffe to Mt Manypeaks. The descriptions of vegetation, associated with the various landforms provided in this latter work, facilitated the establishment of linkages between the geomorphology, landscape and vegetation.
Churchward et al. (1988) covered the full range of geomorphic variation from the Darling Plateau to the coast of the Southern Ocean, from the stable lateritic uplands in the north through several belts of crystalline uplands and intervening sandy plains referred to as the Ravensthorpe Ramp, which progressively drops in altitude, to the Southern Coastal Plain and ultimately to the sand dunes and the outcrops of crystalline rock of the south coast.

The three major categories described by them were:

I. Units developed on granitic rocks and associated unconsolidated sediments,

II. Units developed on siltstones and sandstones, and

III. Units developed in coastal Aeolian and fluviatile sediments.

This subdivision does not distinguish between the Darling Plateau (sensu stricto) and the Ravensthorpe Ramp, though several north/south profiles illustrating the step-wise fall towards the south coast are given. This is presumably because there is no clearly defined boundary between the Plateau and the Ramp and because the same assemblage of crystalline and sedimentary parent material is found on both, though the proportions at the southern and northern extremes are markedly different. In the physiographic map of the study area, distinction was made between the undulating plateau on deeply weathered rocks to the north (Darling Plateau sensu stricto), the complex of hill belts and sandy swampy corridors to the south (Ravensthorpe Ramp)
and dissected plateau of deeply weathered rocks in the west, which is the region primarily described by Churchward (1992).

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 filled in some of the gaps in geomorphologic mapping. Initially the latter mapping did not include areas of State Forest. The areas mapped in the north were the Mandurah and Murray region (Wells 1989), 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 (1990) surveyed the Busselton - Margaret River - Augusta region. The last study of Churchward (1992) in the Manjimup region also formed part of this series, though retaining the CSIRO approach. The key central region of Wellington-Blackwood, which approximates the southern third of the area mapped by Churchward and McArthur (1980) as part of the System 6 project, has been recently remapped from the point of view of land resources (Tille 1996). Concurrently with the vegetation mapping, land resources mapping was in progress on portions of the Blackwood Plateau not covered by Tille and Lantzke (1990) in the west and Churchward (1992) in the east. Stewart-Street and Smolinski1 (personal communication) were mapping the largest as yet unmapped area south of the Blackwood, east of Manjimup and north of the south coast and hinterland. The maps have been made available, but full description of the mapping units is yet to be published.

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1 Agriculture WA, South Perth.
There are differences in the approaches taken by CSIRO and Department of Agriculture. These are reflected in the detail of mapping, and hence in the precision of vegetation mapping. However, both approaches have provided valuable linkages between geomorphology and vegetation which have facilitated the mapping of vegetation in the South-West Forest Region in Western Australia.

There has been a progressive development of concepts and terminology in the land resources surveys of the Agriculture Department, which has culminated in the Wellington-Blackwood survey (Tille 1996). In this publication, the hierarchy of soil-landscape mapping units has been formalised. The current structure of the hierarchy is:

**Regions** - These are broad subdivisions of the Australian continent. The project area is a subset of the Western Region.

**Provinces** - These are determined on broad patterns of soils and landscapes and provide a broad overview of the whole state at the scale of 1:5,000,000. The project area is a western subset of the Avon province.

**Zones** - These are defined on geomorphological and geological criteria and are suitable for getting regional perspectives at the scale of 1:1,000,000. The project area comprises the following zones of the Avon province:

Leeuwin,

Donnybrook Sunkland,

Warren-Denmark Southland,

Western Darling Range, and

Eastern Darling Range.
**Systems** - These are areas with recurring pattern of landforms, soils and vegetation suitable for regional mapping at scale of 1:250,000. They are considered to correspond to the land systems of Christian and Stewart (1953).

**Subsystems** - These are areas of characteristic landform features containing a defined suite of soils, and are suitable for producing maps of catchments at the scale of 1:50,000 or 1:100,000.

**Phases** - These highlight particular features, such as rock outcrops and poorly drained flats.

The hierarchical system described above has as yet not been applied to the whole of the project area. The full description of the various maps, in particular of the component landforms, is given in Appendix 2.1. The location of the landforms can be seen in the maps comprising Appendix 3.4. In these maps the names of the vegetation complexes are based on the underlying landforms.

### 2.3.4 Flora

It is not proposed to cover the ecology of the RFA region here, but merely to highlight some features of south western flora that are relevant to subsequent discussions.

The first of these is the great floristic richness. The most recent estimates (RFA 1998a) is 3244 native flora taxa. As pointed out by Hopper (1979), this number is likely to continue to increase as taxonomic research progresses. Estimates of the flora
richness of the southern portion of the RFA region, the Warren bioregion, are 1628 native taxa by Hopper et al. (1992) and 1853 native taxa by Lyons et al. (2000). The estimate for the northern portion, the Jarrah bioregion, is 784 native taxa (Bell and Heddle 1989).

The second important feature of the flora is the high degree of endemism. Hopper (1979) assessed it at 68%, but anticipated that the proportion would be increased to 75-80% through revision of south western genera. The largest families are considered to be Papilionaceae, Orchidaceae, Myrtaceae, Proteaceae and Cyperaceae (Hopper et al. 1992; Bell and Heddle 1989; Lyons et al. 2000). The tree species primarily belong to the Myrtaceae family, in particular the genera *Eucalyptus*, *Corymbia*, *Melaleuca*, and *Agonis*, and to a lesser degree to the Proteaceae (*Banksia*, *Xylomelum*, *Persoonia*), Mimosaceae (*Acacia*) and Casuarinaceae (*Allocasuarina*, *Casuarina*) families. Many of the genera are highly polyspecific (*Eucalyptus*, *Acacia*, *Melaleuca*, *Banksia*, *Allocasuarina*), with individual species often occupying different positions in the ecological spectrum.

The more unusual components of the flora are arborescent root parasites (*Nuytsia floribunda*, *Exocarpus* spp., *Santalum* spp.) and arborescent monocotyledons (*Xanthorrhoea* spp., *Kingia australis*, *Dasypogon hookeri*).
2.4 Evaluation of the Continuity of Earlier Vegetation Classifications

2.4.1 Approach - Outwards from System 6 – Through Floristic Similarity

An essential early step in the development of a mapping system based on a number of geographically disjunct or partially overlapping classifications is to establish whether there is sufficient continuity between them. If the classifications had employed uniform data collection methodology, the logical approach would be to reanalyse the data quantitatively and arrive at a new, overall scheme of classification. Unfortunately, as recorded in Chapter 1, the data collection has taken place over a period of 40+ years, using divergent plot sizes and recording criteria (presence/absence, percentage cover, frequency). Considerable changes have taken place over this period, such as redefinition and renaming of taxa, description of subspecies and varieties, naming of new taxa and declaration of certain taxa as invalid. Most of these can be allowed for if the collection on which the classification is based still exists (which is not always the case), but some cannot. The change in the name of one of the key tree species of the region, marri, from *Eucalyptus calophylla* to *Corymbia calophylla*, is easy to allow for. The subdivision of the most prominent species of the region, *Eucalyptus marginata* into three subspecies, whose geographical ranges partially overlap, is impossible to trace backwards in time. There is no logical means whereby it could be decided which of the three subspecies was observed by someone 20 years ago in a district where the subspecies overlap. It is likely that the classifications and ordinations of Havel (1975a) and Loneragan (1978) of the northern
jarrah forests/woodlands may have been much more informative and clear cut if the
definition of the subspecies had been completed by then. However, in the subsequent
discussions dealing with the southern classifications, only *Eucalyptus marginata*
subsp. *marginata* is involved.

Because there are so many qualifications about virtually all of the past classifications,
comparisons between them had to be done subjectively, allowing for the taxonomic
changes that have taken place. The concepts of Pojar *et al.* (1987) were utilised in
bringing together the various classifications, but in terms of methodology a less
stringent version of the Braun-Blanquet system, namely that of Bridgewater (1981),
was used. There is, however, a difference between this study and that of Bridgewater,
in that he begins with raw data in the form of relevés, whereas this study begins with
classifications in which plots have been already aggregated into site groups
(community groups or types) and the representative capability of the species has
already been tested. For instance, Havel (1975a) and Strelein (1988) subjected their
indicator species to the scrutiny of how tightly and reliably they defined a particular
vegetation type, and rated the species accordingly. Similarly, in Wardell-Johnson *et
al.* (1995) a species was only listed in the matrix of species x subtypes if its constancy
for that subtype exceeded 50%.

The integration of the various classifications in the project area proceeded outwards
from the region already covered by earlier mapping, namely the northern jarrah
region (Hedle *et al.*, 1980), for which an ordination/classification system, related to
landform by field mapping and quantitative analysis, already existed (Havel 1975a,b).
As a result, there already was a known array of species groups associated with particular sets of environmental conditions that could serve as links to other classifications. The details of these associations are given in Appendix 1.1 and 1.2.

In linking the various classifications, the first step was to use the individual species and the site species groups to form a species/site matrix. This matrix was then manipulated to get the most effective constellations of species. These constellations are considered as indicator species groups or just species groups. The comparison of classifications was based on species groups, that is species which tend to occur together under similar environmental conditions across classifications, as for instance the SAMORG (species occurring on moist sands with high incorporation of organic matter) group of Adenanthis obovatus and Dasypogon bromeliifolius which recurs in numerous classifications (Havel 1968,1975a; Strelein 1988; McCutcheon 1980; Wardell-Johnson et al. 1995).

The species groups, especially those indicative of average conditions (neither excessively dry or wet, of intermediate fertility and soil texture), do not remain constant from one classification to another. For instance, the GRAMED (lateritic gravels in medium rainfall) species group contains Banksia grandis, Hovea chorizemifolia, Persoonia longifolia and Adenanthis barbiger in Havel’s (1975a) classification. In Strelein’s (1988) study, Adenanthis barbiger becomes too rare, and Persoonia longifolia becomes too common, but the core species of Banksia grandis and Hovea chorizemifolia remain. They are joined by new species (Gompholobium ovatum, Agonis hypericifolia) with similar distribution patterns.
The alternative approach is to link the species by referral to site groups (vegetation types or community groups) directly. It is less obvious, but more economical in terms of effort, as the intermediate step of establishing species groups can be avoided. It is an approach which is particularly suitable for terminal classifications, that is those that occur at the margins of the RFA area, such as Gibson’s\(^2\) (personal communication) classification of coastal vegetation, or Worsley Alumina’s (1999) classification and maps of eastern jarrah and wandoo woodlands. For instance, in the latter classification, *Adenantheros barbiger, Banksia grandis, Hovea chorizemifolia* and *Persoonia longifolia* all occur on site groups S, ST, SP, P and H, but are absent from site groups M, Y, L, D and AY. By contrast *Trymalium florbundum, Hypocalymma angustifolium, Baeckea camphorosmae* and *Eucalyptus wandoo* occur primarily on site groups Y and L, with extension on to AY and D, but are absent from S, ST, SP, P and H.

The approach is also suitable for classifications that are used to link together other classifications, such as that of Havel (1975a). The species group shown above to be linked to site groups S, ST, SP, O and H is also linked to site groups S, P, T and R in Havel’s classification, but it is easier to refer to it as the GRAMED group, that is, species associated with lateritic gravel in medium rainfall.

Linking of site groups to species groups is only possible within individual classifications. Even if the nomenclature is superficially similar, eg. number (1, 2, 3,

\(^2\) Department of Conservation and Land Management, WA, Woodvale
or letters (A, B, C, D), the site groups sharing the same letter or number are not transferable from classification to classification.

It needs to be stressed that there is not a simple one to one relationship between species groups (indicator groups) and site groups (vegetation types or plant communities). Just as a site is the sum total of environmental conditions (water regime, nutrient regime), so a vegetation type or plant community group on a particular site is composed of several species groups responding to the environmental factors. For instance, Havel’s (1975a) site-vegetation type S has three main species groups associated with it: GRAMED (already discussed), FREGRA (fresh gravels) of *Macrozamia riedlei*, *Phyllanthus calycinus*, *Leucopogon capitellatus* and *Leucopogon propinquus* and DRYGRA (dry gravels) *Acacia preissiana*, *Styphelia tenuiflora* and *Patersonia rudis*. Although they are constantly associated with it, they are not confined to it. The GRAMED group also extends onto type P and to a lesser extent onto T and R. The FREGRA group extends onto types Z, T, R, U and Q. The DRYGRA group extends onto J, H, P and Z. Expressed in words, the S type occurs on gravelly uplands in medium rainfall. The GRAMED group is centred on S, the FREGRA group extends onto it from moister, more fertile gravels, whereas DRYGRA extends onto it from drier gravels and gravelly sands.

Other species groups may also extend onto S at lower rates and less consistently such as GRAHIR (gravels in high rainfall) group of *Bossiaea aquifolium*, *Lasiopetalum floribundum* and *Acacia urophylla*, which is moister than FREGRA, and is mainly associated with types T and U. The HIGRA (high rainfall gravels) group of *Pteridium*
esculentum and Leucopogon verticillatus which marginally extends onto S, but is primarily associated with types T and U, is similar to GRAHIR. The other end of the moisture / fertility continuum are Daviesia decurrens of DRYSAG (dry sandy gravels) and Allocasuarina fraseriana of SANGRA (sandy gravels), which are both centred on infertile sandy gravels or gravelly sands of types P, H, and J, but may also extend onto S.

Similar continua of species groups and site groups (plant communities or types) occur in most classifications or ordinations. The focus of this section, however, is the continuity between the various classifications. The process of establishing the continuity between the classifications is illustrated by the extension westwards on to the Blackwood Plateau.

2.4.2 Blackwood Plateau – Southern Swan Coastal Plain

McCutcheon 1980

The extension westward on to the Blackwood Plateau (Donnybrook Sunkland) begins with the work of McCutcheon (1980), who carried out vegetation studies in this region, aimed at using shrub and perennial herb species as indicators of site conditions. McCutcheon identified an array of six site types, simply labelled A, C, D, E, F and G, which were defined by 52 species. The sequence of site types reflects the common topographic and edaphic continua/catenas on the Blackwood Plateau, from leached deep sands in upland position (A), through moist sands (C) to wet sandy sites
(D) and on through moist silty sites (E) and heavier-textured soils (F) to sandy or loamy gravels (G). Each species was related to the site types by rating of the strength of relationship, ranging from strong positive relationship (species strongly represented on the site type) to strong negative relationship (species absent). McCutcheon presented his findings in the form of a table intended for field use, in which the species were arranged alphabetically (Table 2.1a).

McCutcheon’s criteria and sequence of site types were retained, but the sequence of species was rearranged so as to highlight the similarity of distribution within the ecological framework (Table 2.1b). This generated groups of indicator species, which could be related to Havel’s (1975a) indicator groups. The first group of indicator species, consisting of Banksia attenuata and Petrophile linearis, is entirely confined to McCutcheon’s site type A, and has strong affinities to Havel’s (1975a) SANLEA (sands, leached) indicator group. Both McCutcheon and Havel associate these species with deep leached siliceous sands, which are acutely deficient in nutrients and have poor nutrient and water retention capacities. Not all of Havel’s indicator species occur in McCutcheon’s classification, as the area covered by Havel extended into a markedly drier climate than that of the Blackwood Plateau.

The second group of indicator species occurs on McCutcheon’s site types A and C, with optimum development on C. Type C is associated with moister sandy sites with organically enriched topsoil. The corresponding indicator group of Havel is SAMORG (sands, moist, organically enriched), which has been retained. One member of this group, Dasypogon bromeliifolius fits in well with McCutcheon’s much
Table 2.1a: Indicator Species of McCutcheon (1980) arranged in Alphabetical Order, against Site Types

Explanation of Abbreviations:

Site-types:
- A - deep leached sands
- C - moist sands
- D - wet sandy sites
- E - moist silty sites
- F - heavier textured soils
- G - sandy or loamy gravels

An early seventh type, B, was incorporated into type C

Ratings:
- O - Obligatory species
- o - Permissible species
- b - Probable species
- x - Prohibited species

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This table is derived from McCutcheon, G.S. (1980) Field Classification of Vegetation Types as an Aid to Soil Survey. *Forest Department WA, Research Paper 57*. Used with the kind permission of the Executive Director of the Department of Conservation and Land Management, Western Australia.
### Table 2.1b: Indicator Species and Site Types of McCutcheon (1980)
Re-arranged to Maximise Ecological Relationships

#### Explanation of Abbreviations:

**Site-types:**
- A - deep leached sands
- C - moist sands
- D - wet sandy sites
- E - moist silty sites
- F - heavier textured soils
- G - sandy or loamy gravels

An early seventh type, B, was incorporated into type C

**Ratings:**
- O - Obligatory species
- o - Permissible species
- b - Probable species
- x - Prohibited species

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larger group of indicators. The other, *Adenanthes obovatus*, has a slightly wider range, extending on to McCutcheons’s site type D, of sandy swamps, and to a lesser degree to type E, of loamy swamps. McCutcheon’s larger group, consisting of *Adenanthes meisnerii*, *Banksia ilicifolia*, *Daviesia incrassata*, *Hibbertia pachyrrhiza*, *Hibbertia vaginata*, *Melaleuca thymoides*, *Stirlingia latifolia* and *Leucopogon glabellus* is referred to as MOSAN (moist sands).

Another group of indicators, consisting of *Mesomelaena tetragona*, *Leptospermum crassipes* and *Kingia australis*, has a broader and less consistent range of occurrence centred on C and D. It corresponds to Havel’s indicator group BROMO (broad tendency toward moist sites), and the name has been retained.

The group centred on McCutcheon’s site types C and D, but absent from A, consists of *Banksia littoralis*, *Hakea ceratophylla*, *Melaleuca preissiana*, *Pultenaea reticulata* and *Hypocalymma angustifolium*. The first three belong to Havel’s (1975a) indicator group VERWET (very wet sites). *Pultenaea reticulata* has not been used by Havel, and *Hypocalymma angustifolium* belongs to his indicator group FERMO (fertile moist sites). The descriptor VERWET is used to cover all five species.

The next group of indicators covers a broad range of moist site types from C to E. Only two of its members, *Meeboldina scariosa* (formerly *Leptocarpus scariosus*) and *Pericalymma ellipticum*, have been used by Havel in his group BROWET, and to retain distinction the McCutcheon’s group also consisting of *Acacia mooreana*, *Agonis*
parviceps, Dasypogon hookerii and Lyginia barbata, will be named WESBROWET. Most of these species have a south western bias in their overall distribution.

A much narrower group of indicators of wet loamy alluvium, absent from the sandy sites A, C and D, consists of Agonis linearifolia, Eucalyptus megacarpa, Eucalyptus patens, Hibbertia commutata (formerly Hibbertia montana), Pericalymma elliptica (formerly Leptospermum ellipticum) and Tetratheca viminala. The first two belong to Havel’s indicator group WETAL (wet alluvium) and this name is retained, even though Eucalyptus patens belongs to Havel’s group FERMO.

A broader group of indicators, which extends over site types D, E, F and G, and consists of Leucopogon australis, Pimelea spectabilis, Pultenaea drummondii, Hakea lissocarpa, Hibbertia quadricolor and Xanthorrhoea gracilis, has no counterpart in Havel’s classification and has been labelled LOSAN (loamy sands). It is the last of the groups extending on to wet and moist sites.

The next group consists of species occurring mainly on upland lateritic site types F and G, namely Acacia browniana, Adenanthis barbigera, Allocasuarina fraseriana, Daviesia decurrents (formerly D. pectinata), Daviesia preissii, Hakea lasiantha, Isopogon sphaerocephalus and Leucopogon verticillatus. Several of these are members of Havel’s indicator groups of lateritic gravels such as SANGRA (Allocasuarina fraseriana), GRAMED (Adenanthis barbigera), DRYSAE (Daviesia decurrents), BROFER (Hakea lissocarpa) and HIGRA (Leucopogon verticillatus). Others, such as Daviesia preissii, Hakea lasiantha and Isopogon sphaerocephalus, have not been used
by Havel. The group is labelled WESANGRA (western sandy gravels). It has lesser climatic discrimination power than Havel’s groups.

A narrower group of indicators of lateritic gravels, confined to McCutcheon’s type G, contains components of Havel’s indicator groups for lateritic gravels - GRAMED (*Hovea chorizemifolia*, *Persoonia longifolia*), FREGRA (*Leucopogon capitellatus*) and DRYGRA (*Styphelia tenuifolia*, *Acacia preissiana*). It also contains *Bossiaea ornata*, a species considered by Havel to have a broad range in the northern jarrah forest. The label GRAMED is retained.

There is thus a considerable similarity between Havel’s and McCutcheons’s classifications. However, there are also differences arising out of the smaller edaphic and climatic range of the Blackwood Plateau which is composed of sedimentary rocks. Because of these differences, some additional indicator species groups need to be added for the Blackwood Plateau, namely MOSAN, LOSAN and WESANGRA.

McCutcheon’s classification also forms a natural link, both in terms of geographic proximity and botanical affinities, to the survey by Mattiske Consulting Pty Ltd (1996) of parts of the Scott Coastal Plain to the south and to the survey by Gibson *et al.* (1994) of the southern Swan Coastal Plain to the west and north. However, the study of Mattiske Consulting Pty Ltd (1996) also has considerable links to Strelein’s (1988) study of the southern jarrah, in particular, that portion of the study area located along the southern coast. For that reason it will be considered after Strelein. It also
forms a link to Gibson’s (personal communication) survey of the south western coast.

**Gibson et al. 1994**

There is limited overlap between McCutcheon (1980) and Gibson et al. (1994), as the former covers the uplands and valleys of the Blackwood Plateau, whereas the latter covers the Swan Coastal Plain below the plateau and is separated from it by the Whicher Scarp. Despite the dissimilarity in geomorphology, there is some overlap in soils and climate and hence in vegetation.

Gibson’s type 2, described as southern wet shrublands, has links to McCutcheon’s site-type D in *Hakea ceratophylla* and *Hypocalymma angustifolium* of McCutcheon’s VERWET, *Pericalymma ellipticum* and *Lyginia barbata* of WESBROWET, *Kingia australis* and *Mesoselaena tetragona* of BROMO. These species are indicative of moist to wet sites.

Gibson’s type 4, described as Melaleuca preissiana damplands, has links to McCutcheon’s site-type D in *Melaleuca preissiana* and *Hypocalymma angustifolium* of McCutcheon’s VERWET, *Lyginia barbata* and *Pericalymma ellipticum* of WESBROWET and *Adenanthis obovatus* and *Dasypogon bromeliifolius* of SAMORG. These species are indicative of wet sites with sandy soils.
Gibson’s type 21b, described as woodland of *Banksia attenuata* and *Eucalyptus marginata* subsp. *marginata*, has links to McCutcheon’s site-type A in *Banksia attenuata* and *Petrophile linearis* of McCutcheon’s SANLEA, *Stirlingia latifolia*, *Melaleuca thymoides* and *Hibbertia vaginata* of MOSAN and *Dasypogon bromeliifolius* of SAMORG, most of which are associated with sandy soils that are drier than those of Gibson’s type 2.

Gibson’s type 22, described as woodland of *Banksia attenuata* and *Banksia ilicifolia*, has links with McCutcheon’s type C in *Banksia attenuata* and *Petrophile linearis* of McCutcheon’s SANLEA, *Banksia ilicifolia* of MOSAN, *Dasypogon bromeliifolius* of SAMORG, *Melaleuca preissii* of VERWET and *Lyginia barbata* of WESBROWET, most of which are associated with moist sandy soils.

Gibson’s types 21b, 22 and 4 form a gradient from dry to wet sandy sites which has a close parallel in McCutcheon’s gradient from site-type A through C to D and in continuum segments H, I, J and K described from the northern Swan Coastal Plain by Havel (1968). Gibson’s type 2 represents a heavier-textured variant of type 4.

Gibson’s type 3b represents a heavier-textured equivalent of Gibson’s type 22. It consist of woodland of *Corymbia calophylla* and *Eucalyptus marginata* subsp. *marginata*, with understorey of *Kingia australis*, *Mesomelaena tetragona*, *Xanthorrhoea preissii*, *Bossiaea eriocarpa* and *Hibbertia hypericoides*. It has a weak link to McCutcheon’s site-type C in *Kingia australis* and *Mesomelaena tetragona* of BROMO.
As anticipated, the linkage between McCutcheon (1980) and Gibson et al. (1994) is limited, but the distribution of species along the moisture gradient is parallel for both classifications.

2.4.3 Southern Jarrah - Scott Coastal Plain - Coastal Dunes

The linkage process was also carried through in a south westerly direction from the northern jarrah forest into the southern jarrah forest classified by Strelein (1988), further on to the Scott Coastal Plain mapped by Mattiske Consulting Pty Ltd (1996) and finally to the coast of the Southern Ocean classified by Gibson (personal communication).

Strelein 1988

Strelein’s (1988) classification of the southern jarrah forest is a valuable link with other classifications because of the similarity of his concepts and methods used in the northern jarrah forest, and the thoroughness with which he tested his indicator species. The area surveyed by him partially overlaps the areas covered by Inions et al. (1990a,b) and Wardell-Johnson et al. (1995).

Strelein (1988) used similar nomenclature to Havel (1975a), namely letters of alphabet to define site types described in terms of indicator species and underlying environmental factors. Some of his types are very close to Havel’s types.
The linkage process is described in Appendix 2.2. On the whole, the linkage of Strelein’s (1988) classification to that of Havel (1975a) is strong. What differences there are can be primarily attributed to the following factors:

1. Cooler and moister climate of the southern jarrah, and

2. Concentration by Strelein on sites dominated by jarrah, which excluded most of the fertile dissected slopes in the high rainfall zone.

The shift into a cooler and moister climate has resulted in the shift in the indicator value of some species and groups. Generally the narrow indicators of the high rainfall became more general in their distribution, those of medium rainfall zone became more restricted and many of those of the northern low rainfall/high evaporation zone disappeared altogether. By contrast, many new species with bias toward cool moist climate entered into the picture.

To account for these differences, a number of new indicator groups had to be defined, such as SOGRAF, SOGRA, SOSALOM, SOSAM, SOWET, SOFER and SOBROSAN. These are described in Appendix 2.2.

Mattiske Consulting Pty Ltd 1996

Mattiske Consulting Pty Ltd (1996) data set consists of a larger number of species, whose identification is more up to date than that of McCutcheon (1980) and Strelein
(1988) because of a shorter time lapse, but the indicator values of individual species have not been defined. There is, however, a record of the distribution of all the species on the 27 vegetation types identified by the study, which made it possible to analyse the patterns of occurrence. Only a portion of the data set (148 species), chiefly perennial species encountered in other data sets, has been utilised, but those identified as being of special significance to the Scott Coastal Plain have been retained.

The description of the classification, and of the linkage process are covered in Appendix 2.3.

Summing up, there is a considerable linkage between Mattiske Consulting’s, Strelein’s, McCutcheon’s and Havel’s indicator species groupings, but overall the vegetation described by Mattiske Consulting is at the wet end of the regional continuum.

Gibson personal communication

Mattiske Consulting (1996) classification forms a natural link between the classifications so far discussed and that of Gibson (personal communication), confined to the southern and western coast. The linkage is directly to Gibson’s communities, without defining species groups.

The linkage between the two classifications is largely confined to the swampy sites, as Mattiske Consulting did not survey coastal dunes and Gibson did not cover inland
forests. In Table 2.2 this source is referred to as Gibson 97 to distinguish it from Gibson et al. (1994)

Gibson et al. 1994 and Mattiske Consulting Pty Ltd 1996

Although there is no geographic overlap between the areas covered by Mattiske Consulting Pty Ltd (1996) and Gibson et al. (1994), there is considerable ecological similarity between the Scott Coastal Plain surveyed by Mattiske Consulting and the southern end of the Swan Coastal Plain surveyed by Gibson et al. (1994), both of which border the Blackwood Plateau. The main difference is that whereas the Scott Coastal Plain merges almost imperceptibly into the mildly sloping southern edge of the Blackwood plateau, the Swan Coastal Plain is separated from the northern edge of the plateau by the moderately steep Whitcher Scarp. However, away from the scarp the Swan Coastal Plain also incorporates near-level poorly drained plains and swamps, which characterise the Scott Coastal Plain, though the latter has a significantly wetter and cooler climate. Consequently there is a greater degree of linkage between Mattiske Consulting Pty Ltd (1996) and Gibson et al. (1994), than between Gibson et al. (1994) and McCutcheon (1980), despite the geographic proximity of the latter two.

The integration of the south western classification is summarised in Table 2.2. Only multiple entry species, that is, species identified as significant (indicators, characteristic species) by two or more classifications are entered. Mattiske Consulting Pty Ltd’s (1996) classification is used as the starting point as it has the widest range of species and widest range of sites. In this table, species groups developed for
Table 2.2: Integration of South Western Classification Systems (Blackwood Plateau, Southern Swan Coastal Plain, Scott Coastal Plain)

Source of Information:

<table>
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<tr>
<th>Species</th>
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<th>McCUT</th>
<th>STREL</th>
<th>HAV75</th>
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Mattiske's classification are examined in terms of their occurrence in site groups generated by other classifications for the western sub-region. Havel's (1968, 1975a) classifications are used as links to the northern jarrah forest and the northern coastal plain.

2.4.4 Southern Jarrah - Karri - Walpole National Park - Tingle Mosaic - Coastal Dunes

The ease of southward extension into the area covered by Christensen (1980) (south eastern jarrah and wandoo), Strelein (1988) (southern jarrah and wandoo) and Inions et al. (1990a,b) (karri) varies markedly. Christensen (1980) was primarily interested in vegetation as a setting for fauna studies and did not develop his classification to the same degree of detail as that of Strelein (1988), with which it overlaps. Both followed the methodology of Havel (1975a) closely, and as the main tree species are also shared with Havel, the agglomeration can be expected to be relatively easy. By contrast Inions et al. (1990a,b) focused on a different species and utilised a radically different methodology, so that integration with other classifications or ordinations may prove difficult. His coverage complements that of Strelein, in that both covered a comparable climatic region, but different landforms within it. The strategy adopted here is therefore to use the links established between the classifications of Strelein and Havel as a bridge to Christensen and Inions et al.
Christensen 1980

Christensen's (1980) classification, though predating that of Strelein (1988) is best dealt with as a supplement to it. In terms of the area covered it is largely a northeastern subset of Strelein's, and because of its focus on fauna it lacks the detail of Strelein's analysis of individual species and definition of site types. Nevertheless, it can be used to add to Strelein's classification. In Christensen's ordination the extreme +C3 defines a treeless shrubland on shallow soils over granite, dominated by *Gastrolobium spinosum, Dryandra armata, Baeckea camphorosmae, Hakea undulata* and *Hakea incrassata*, which is more drought affected than any of the types described by Strelein and fits outside Strelein's types Z and M. It is equivalent to Havel's (1975b) type G. Similarly, in Christensen's ordination, the extreme +C2 and +C4 define a jarrah woodland with a shrub storey of *Petrophile serruriae, Hibbertia quadricolor, Banksia sphaerocarpa, Pimelea suaveolens, Pultenaea ericifolia* and *Leucopogon pulchellus*, which also fits outside Strelein's type Z, on the sandier, less fertile side. Its northern equivalent is Havel's (1975a) type H.

One of Christensen's major sampling localities consisted of a cluster of sites in which wandoo was a dominant, rather than an associate of jarrah. It occurred on heavy textured soils and had a shrub storey of *Hypocalymma angustifolia, Acacia pulchella, Leucopogon pulchellus* and *Dryandra nivea* (now *lindleyana*). It lies on the outside of Strelein's types M and Y, and is the southern equivalent of Havel's (1975a) type Y. In Christensen's ordination it fits in at +C1 and +C2.
The remaining vegetation types described by Christensen are covered by Strelein’s classification. The -C2 extreme of Christensen’s ordination coincides with his westernmost sampling locality, and carries a tall open jarrah forest with shrub storey of Bossiaea linophylla, Hovea elliptica and Clematis pubescens, which links it with Strelein’s types T, Q and U. Like them, it occurs on fertile slopes in medium to high rainfall. The –C4 extreme of Christensen’s ordination consists of woodland of Melaleuca preissiana, Banksia littoralis and Eucalyptus rudis, with an understorey of Astartea fascicularis and Melaleuca viminea. Its closest associates are thus Strelein’s type A and Havel’s (1975a) type A, and like them, it occurs on poorly drained, swampy valley floors.

**Inions et al. 1990a and 1990b**

As briefly mentioned above, the classification of Inions et al. (1990a,b) represents a radical departure, both in terms of the dominant species (karri), age of the stand (regrowth following clearfelling), methodology (agglomerative hierarchical cluster analysis and discriminant analysis) and terminology (community types numbered and also named after former prominent foresters).

Nevertheless, it is possible to link it to Strelein’s (1988) classification to some degree, because the two classifications refer to the same geographic region, their coverage of landforms is complementary and there is an overlap at the margins, generally on sites of below average fertility and above average drought risk for karri. It is important to recognise that in Inions et al. the presence of karri is assumed in all the community
types which only differ in the associates of karri. The full description of the linkage process, which includes description of the site groups and species is given in Appendix 2.4.

The difficulty of relating the classification of Inions et al. (1990b) to that of Strelein (1988) arises from the fact that apart from a few shared transitional types, the two classifications look in opposite directions. Species that are common in the jarrah forest have been identified by Inions et al. as strong indicators of inferior karri sites, being departures from the karri norm. Similarly, species that are common in the karri forest have been identified as strong indicators of superior sites within the jarrah forest by Strelein, being departures from the jarrah norm.

Bridgewater 1981

The relationship between Strelein's (1988) classification of the southern jarrah forest and Inions et al. (1990b) classification of the karri forest can be elucidated by examining the study of Bridgewater (1981) from the interface between karri and jarrah forest near Pemberton. Bridgewater was demonstrating the applicability of the Zurich-Montpellier methodology (Braun-Blanquet) to Australian conditions. He located his relevés along a 5 km gradient spanning the two forest types and arranged them into a relevé/species matrix according to their floristic similarity. He grouped the relevés into six groups, each defined by several sets of species. Two of the relevé groups contained jarrah and no karri, two contained karri and no jarrah, whereas the two intermediate groups contained predominantly karri but with some jarrah. The two
jarrah groups and the two intermediate groups also had a strong development of marri, understorey tree Alloca\,suarina decussata, tall shrub Bossiea aquifolium subsp. laidlawiana, fern Pteridium esculentum, and climber Clematis pubescens. Chorilaena quercifolia had a range similar to karri. The jarrah groups had a set of tree, shrub and herb species largely confined to them, namely Persoonia longifolia, Lindsaea linearis, Logania vaginalis, Acacia drummondii and Billardiera floribunda. Similarly, one of the karri groups had two species, Trymalium floribundum and Acacia urophylla, largely confined to it. Two other species used by Strelein (1988) and Inions et al. (1990b) in their classifications, Leucopogon verticillatus and Crowea angustifolia, occurred inconsistently across the whole range. On the basis of the indicator species, the range appears to extend from type T through K and N of Strelein to community types Beggs and Shea of Inions et al. Depending on which of Bridgewater's set of species was considered, the entire range could be seen as a continuum or as a number of distinct types. The range or continuum could be expanded in one direction to cover all of Strelein's jarrah types, and in the other direction to cover all karri types of Inions et al.

Wardell-Johnson et al. 1989

The departure from the northern jarrah framework reaches the maximum with those classifications centred on the south coast, namely Wardell-Johnson et al. (1989), Wardell-Johnson et al. (1995) and Gibson (personal communication). Wardell-Johnson et al. (1989) is essentially a subset of Wardell-Johnson et al. (1995), but will be considered because it gives considerable attention to indicator species. Both overlap
to some degree with Gibson (personal communication), which is essentially a coastal classification. The details of the linkage process, and description of the site groups and species groups, are given in Appendix 2.5.

The Wardell-Johnson et al. (1989) classification, whilst covering a relatively small area of land on the south coast, is important in that it provides linkage from the classifications of Inions et al. (1990b) and Strelein’s (1988) to the classifications of Wardell-Johnson et al. (1995) and Gibson (personal communication). The overlap with Strelein and Inions et al. is mainly in open forest and high open forest formations. The community types and characteristic species groups of Wardell-Johnson et al. (1989) are generally broader than those of Inions et al. (1990b) and Strelein’s (1988), chiefly because only twelve types are used to describe a wider ecological range.

**Gibson personal communication**

Gibson (personal communication) covers a very long but also very narrow strip along the entire coast of the RFA project from the northwest to the southeast, and types 9-12 of Wardell-Johnson et al. (1989) have a strong affinity with those of Gibson’s (personal communication).
However, the key to understanding the plant ecology of the Warren bioregion is the classification of Wardell-Johnson et al. (1995), because it is not limited to a particular forest type or geomorphic surface and covers an extensive and diverse area. It still has limitations. It is difficult to interpret floristically, as the thirteen indicator species groups, corresponding to twelve community groups, are influenced by the disparity, in both size and uniformity, of the community groups. At one extreme there are large but uniform community types such D1, D2 and E1, which all contain in excess of 60 plots and yet are floristically simple and edaphically homogeneous. At the other extreme there are small but diverse groups, such as C1, C2 and C3, each of which contains less than 15 plots and yet is floristically diverse and edaphically heterogeneous. The species group derived by the analysis vary from a few large groups, too heterogeneous to be of use as indicators, through some medium-size groups with well defined ecological affinities, to small groups associated narrowly with just a few plots. Overall, they are of limited use.

The problem of flawed species groupings was experienced by Havel (1975a) when using classificatory programs in the northern jarrah forest. In the case of monothetic divisive classification using the DIVINF program (Lance and Williams 1968) the heterogeneous groups were the product of a long chain of negative decisions, which lumped together uncommon species of diverse site preferences. In the case of polythetic agglomerative classification using the program CLASS (Lance and Williams 1967), the normal analysis produced sound grouping of plots, but the inverse analysis
produced both very large heterogeneous groups of species and small groups of just one or two species. A similar problem in the use of classification programs was experienced by Young and Watson (1970). In the case of Wardell-Johnson et al. (1995), this problem was aggravated by the imbalance between few plots from the low rainfall areas as compared with a very large number from the high rainfall areas, and by the contrast between floristically simple and uniform plots from forested uplands and floristically diverse plots from extreme edaphic sites such as rock outcrops and swamps.

At the finer level of definition (44 community types), which is closer to the level of definition of Strelein (1988) and Inions et al. (1990b), no species groups were derived. However, a comprehensive list of species for the 44 types has been made available for my study and was subjected by me to the Zurich-Montpellier type of analysis like that carried out for the jarrah-karri ecotone by Bridgewater (1981). The definition and sequence of community subtypes given by Wardell-Johnson et al. (1995), were retained but the species were rearranged by me using the species groups defined by Havel (1975a); Strelein (1988); Wardell-Johnson et al. (1989) and Inions et al. (1990b), as the condensation nuclei. To make the rearrangement feasible, the analysis was limited to those species which reached a constancy of 50% or higher within at least one community type. The resulting matrix of 44 types by 381 species (Appendix 2.6) depicts the usual pattern of lumpy continuum encountered in other studies of south western vegetation, but has an unusually high number of singletons (site group with only one member). Forty two indigenous species groups and one exotic species groups have been defined. As many can be readily related to the species
groups defined by Havel (1975a); Strelein (1988); Wardell-Johnson et al. (1989) and Inions et al. (1990b), they were given mnemonic labels reflecting their similarity, though not equivalence, to the groups based on the work of these authors. Most of the indicator species identified by these authors are represented in the matrix. Additional mnemonic names, reflecting the known or assumed links to environmental factors, were also generated to accommodate the broader ecological range of Wardell-Johnson et al. (1995) data set. As in the case of Havel’s (1975a) studies in the northern forest, the more extreme sites of Wardell-Johnson et al. (1995) classification, such as his community groups 13, 19 and 25-32, have a narrow and precise set of species, whereas the intermediate sites 2-9 and 37-42 are loosely defined by several sets of species with broad environmental tolerances. Correspondingly, species with a narrow environmental range, such as *Pimelea longiflora* subsp. *longiflora* and *Leucopogon glabellus* of the EXSAN (extreme sands) groups, are confined to just one or two community types. A species with a broad environmental range, such as *Agonis parviceps* of SOSALOM (southern sandy loams, moist), is prominent on 14 of the 44, and *Leucopogon capitellatus* of BROMOF (broadly moist fertile) on 18 out of 44 community types of Wardell-Johnson et al. (1995).

The Wardell-Johnson et al. (1995) classification of the Tingle Mosaic has been used as the framework for such integration in the eastern portion of the Warren bioregion, as it has the widest ecological range, the greatest number of individual species, and in addition has geographical overlap with most other classifications. It is also based on
the largest set of field plots, and has a sound statistical definition of community types, which in turn forms the basis of the species group definition.

The species groups were compared by me, species by species, with the other classifications (Havel 1975a; Christensen 1980; Strelein 1988; Wardell-Johnson et al. 1989; Inions et al. 1990a,b; Gibson personal communication;). Havel (1975a) was included as linkage with classifications in the north of the Jarrah bioregion, even though it does not have a geographic overlap with Wardell-Johnson et al. (1995). An example of the higher level linkage process is given below.

One of the more extreme community types within the Wardell-Johnson et al. (1995) classification is community type 1. It is composed of plots situated on extreme sandy sites, with a high degree of leaching and infertility. It is primarily defined by the species groups EXSAN and DRYSAN (dry sands), in fact, the EXSAN group occurs on this type alone. Of the EXSAN species with fidelity in excess of 50%, four also occur in other classifications:

*Pimelea longiflora* subsp *longiflora* is a characteristic species in the PIMLONG group of Wardell-Johnson et al. (1989), and also occurs in Gibson's (personal communication) community group 14; *Bossiaea rufa* also occurs as characteristic species of Gibson's (personal communication) community group 13. *Daviesia decurrens* is also a member of Havel's (1975a) indicator group DRYSAG. *Leucopogon glabellus* is also a member of McCutcheon's (1980) group MOSAN. Although *Banksia attenuata* does not reach the 50% fidelity
criterion in community type 1, it is often the structurally dominant tree species of this type and of Gibson’s (personal communication) community groups 14 and 15. It is a common associate of *Daviesia decurrens*. The remaining species of the EXSAN group, namely *Petrophile longifolia,* and *Hypocalymma strictum,* do not feature in the other classifications, but that does not necessarily mean that they are absent in the areas covered by them.

The species group DRYSAN is mainly, but not exclusively, confined to community types 1 and 2 of Wardell-Johnson *et al.* (1995). Of its component species, three also occur in other classifications:

*Lyginia barbata* is also a member of the PIMLONG group of Wardell-Johnson *et al.* (1989) and is a characteristic species of Gibson’s (personal communication) community groups 10, 14 and 30. *Melaleuca thymoides* is a member of the SOSAM group of Strelein (1988) and Wardell-Johnson *et al.* (1989) and is a characteristic species of Gibson’s (personal communication) community groups 10, 14, 15 and 30. *Allocasuarina fraseriana* is a characteristic tree species in Wardell-Johnson *et al.* (1989) and Havel’s (1975a) SANGRA group. *Hakea ruscifolia* is a member of the SOSAM group of Strelein (1988) and DRYSAG group of Havel (1975a). Although *Banksia ilicifolia* does not reach the 50% fidelity criterion in community type 2, it is often the structurally dominant tree species of this type and of Gibson’s (personal communication) community group 14. The DRYSAN group is indicative of less extreme sandy sites than EXSAN.
The next species group, BROGRA (broadly gravelly), has much greater environmental amplitude than either EXSAN or DRYSAN, extending across community types 1 to 10 of Wardell-Johnson et al. (1995), and absent from community types 11 to 17 (coastal dunes), 18 to 25 (swamps) and 26 to 30 (rock outcrops). It reappears in community type 31 and 39-41 (lateritic uplands), but is again absent from types 42 to 44 (karri forest), and is thus essentially composed of species of the jarrah forest, including jarrah itself:

The component species are common in other classifications. *Eucalyptus marginata* subsp. *marginata* occurs in Gibson's (personal communication) community groups 14, as do *Anarthria scabra* and *Andersonia caerula*. *Eucalyptus marginata* subsp. *marginata* also enters into the DRYKA species group of Wardell-Johnson et al. (1989) and Inions et al. (1990b), and is so prevalent in the Strelein (1988) classification of southern jarrah as to have only a negative indicator value (NEGIN), that is, it is only absent from the most extreme sites. The same is also true of *Persoonia longifolia*. In Havel's classification of the northern jarrah forest, *Eucalyptus marginata* fits into a category of its own (JARRAH), which also has a very wide ecological amplitude. *Persoonia longifolia* is a key species of ecological species group GRAMED in Inions et al. (1990b) and Gibson's (personal communication) community groups 14, as is *Agonis hypericifolia*. Another species of very wide amplitude is *Xanthorrhoea preissii*, which is included in species group BROMO of Wardell-Johnson et al. (1989) and Inions et al. (1990b) and
Gibson's (personal communication) community groups 20 and 30. In Wardell-Johnson et al. (1989), *Lindsaea linearis* is a member of species group JACFUR. The BROGRA species group is thus essentially a group of broad amplitude covering the jarrah forest on coarse grained and infertile soils, such as sands and sandy gravels.

Further details of the linkage process are given in Appendix 2.7. The outcome of the process is shown in Table 2.3.

The relationship between Wardell-Johnson et al. (1995) and Strelein (1988) classifications can be summarised as follows: there are quite strong matches between them involving species characteristic of the jarrah forest. In both classifications there is a continuum in moisture and fertility from infertile sands to moderately fertile loams, involving such species groups as SAMORG, SOWET, DRYGRA, SOGRA, SOGRAF, FREGRA, HIGRA, SOFER and SOFERMO. However, many of the species groups of Wardell-Johnson et al. (1995), which are characteristic of extreme sites such as coastal sand dunes, deep swamps and rock outcrops, have no counterpart in Strelein, who was primarily concerned with the southern jarrah forest.

The relationship between the classifications of Wardell-Johnson et al. (1995) and Inions et al. (1990b) is influenced by the fact that Inions et al. covered regenerated stands of karri over a great geographic range, but excluded other vegetation types, whereas Wardell-Johnson et al. (1995) covered all vegetation types over a more limited, and only partially overlapping geographic range. There is thus no match in
Table 2.3: Integration of South Eastern Classification Systems  
(Southern Darling Plateau, Ravensthorpe Ramp, Southern Coastal Plain)

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<td>GIB97</td>
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<td>INIONS</td>
<td>Inions et al. (1990a,b) Classification and evaluation of sites in karri regeneration</td>
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<td>Strelein G.J. (1988) Site classification in the southern jarrah forest of Western Australia</td>
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<td>HAV75</td>
<td>Havel J.J. (1975a,b) Site vegetation mapping in the northern jarrah forest (Darling Range)</td>
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<td></td>
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the Inions et al. classification for most of the species groups defined in Wardell-Johnson et al. (1995) species/type matrix, particularly those of extreme sites such as swamps and rock outcrops. There is, however, a good linkage for tall open forest of karri. On the whole there is thus only localised correspondence between Wardell-Johnson et al. (1995) and Inions et al. (1990b).

Localised correspondence was also found between Wardell-Johnson et al. (1995) and Gibson (personal communication), as Gibson’s study was focused on coastal dunes and nearby swamps, avoiding forests which are the main focus of Wardell-Johnson et al. (1995). However, within the coastal sand dunes and swamps of the southern coastal plain, there is a good correspondence between them.

The association (grouping) of species varies from study to study, as each study was carried out from a different perspective and in a different area, but the relationship of the species groups to environmental factors on the whole holds good, that is basically the same species are associated with particular sets of environmental conditions:

*Pimelia longiflora*, *Lyginia barbata*, *Melaleuca thymoides* and *Allocasuarina fraseriana* are associated with extremely infertile sandy sites,

*Eucalyptus marginata*, *Persoonia longifolia* and *Agonis hypericifolia* with infertile gravelly sites,

*Adenantheros obovatus* and *Dasypogon bromeliifolius* with moist humus podzols,

*Homalospermum firmum*, *Anarthria prolifer* and *Beaufortia sparsa* with swamps,
and Acacia urophylla, Clematis pubescens, Eucalyptus diversifolia and Pteridium esculentum with finer textured and more fertile soils.

Some of the species have consistent association with one another, such as Dasypogon bromeliifolius and Adenanthos obovatus of SAMORG and Agonis flexuosa and Anigozanthus flavidus of SOBROSAN. Other association between species, especially those based on joint occurrences in ecotones such as the Harris community type of Inions et al. (1990b) and community types No 4 and No 5 of Wardell-Johnson et al. (1989), are unstable and vary from classification to classification. For instance, the characteristic species described for community type No 5 of Wardell-Johnson et al. (1989) (Acacia browniana, Agonis parviceps, Bossiaea webbii, Burchardia umbellata, Leucopogon australis, Pimelea longiflora, Stylidium scandens and Xanthosia rotundifolia) are brought together because the type represents an ecotone between Agonis parviceps shrubland and forest with Acacia browniana understorey, developed over a wide range of soil types. They form different associations in other classifications.

It is apparent from the above discussions that the various local classifications within the southern subregion are mutually linked, though the linkage is not a case of one to one correspondence. They are also linked, chiefly through Strelein (1988), to the other subregions.
2.4.5 Northern Jarrah – Collie Basin – Wandoo Woodlands

In the northern subregion, the term jarrah cannot be equated solely with *Eucalyptus marginata* subsp. *marginata*, as other subspecies also occur. However, it is difficult to allot references in earlier studies to a particular subspecies.

The classification covering the bulk of the subregion (Havel 1975a,b) was used as the basis for the linkage, as it has the widest ecological as well as geographical coverage. Its linkage to Mattiske, E.M. and Associates (1991) classification of the Collie Coal Basin is strong for those of Havel’s species groups and site groups characteristic of sands and sandy gravels, but weak with those characteristic of loamier, more fertile soils of the major valleys in crystalline terrain. Mattiske Consulting Pty Ltd used a comparable classification to that of Havel, refined to a greater detail (A→A1, A2, A3, S→S1, S2, S3) for the prevalent types.

Worsley Alumina Pty Ltd’s (1999) study has strong linkage to Havel (1975a,b) in the types characteristic of uplands and valleys of crystalline terrain in medium to low rainfall. The linkage is weak to types developed on sedimentary deposits, which are largely absent in Worsley’s project area. The linkage is reinforced by similarity of classification, refined in greater detail for rocky sites (G→G1, G2, G3, G4).

The earlier maps and classifications of Worsley Alumina’s Pty Ltd (1981,1985) employ a radically different nomenclature which reflects structure as well as floristic composition, but this is relatively readily linked with that of Havel (1975a,b), namely:
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<table>
<thead>
<tr>
<th>Havel (1975a,b)</th>
<th>Worsley Alumina (1985)</th>
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<td>M, Y</td>
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<tr>
<td>S</td>
<td>19JBg, 19JSD</td>
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<td>W</td>
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<tr>
<td>P</td>
<td>19JLC</td>
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<td>R</td>
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<td>H</td>
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<td>G, M</td>
<td>21HHU</td>
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</table>

Loneragan (1978) did not attempt to relate his findings to Havel’s (1975a) site-vegetation types, though this is relatively easy to do so for the tree data. In the wandoo dominated clusters TG1 is largely equivalent to Havel’s types Y and L and TG3 to M. Similarly in the jarrah dominated clusters TG5 represents Havel’s types R and T and TG6 represents mainly P, H and S. Loneragan’s TG2 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. Only the highly polyspecific and geographically widespread T4 cluster is problematic. It is more difficult to relate Loneragan’s understorey species groups based on common species to Havel’s indicator groups based on species selected for their discriminatory capacity.

The linkage to Ecologic Environmental Consultant’s (1994) survey of the wandoo woodlands is affected by the fact that wandoo is central to the Ecologia’s studies, but peripheral to Havel’s classification and mapping. Nevertheless, there is considerable sharing of species and species groups. Ecologia’s communities 1 and 2 resemble Havel’s types Z, H and P, community 3 resembles M and 5 resembles Y and L. Ecologia’s community 4 has definite links with G and community 6 has a link to A and AY.
The linkage is even more tenuous between Griffin's (1992) classification of the northern most tip of the RFA region and that of Havel's (1975a,b) due to complete lack of geographic overlap, and the differences in the degree of detail. Griffin's relevé groups 35, 43, 44, 40 and 41 describe lateritic uplands comparable edaphically but not climatically to Havel's types SP and S. Climatically, a better match for lateritic uplands is between Havel's Z and Griffin's 7. On the shallow rocky sites Griffin's 38, and to a lesser degree 9 and 4, match Havel's G. On the sandy sites, there is a much clearer equivalence between Griffin's relevé groups 2 and Havel's types B and J. Similarly, on the swampy sites there is a strong linkage between Griffin's 15 and 27 and Havel's A and AY.

There are also coarse but strong linkages between Heddle and Marchant (1983) and Havel (1975a,b). Heddle and Marchant's structural category JMOF (jarrah-marri open forest) corresponds to Havel's types P, S and T, and their category WMW (wandoo-marri woodland) corresponds to Havel's type M. Heddle and Marchant's mix of heathy and shrubby categories (H, HB, HT, RSLW) corresponds to Havel's types G and R.

The summary of the linkages is given in Table 2.4. In this table species groups developed in Havel (1975a,b) classification are examined in terms of their occurrence in site groups generated by other classifications for the northern subregion. Basically the strength of linkages between the various classifications of the Jarrah bioregion is governed by ecological overlap. Havel's (1975a,b) classification and mapping is
Table 2.4: Integration of Northern and North Eastern Classification Systems (Northern Darling Plateau)

Source of Information:

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<thead>
<tr>
<th>Species</th>
<th>HAV75</th>
<th>MAT91</th>
<th>WA99</th>
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2.4.6 Summary of linkages over the Western Australian RFA region

Although the areas classified by Gibson (personal communications) on the wet and cool south coast and by Ecologia (1994) on the dry north eastern periphery are at the extremes of the RFA region and do not have much in common, they are nevertheless part of a continuum. The classifications that are environmentally broader and geographically more extensive, such as those of Havel (1975a); Strelein (1988) and Wardell-Johnson et al. (1995), between them cover the middle of this continuum. The linkages are not solely dependent on geographical proximity. The species groups characteristic of the more extreme site conditions, such as deep leached sands, shallow rocky sites and seasonal swamps, recur on these sites irrespective of distance, often spanning major environmental discontinuities. On the less extreme and more common sites, such as the well-drained lateritic uplands, there is a progressive change from south west to north east, which is barely detectable in the middle of the climatic continuum, but clear cut between the extremes. The clearest and most rapid rate of change along the climatic continuum is on moderate valley slopes with fertile soils of medium depth. Even the districts not covered by any publications, such as the
Margaret River Plateau and the Blackwood catchment east of the Darling Scarp, largely appear to fit within this continuum.

The task that remains is to convert the knowledge acquired by reviewing the existing classifications to vegetation, and the available climatic and geomorphic framework, into a workable mapping scheme. The first step toward that objective is to firm up the relationships between vegetation and the environment. The second step is to use these relationships to fit vegetation into the environmental framework of climate and landform. This is undertaken in Chapter 3.
Chapter 3: Methodology

3.1 Introduction

In the previous chapter, the methodology of mapping at a bioregional scale was reviewed and it was concluded that the most appropriate approach was the fitting of the finer scale vegetation patterns within the broadscale environmental framework (Chapter 2.2). On the basis of the review of past classification studies, it was also concluded that the lumpy continuum model was the most appropriate model for south western Australia. The essence of this is that vegetation varies continuously, but that it is possible to subdivide the vegetation by focusing on species that have narrow ranges and are responsive to environmental factors. As the next step, the key environmental factors, namely climate and landform, were described (Chapter 2.3). Finally, the earlier classifications were tested for continuity and similarities, and it was established that many key species (indicators, characteristic species) were shared between them. These species belong to groups which are associated with a particular combination of environmental factors (Chapter 2.4). It is now proposed to link the environmental factors, in particular climate and landform, into a framework (3.2) to examine the relationships between vegetation and the environment in greater depth (3.3) and to utilise these relationships to fit the fine scale vegetation patterns into the broadscale environmental framework (3.4). As a final step, an agglomeration process is carried out which condenses six maps of vegetation complexes into a single map of ecological vegetation systems, which covers the entire project area (3.5).
3.2 Development of a Computer-based Mapping Framework

3.2.1 Climate

For the purpose of mapping, Gentili’s (1989) climatic criteria were modified for plotting as a single parameter by using the summer evaporation to discount the annual median rainfall. The rate of discounting that was found to reflect vegetation pattern best was to reduce the median rainfall by 100 mm for every 50 mm increase in summer evaporation. Although the discounting was developed by trial, it was influenced by the formula of Bagnouls and Gaussen (1957) \( r = 2t \), namely that a month in which rainfall \( r \) is less than twice the temperature \( t \) is a dry month. In that formula, temperature serves as a proxy for evaporation and transpiration. The total range of the discounted median rainfall was subdivided into climatic subzones of 200 mm width. Gentili’s terminology was used to describe the full range from 1200+ mm rainfall/less than 400 mm evaporation (hyperhumid) to less than 600 mm rainfall/800+ mm evaporation (perarid). The terminology adopted may not fit in with terminology for all of Australia as there are climatic zones both wetter and drier than those dealt with here. However, it is a useful tool for dealing with climatic variation in the forested bioregions (Jarrah and Warren).

An alternative method of combining the annual rainfall with summer evaporation into a single parameter is to express them as a ratio. This parameter ranges from more than 3 for the hyperhumid south coast to less than 0.66 for the perarid northeast.
The relationship between annual median rainfall and summer (December to February) evaporation is considered here to be the broad-scale determinant of regional vegetation patterns. It is modified locally by topographic and edaphic factors, in particular by their effect on the storage of the winter rainfall toward the summer water stress. The range extends from steep rocky slopes with shallow soils, from which the incoming rainfall is shed almost immediately, through milder slopes with deep soils capable of storing the bulk of the winter rainfall, to level depressions which receive runoff from the surrounding uplands and are flooded or waterlogged for a significant portion of the winter and spring seasons. This aspect will be discussed in greater detail in section 3.3, dealing with the relationship between vegetation, geomorphology and climate. The climate zones are depicted in Figure 3.1.

3.2.2 Geomorphology

Systems

The vegetation systems mapped here, at the scale of 1:500,000, are close to Tille's (1996) land systems in the terms of concept, though not of scale, in that the polygons are smaller and the texture of the map is finer. This was done so that the whole project area could be displayed on one map sheet and the overall control of climate over the vegetation patterns illustrated. Although the vegetation complexes are mapped at a comparable scale of 1:250,000, their definition, in terms of geomorphology and climate is finer, and comparable to Tille's (1996) subsystems.
Figure 3.1 - Climatic zones of the area covered by the Regional Forest Agreement (developed from Gentili 1989)
Subsystems

The vegetation complexes are of comparable scale and degree of detail, in terms of landforms, to Tille’s subsystems particularly in the northern portion of the project area. In the southern two-thirds of the project area, where landform mapping has been more precise, they correspond to Tille’s phases.

Phases

The maps of vegetation complexes are dependent on the landform maps, though the detail mapped at 1:50,000 (King and Wells 1990; Tille and Lantzke 1990) for phases could not always be accommodated in the vegetation complex maps at 1:250,000.

3.2.3 Integration of Climate and Landforms

At the other end of the scale the larger units, such as Bevan (BE), which extend across several climatic zones, were subdivided into subsystems based on climate, such as:

- **BE1** southern lateritic uplands in perhumid-humid zones
- **BE2** southern lateritic uplands in humid-subhumid zones
- **BE3** southern lateritic uplands in subhumid-semiarid zones.

Similarly, in the northern Darling Range the equally extensive Dwellingup unit (D) was subdivided into:

- **D1** northern lateritic uplands in the humid-subhumid zones
D2 northern lateritic uplands in the subhumid-semiarid zones

D3 and D4 northern lateritic uplands in the semiarid to arid zone.

The purpose of subdividing geographically extensive landforms on the basis of climate was to define categories that were homogeneous in terms of their potential to support vegetation. In the case of the more highly structured classification systems, such as Tille’s (1996) Wellington-Blackwood, the climatic zoning was already partially built in by differentiating between the Western and Eastern Darling Range Zones and the Warren-Denmark Zone, within which the lateritised uplands were named Dwellingup and Hester; Dalmore and Sandalwood; and Bevan, Collis and Mattaband, respectively.

The importance of the climatic subdivision of the landforms can be seen in the case of such a widespread landform as Wheatley, which is described by Churchward (1992) as upstream valleys incised 20-40 m into the southern Darling Plateau. In the perhumid zone near Pemberton (WH1), the vegetation of the slopes is a karri-marri tall open forest with a second storey of Allocasuarina decussata, Agonis flexuosa, Banksia grandis and Persoonia longifolia, and a tall shrub storey of Trymalium floribundum, Tremandra stelligera, Hovea elliptica, Bossiaea aquifolium subsp. laidlawiana, Lasiopetalum floribundum, Clematis pubescens and Pteridium esculentum, corresponding to Beggs and Shea types of Inions et al. (1990b). In the humid-subhumid zone immediately east of Manjimup the slopes of the same landform (WH2) support an open forest of marri, yarri and jarrah; with a second storey of Banksia grandis, Persoonia longifolia, Agonis flexuosa and Hakea oleifolia and an understorey of Trymalium floribundum, Tremandra stelligera, Hovea elliptica,
*Bossiaea aquifolium* subsp. *laidlawiana*, *Lasiopetalum floribundum*, *Clematis pubescens*, *Macrozamia riedlei*, *Leucopogon capitellatus*, *Leucopogon verticillatus*, *Phyllanthus calycinus* and *Pteridium esculentum*, corresponding to Strelein’s site types Q, U and V. In the driest variant in the semiarid-arid zone (WH3), the slopes of the landform support a woodland of wandoo and marri, largely without a second storey and with an understorey of *Macrozamia riedlei*, *Hibbertia commutata*, *Hakea lissocarpha*, *Leucopogon propinquus*, *Leucopogon capitellatus* and *Trymalium ledifolium*, corresponding to +C1 and +C2 of Christensen’s (1980) ordination.

By subdividing landforms on the basis of climate, the first stage of correlation between factors of the environment and the vegetation was reduced to a correlation between vegetation and landform. This was based on the assumption that in the south western region, where plateau landscapes are prevalent, there is a high degree of integration between topography and soils. That is, in the plateau landscapes, fertile soils are generally confined to areas of strong dissection, in which the old leached and infertile soils, such as sands and lateritic gravels, are stripped by erosion. The relatively fertile young soils then develop directly from the parent material in a new cycle of soil formation. The assumption that steeper slopes are linked with shallower but more fertile soils was built into the vegetation maps.

The above assumption is particularly relevant to the crystalline plateaus. It is less relevant to sedimentary plateaus, because the parent material has already undergone at least one cycle of weathering and leaching. On the coastal plains, the chief determinants are the nature of the deposit, that is whether it is heavy (clay) or light
textured (sand), and the time since deposition. For instance, recently deposited sand
dunes tend to be alkaline and calcium-rich, whereas old dunes tend to be acid and low
in calcium and iron, though iron is more available in the latter.

The secondary assumption made was that steep slopes have a high degree of both
external (slope) and internal drainage (stoniness). This means that even during winter
rains they are not waterlogged and during summer drought they are acutely water
deficient. By contrast, level or concave depressions receive runoff from neighbouring
slopes and are often waterlogged in winter. However, they benefit from the additional
water during summer drought.

3.2.4 Fieldwork – Pattern of Sampling; Data Recorded (plots, toposequences)

The fieldwork consisted of the following stages:

(a) Checking field boundaries, particularly when landform maps by different
    authors had to be matched,

(b) Establishment of plots to ensure that each landform had some representation in
    terms of vegetation within the database, and

(c) Description of toposequences representing various landform/climate
    combinations, particularly those not covered by earlier vegetation
    classifications.

The checking of field boundaries was largely determined by need and by feasibility. It
was focused on areas where differing landform maps met, and where reasonable
access was available.
The establishment of plots to ensure representation of all landforms was based on the review of historical data, the focus being on eliminating major gaps in coverage by previous studies. The teams organised by Mattiske Consulting Pty Ltd established 1200 permanent plots to achieve that objective.

The plots were located to sample, as far as possible, all landform/climate combinations. The specifications also included absence of disease expression, adequate time (3 years plus) since last fire, and freedom from recent disturbances and weed infestation. The latter specification was difficult to meet on some landforms preferred for agriculture, particularly on the Margaret River Plateau and in the Blackwood River catchment east of the Darling Scarp.

All permanent plots were located using a Geographical Positioning System (GPS). Within the plots (10 m x 10 m), all vascular plant species were recorded by their height and their contribution to percentage foliage cover. Site parameters such as estimated time since fire, number of tree stumps, topographical position, degree of outcropping and soil type, were also recorded. The observations were supported by specimen collections, that were lodged at the Western Australian Herbarium.

All data were 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).
As the data collection was undertaken under contract to the Department of Conservation and Land Management of Western Australia and Environment Australia, it is owned and held by these organisations. It is also held by the contractor, Mattiske Consulting Pty Ltd.

In spite of the magnitude of the sampling, it was necessary to supplement it by toposequences based on reconnaissance, particularly on those landforms that had been extensively modified by agricultural activities.

The toposequences were constructed so as to record the range of variation in topography, soils and vegetation within a set of climate/landform combination. Wherever possible, this was done in a specific locality, but often information had to be obtained from more than one locality. For example, to describe the changes between plateau, upland landforms and neighbouring valley landforms, the extensive and relatively uniform upland landform had to be condensed into a fraction of its full extent. This means that the valleys shown on the toposquence as separated by a plateau of 100-150 m width may in fact be separated by several hundreds or even thousands of metres. The construction of toposequences is discussed in greater detail in Section 3.4.
3.3 Definition of Relationship between Climate, Landform and Vegetation

The aim of this section is to define relationships between environmental factors, in particular climate and landform, and the vegetation, as the next step in defining mapping units that combine both abiotic and biotic components of the ecosystem. To a degree this has been already done in establishing the continuity between existing localised classifications (Chapter 2), as such classifications are usually based on relationships between the vegetation and underlying environmental factors.

However, it is proposed to examine these in greater detail in this section. The effectiveness and reliability of the approach is determined by the degree of understanding that exists on the relationship between the gross environmental features such as landforms and climate and the finer features of the vegetation, in particular its floristic composition. The understanding has to cover the intermediate scale features such as soils and structure of the vegetation. Because fires are relatively frequent in the forests of south western Australia, there is a high proportion of fire-tolerant species. Consequently there is less difference between pre- and post-fire vegetation than in regions with infrequent fires and fire-susceptible species.

A plant community or vegetation type, defined by a set or sets of species (characteristic species, indicator species), is an implicit statement that a relationship exists between vegetation and the site on which it grows. There are numerous examples in the Australian ecological literature of studies of relationship between the
vegetation and the underlying environmental factors (Elliott et al. 1983; Busby 1986; Froend et al. 1987; Kirkpatrick et al. 1987; Burgman 1988; Brown 1989; Davidson and Reid 1989; Coates and Kirkpatrick 1992; Enright et al. 1994; Le Brocque and Buckney 1995 and Hahs et al. 1999;), and most of these will be discussed further in Chapter 5. There are also some articles which deal specifically with the methodology of relating vegetation to the environment, in particular Austin et al. (1983) and Austin et al. (1996). Regrettably, the heterogeneous nature of the vegetation data available for the southern forests preclude the use of these more objective methods here.

3.3.1 Early Qualitative Descriptions

Even though quantitative analyses were not feasible in the earliest vegetation studies, the conclusions reached by the early ecologists are generally still valid, and are considered here. Diels (1906) considered the jarrah forest to be delineated by the 750 mm isohyet. This is only a rough approximation that ignores the effect of evapotranspiration, for which no data were available at the time. He recognised that edaphically favourable sites compensate for lower rainfall in the most easterly extension of the species. Jarrah was seen as being associated with gravelly uplands, but its extension on to the sandy coastal plain, with a corresponding reduction in structure from forest to woodland, was recognised.

In dealing with other tree species, he associated marri with moist, fertile sites, 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 was considered to
be restricted to heavy-textured soils underlain by clay, alternately wet in winter and
dry in summer, and *Allocasuarina huegeliana* to granite outcrops. Even more
remarkable 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 Eparidaceae 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.

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.

Williams (1932, 1945) concluded that plant communities were indicative of soil
conditions, but that individual 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.

Marri was considered by Holland (1953) 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.

The 500 mm isohyet was considered by Lange (1960) as being the most significant climatic criterion, dividing the coastal high rainfall tree species from the inland low rainfall ones. 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.

The vegetation of south western Australia, within which the Jarrah and Warren bioregions are located, was considered by Churchill (1961,1968) to be a continuum primarily determined by rainfall, in which each species occupied a distinct segment. To illustrate this, he provided distribution maps of many tree, shrub and perennial herb species. Havel (1975a) examined these distribution maps for communality of distribution and identified 16 groups of species, which had a shared distribution pattern. These are described in Appendix 1.1. Churchill (1961,1968) considered the balance between the major forest components (jarrah, karri and marri) to be determined by the rainfall of the wettest and the driest months of the year, indicating
that water availability was a major influence. He considered these species to have very wide edaphic tolerances within the high rainfall belt. By contrast, no such relationship with temperature data was found.

Finally, in relating the vegetation types to edaphic and geologic units, Griffin (1992) found that vegetation was 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.

3.3.2 Principal Component Analysis and Regressions

The establishment of relationships between vegetation and soils was the principal objective of Havel's (1968) studies of the northern Swan Coastal Plain. He utilised the factor analysis of Goodall (1963) as the primary tool for this. 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 factor framework, it was possible to assess their value as indicators of the soil parameters. The capacity of vegetation to reflect environmental factors is illustrated in Figures 3.2 and 3.3.
Figure 3.2: First stage of output from the factor analysis programme, that is, the loadings on the first and third factors of the 30 species from the northern Swan Coastal Plain used in the analysis. The first factor reflects the leaching of the soil.

After Havel (1968), with kind permission of the Executive Director of the Department of Conservation and Land Management, Western Australia.
Figure 3.3: Distribution of two shrub indicator species of the northern Swan Coastal Plain plotted within the factor space. The species are those with the highest positive and highest negative loading on the first factor, which reflects the leaching of the soil.

The broken lines refer to geomorphical and edaphic subdivisions.

After Havel (1968), with kind permission of the Executive Director of the Department of Conservation and Land Management, Western Australia.
This relationship was expanded to more extreme sites, not covered by initial sampling, by combination of permanent transects and Pogrebnyak's (1955) edaphic net. The edaphic net covering the deep leached sands of the Bassendean Dune System identified a dynamic rather than static parameter, that is annual fluctuations of the groundwater table, as the chief determinant of vegetation patterns (Figure 3.4). Subsequent observations over 33 years (1966-1999) have shown that even this parameter is subject to year-to-year fluctuations. When these combine into a trend, such as that caused by a sequence of years of below-average annual rainfall, there is a corresponding shift in the vegetation continuum (Heddle 1980; Mattiske Consulting 1995).

In the northern jarrah forest, Havel (1975a,b) attempted to relate vegetation patterns to the underlying environmental factors through a number of different approaches. The most quantitative of these was by means of stepwise multiple regression of plot scores, derived by principal component analysis of floristic data, against observed environmental parameters, for 171 plots from the northern sector of the jarrah forest. An example of the integration of the vegetation and the environment is described below. The first component (F1) was most closely related to the maximum slope (r = + 0.536) and percentage gravel in topsoil (r = + 0.390). Site-vegetation types T and U are associated with +F1. These types thus occur in the highly dissected western zone of the jarrah forest, on gravelly loams and loamy gravels, and are defined by three indicator groups: HIGRA (high rainfall gravels) which consists of *Leucopogon verticillatus*, *Pteridium esculentum*, *Clematis pubescens*; FREGRA (fresh gravels) which consists of *Macrozamia riedlei*, *Leucopogon capitellatus*, *Leucopogon propinquus* and *Phyllanthus calycinus*; and GRAHIR (gravels, high rainfall) which
Moisture levels:
Blank = 0-3%, Dotted = 3-10%, Vertical Lines = 10-20%, Horizontal Lines = 20+%
Circles = Deposition horizon

CORRESPONDING RELATIVE BASAL AREA (%) OF TREE SPECIES

<table>
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<th>Tree Species</th>
<th>1.4</th>
<th>11.4</th>
<th>13.1</th>
<th>21.7</th>
<th>55.1</th>
<th>44.8</th>
</tr>
</thead>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Banksia menziesii</td>
<td></td>
<td></td>
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<tr>
<td>Banksia ilicifolia</td>
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<td>6.0</td>
<td>12.6</td>
<td>44.5</td>
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<td>17.5</td>
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<td>Nuytsia floribunda</td>
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</tbody>
</table>

Figure 3.4: An example of an edaphic net sensu Pogrebnyak (1955) from the northern Swan Coastal Plain. Tree species of the Bassendean Dune System arranged in a coordinate framework based on depth to deposition horizon (organic hardpan) and maximum height of the groundwater table during the period, September 1965 to September 1966.

After Havel (1968), with kind permission of the Executive Director of the Department of Conservation and Land Management, Western Australia.
consists of *Acacia urophylla*, *Lasiopetalum floribundum* and *Bossiaea aequifolium*. There were weaker correlations between the first component and cation exchange capacity of the soil (CEC), percentage saturation of the CEC and levels of calcium, phosphorus and potassium. The average percentage saturation of the CEC was 70 for type T and 82 for U, which is well above average for the forest as a whole. The average calcium level [ex Ca (me%)] was 7.3 for T and 13.1 for U, again well above average for the forest as a whole. The multiple regression coefficient for combined maximum slope, percentage gravel in topsoil, percentage saturation of the CEC and level of calcium in the soil was 0.633. The equivalent process for components F2, F3 and F4 is given in Appendix 1.1.

Havel (1975a) also detected a strong correlation between parameters reflecting site fertility, and between these and pH, percentage of silt and clay, field capacity and available moisture. All of these were highly significantly correlated with maximum slope, presumably because of the strong geomorphological control over soil formation. Fresh loamy soils with high fertility and moisture retention can only develop where the lateritic or siliceous overburden has been stripped by erosion.

He summarised the correlations between component scores derived from vegetational parameters and directly measured environmental parameters as follows:

a) The component scores cannot be simply expressed in terms of individual environmental parameters.

b) Environmental parameters explain only a portion of the total variation in component scores. In view of the fact that only a portion of the environmental
complex (some aspects of topography and some physical and chemical factors of the topsoil) could be quantified, this too can be expected.

To facilitate the examination of the relationships between the plots, i.e. 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 plotted 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 groups of species with similar attributes. The distribution of some of the species groups in the component space is shown in Appendix 1.1.

The graphical approach made it possible to relate the environmental factors to more than one principal component at a time. For instance, the component space delineated by -F2 and -F4 was characterised by high levels of phosphorus (Figure 3.5), potassium, calcium and magnesium, by high cation exchange capacity, by high field capacity and high wilting point. By contrast, the component space delineated by high -F1 and -F3 was characterised by acid soils with the lowest phosphorus, potassium, calcium and magnesium levels, high exchangeable hydrogen, mild slopes and absence of gravel. Whist in many environmental parameters the combinations -F1 x -F3 and -F2 x -F4 appeared to be diametrically opposed, this was not true of all parameters. It can, however, be assumed that these two combinations do provide two extremes of the
environmental continuum, namely the fresh, well drained and fertile loams on the slopes of the major valleys and the leached, impoverished sands in mildly sloping, poorly drained depressions in the headwaters of rivers. Havel (1975a) concluded that both the mathematical and graphical approaches pointed to a highly interrelated environment/vegetation complex.

<table>
<thead>
<tr>
<th>Total phosphorus (P, μg/kg) in top soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>102</td>
</tr>
<tr>
<td>232</td>
</tr>
<tr>
<td>- F2</td>
</tr>
</tbody>
</table>

Figure 3.5: Patterns of environmental parameters within component space calculated on the basis of vegetational data (55 shrub and tree species) from the northern jarrah forest. The values plotted are the mean values for sample plots falling into the particular segments of component space. For full details, see Appendix 1.1.

After Havel (1975a), with kind permission of the Executive Director of the Department of Conservation and Land Management, Western Australia.

Principal component analysis (PCA) was also used as the most convenient method of dealing with the environmental (site) data by Loneragan (1978). This elucidated the relationship between the site descriptors, namely that they formed a continuum. It
indicated that in Loneragan's studies 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 soils of finer texture and higher level of nutrients, indicating greater dissection of the lateritic plateau, described as an erosional surface. Most of the latter sites presumably occurred on the strongly dissected slopes caused by eastward flowing tributaries of the Avon River. The coarsest textured soils of more that 70% of coarse sand, occurred in depressions within the plateau, on sites described as depositional.

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 and clay fraction. The correlations with soil chemical attributes such as N, P and K were weaker.

The chief factors determining the vegetation patterns on the Blackwood Plateau were considered by McCutcheon (1980) to be 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. 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 the 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.

Strelein (1988) used the output of the principal component analysis of the southern
jarrah forest to interpret the interspecific relationships and to assess the underlying
factors. The second stage of the output, namely component scores for the plots, was
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.

Strelein (1988) related his vegetation types to factors of the environment both verbally
and by means of diagrams. The summary of his observations is given in Appendix
3.1. On the whole, Strelein (1988) detected similar basic relationships between
vegetation and the underlying environmental factors in the moister southern jarrah
forest as Havel (1975a,b) did in the drier northern jarrah forest. There was, however,
a significant shift that reflected the climatic differences between the two. Wandoo was
restricted to the dry north eastern quadrant of the area studied by Strelein, due to the
higher rainfall and lower summer evaporation. It was a less significant component
than was the case in the north.
3.3.3 Test Surveys, Computer-based Map Overlays and Chi-square Test

Having defined site-vegetation types in the northern jarrah forest by principal component analysis and ancillary programs, Havel (1975b) set out to test whether the categories defined were more than mathematical abstractions without a counterpart in the real world. In order to test this, and 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 contours, 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 800 m x 200 m. 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 were 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), adjusted for local use. The map data was entered by means of a numerical code for cells 4 mm x 5 mm, equivalent to 0.54 ha on the metric scale. The MIADS system made it possible to overlay maps and assess the degree of covariance 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 Chi-square test for goodness of fit (Fienberg 1970). The full study cannot be reported here, but is contained in Appendix 1.2. A specific example is presented here which involves the site-vegetation types described earlier. The westernmost test area surveyed (Ashendon) was largely a catchment of a minor tributary of the Canning River, in which high rainfall (1200-1350 mm/year) was combined with strong dissection of the plateau because of proximity to the Darling Scarp. A brief resume of the relationships, and the conclusions reached is described below.
The site-vegetation recorded in this test area were C, D, W, Q, R, T, S and P (Figure 3.6; Table 3.1). The T site-vegetation type, an open forest of *Eucalyptus marginata* subsp. *marginata* – *Corymbia calophylla* with minor admixture of *Eucalyptus patens*, was found at 4.4 times above the expected occurrence (assuming random distribution) below 213 m a.s.l., at 4.7 times between 213 and 244 m, at 2.2 times between 244 and 274 m and at below the expected occurrence above 274 m. The ratio of observed to expected occurrence in relation to slope was 2.6 for slopes of more than 8°, which in local context is steep, and below 1.0 for plateaus, depressions and mild slopes of less than 8°. The ratio in relation to soil texture was 0.2 for sand, 0.3 for gravelly sand, 0.6 for sandy loam, 0.7 for sandy gravel, 1.8 for silty loam and 3.4 for loamy gravel. The site-vegetation type T can thus be expected to occur on valley slopes below the main level of the plateau, on loamy gravels and loams.

On the basis of the tests described in Appendix 1.2 it was established that the site-vegetation types exist in real space. Two of the types established by the ordination process (U, F) 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. A whole new complex of types, from woodlands to herbfields, with pattern too fine to be separated into mappable homogeneous types at the scale of 1:10,000, was found on the rocky slopes of the Cooke monadnock and was defined as a new category G.
Figure 3.6: Distribution of site-vegetation types in the Ashendon test survey area, northern jarrah forest.

After Havel (1975b), with kind permission of the Executive Director of the Department of Conservation and Land Management, Western Australia.
Table 3.1: Relationships Between Site-Vegetation Types, Environmental and Stand Parameters, Ashendon Test Area
(Ratio of observed to expected joint occurrences)
For full details refer to Appendix 1.2
After Havel (1975b) with kind permission of the Executive Director of the Department of Conservation and Land Management, Western Australia

<table>
<thead>
<tr>
<th>Environmental Parameters</th>
<th>C</th>
<th>D</th>
<th>W</th>
<th>Q</th>
<th>R</th>
<th>T</th>
<th>S</th>
<th>P</th>
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<td>Altitudinal Zones (m)</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>&lt;213</td>
<td>2.8</td>
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<td>0</td>
<td>16.5</td>
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<td>4.4</td>
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<td>0</td>
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<tr>
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<td>7.8</td>
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<td>4.7</td>
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<tr>
<td>244 - 274</td>
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<td>1.1</td>
<td>1.3</td>
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<td>1.0</td>
<td>0.4</td>
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<td>274 - 305</td>
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<td>0.9</td>
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<td>1.0</td>
<td>1.3</td>
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<td>&gt;335</td>
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<td>0</td>
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<td>1.6</td>
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<td>Maximum Slope</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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<td>0-4° depressions</td>
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<td>2.7</td>
<td>2.4</td>
<td>1.5</td>
<td>1.4</td>
<td>0.5</td>
<td>0.5</td>
<td>1.3</td>
</tr>
<tr>
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<td>5-8° mild slopes</td>
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<td>1.1</td>
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<td>&gt;8° steep slopes</td>
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<td>Soil Texture (Topsoil only)</td>
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<td>Sand</td>
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<td>Sandy loam</td>
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<td>3.7</td>
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<td>Silty loam</td>
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<td>0.6</td>
<td>1.8</td>
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<td>0.4</td>
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<td>0.3</td>
<td>0.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Sandy gravel</td>
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<td>2.9</td>
<td>0.7</td>
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<td>Loamy gravel</td>
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<td>3.4</td>
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<td>Stand Parameters</td>
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<tr>
<td>Stand Basal Area (m³/ha)</td>
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<td></td>
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<tr>
<td>&lt;9.2</td>
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<td>2.7</td>
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<td>1.2</td>
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<tr>
<td>9.2 - 18.4</td>
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<td>1.1</td>
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<td>0</td>
<td>0.1</td>
<td>0.7</td>
<td>1.4</td>
</tr>
<tr>
<td>18.4 - 27.6</td>
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<td>0.9</td>
<td>0.9</td>
<td>1.5</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
<td>0.9</td>
</tr>
<tr>
<td>&gt;27.6</td>
<td>0.3</td>
<td>0</td>
<td>0.3</td>
<td>0.6</td>
<td>0.4</td>
<td>1.3</td>
<td>1.3</td>
<td>0.9</td>
</tr>
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<td>Dieback Occurrence</td>
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<td></td>
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<td></td>
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<tr>
<td>Dieback symptoms present</td>
<td>2.7</td>
<td>3.8</td>
<td>2.6</td>
<td>1.1</td>
<td>1.3</td>
<td>0.5</td>
<td>0.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Dieback symptoms absent</td>
<td>0.5</td>
<td>0.1</td>
<td>0.5</td>
<td>0.9</td>
<td>0.9</td>
<td>1.2</td>
<td>1.2</td>
<td>0.9</td>
</tr>
</tbody>
</table>
It was also confirmed that site-vegetation relationships identified by the principal component analysis exist in real space, e.g. that site-vegetation type A is invariably found on water-gaining sites and types T and S on uplands, type J on sandy soils and type Q and T on loamy soils, types S and H predominantly on plateau uplands and Q in dissected valleys, types Q and T in high rainfall and types H and J in low rainfall.

Havel (1975b) summarised the survey information in the form of cross-country transects (Figure 3.7), which are the near-equivalent of Canadian toposequences used by Cartier et al. (1996) and Roberts et al. (1996). These show, in profile, the shape of the landforms and the distribution of the tree species, site-vegetation sites and soil-texture classes. This facilitates understanding of the relationships between the various components of the landscape.

As a final summary of the trends he concluded that "... in the Darling Range one encounters the unique situation in which a strong geomorphological trend, largely controlled by distance from the escarpment, is overlain by an equally strong, parallel climatic trend also conditioned by distance from the escarpment. This reinforces the integration already described on a local scale, and leads to further simplification of vegetational patterns. There are, however, several exceptions to this, and these provide valuable reference points by which the effect of the integration can be measured."
Figure 3.7: Topographic, edaphic and vegetational transect through the northern sector of the Ashendon Test Area, lateritic uplands and Murray-type valley in high-rainfall zone, from the northern jarrah forest. For full details see Appendix 1.2.

After Havel (1975b), with kind permission of the Executive Director of the Department of Conservation and Land Management, Western Australia.

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 the 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 a 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.

3.3.4 Other Studies that Relate Vegetation to Landscape.

Bettenay et al. (1980) linked together the hydrology, pedology and plant ecology of a set of minor catchments in the centre of the Jarrah bioregion. They defined four hydrologic provinces in each catchment, ranging from the slopes adjacent to the streamline which contributed to the stream flow, to the upper slopes and divides on which the incoming rainfall was fully absorbed into the highly permeable soil. A resume of this important study is contained in Appendix 3.2.
Heddle (1979) and Heddle et al. (1980) extended the interpretation of vegetation patterns in relation to landforms and climate into vegetation complex mapping for the Darling System (System 6 mapping). This area covers approximately a third of the South-West Forest Region. The definition of the vegetation complexes in terms of floristics is given in Table 3.2. In the development of this mapping technique Heddle et al. (1980) relied on the previous studies in the area and in particular the detailed site-vegetation type work of Havel (1975a,b), the Aerial Photographic Interpretation (API) mapping by the Forests Department of Western Australia, the topographic data held by the Department of Land Administration, the landform and soil mapping of Churchward and McArthur (1980) and, the previous vegetation mapping by Smith (1974) for the Collie area. It was similar to the land system approach of Christian and Stewart (1953) used in the Katherine - Darwin region. The studies by Beard (1979a,b) were developed concurrently with those of Heddle et al. (1980) and therefore the essentially structural formation mapping of Beard was not available to Heddle et al. (1980) at the time of the mapping.

Havel Land Consultants (1987) surveyed four river basins in the northern jarrah forest by means of cross-contour (across valley) surveys. The basins studied covered quite a wide climatic range as well as considerable geological variation. The most northern of the river basin (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 plant indicators of fertile sites.
Table 3.2: Summary of Vegetation Complexes of the Darling Plateau in Relation to the Site-Vegetation Types

After Heddle et al. (1980) by kind permission of the Chief Executive Officer of the Department of Environment and Protection, Western Australia

Symbol Explanation:
+ - Site-vegetation type should be present
o - Site-vegetation type should be present, but absence not critical
- - Site-vegetation type generally absent
* - Site-vegetation types as defined by Havel (1975a,b) which are contained in Appendices 1.1 and 1.2

<table>
<thead>
<tr>
<th>Mapping Unit No.</th>
<th>Vegetation Complexes</th>
<th>Site-Vegetation Types (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>1</td>
<td>Dwellingup-Hester</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Dwellingup</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Dwellingup-Yalanbee</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Dwellingup-Yalanbee-Hester</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Yalanbee-Dwellingup</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Yalanbee-Dwellingup</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Cooke</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Goonaping</td>
<td>0</td>
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<tr>
<td>9</td>
<td>Wilga</td>
<td>-</td>
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<tr>
<td>10</td>
<td>Yarragil (Min. Swamps)</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>Yarragil (Max. Swamps)</td>
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<td>12</td>
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</tr>
<tr>
<td>14</td>
<td>Coolakin</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>Catterick</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>Helena (High Rainfall)</td>
<td>-</td>
</tr>
<tr>
<td>18</td>
<td>Helena (Low Rainfall)</td>
<td>-</td>
</tr>
<tr>
<td>19</td>
<td>Bridgetown</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>Murray</td>
<td>-</td>
</tr>
<tr>
<td>21</td>
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</tr>
<tr>
<td>22</td>
<td>Balingup</td>
<td>-</td>
</tr>
<tr>
<td>28</td>
<td>Darling Scarp</td>
<td>-</td>
</tr>
</tbody>
</table>
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, C, W and Y.

Finally, the environmental impact assessment for the Boddington Goldmine (Worsley Alumina 1999) resulted in the production of a detailed vegetation map. This gave the opportunity to relate vegetation patterns in relation to landform. There was a strong relationship between vegetation types and land forms, the woodlands of wandoo (Y, AY), yarri (L) and flooded gum (AX) being mainly confined to the Pindalup and Swamp landforms and optimum development of the jarrah forest and woodland occurring on the Dwellingup landform. The Melaleuca shrubland type (A) was confined to the Swamp landform. The heath complexes (G3, G4) were, however, not confined to the Cooke landform, but also occurred in small patches at the interface between the Pindalup and Dwellingup landforms. The maximum occurrence of the ST type, normally associated with high rainfall and moderately high fertility, was on the Cooke landform along the western boundary, where basic parent material and additional orogenic rain presumably provided optimum conditions.
3.3.5 UPGMA Analysis and Ordination

In their study of the karri forest, Inions et al. (1990a,b) used separate classifications of edaphic and climatic attributes to define 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 Strelein (1988).

Inions et al. (1990a,b) also 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 the basis of precipitation in the driest quarter, radiation in the driest quarter and phosphate content of the soil (Figure 3.8). 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 the drier and hotter inland margin in the north of the species' distribution.

Inions et al. (1990b) provided a set of indicator species which covered the continuum. The vegetation/site relationships described by them include the following linkages:
Figure 3.8: Position of karri community-types in 3 dimensional space defined by the mean values for PD4 (precipitation in the driest quarter (mm)), RD4 (radiation in the driest quarter (MJ m⁻² day⁻¹)) and PHCL(A) (phosphorus in the soil sample, µg/kg).


- Marginal sandy acidic sites with low HCl extractable phosphate (25.2 ± 3.1 µg/kg)
  - Boronia gracilipes, Macrozamia riedlei, Persoonia longifolia and Podocarpus drœynianus (Ednie-Brown community type)
- Gravelly yellow or brown duplex soils with moderately high HCl extractable phosphate (51.7 ± 16.8 μg/kg) – *Chorizema ilicifolium*, *Lasiopetalum floribundum*, *Pteridium esculentum* and *Macrozamia riedlei* (Kessel community type)

- Cold, wet, acidic sites with fairly low HCl extractable phosphate (37.5 ± 4.6 μg/kg) – *Acacia pentadenia*, *Allocasuarina decussata*, *Hibbertia furfuracea* and *Lepidosperma effusum* (Harris community type)

- Warm, moist sites with moderately high HCl extractable phosphate (50.9 ± 6.7 μg/kg) – *Hibbertia grossulariifolia*, *Callistachys* (formerly *Oxylobium*) *lanceolatum* and *Pteridium esculentum* (White community type)

- Warm, seasonally dry sites with moderately high HCl extractable phosphate (54.6 ± 4.0 μg/kg) – *Acacia urophylla*, *Hardenbergia comptoniana*, *Hibbertia amplexicaulis*, *Leucopogon verticillatus* and *Logania vaginalis* (McNamara community type)

Overall, Inions et al. (1990a,b) considered water availability during the dry season, degree of inundation during the wet season, minimum temperature and soil phosphate to be the chief determinants of floristic patterns.

It is significant that although three dimensions were used in the ordination, there was a single overall continuum stretching between the Harris and McNamara types. Infertile sites (HCL extractable phosphorus in the A soil sample of less than 46.30 μg/kg)
supported karri mainly in high summer rainfall (precipitation in driest quarter of more than 84.75 mm) and low summer radiation (MJ m$^2$ day$^{-1}$ of 79.92). By contrast, sites with low summer rainfall (less than 84.75 mm) and high summer radiation (more than 79.92 MJ m$^2$ day$^{-1}$) mainly carried karri if the sites were relatively fertile (HCL extractable phosphorus in A soil sample of more than 46.30 µg/kg).

This strong gradient in environmental variables was accompanied by a similar strong gradient in characteristic (indicator) species. The wet infertile extreme is represented by the species group consisting of *Acacia divergens*, *Dampiera hederacea*, *Hibbertia cuneiformis*, *H. furfuracea*, *Pimelea clavata*, *Scaevola microphylla* defined by Inions *et al.* (1990b) and labelled here HEATECO (heath ecotope). The dry, fertile extreme is represented by the NOREKA (north eastern karri) group of *Amperea ericoides*, *Hardenbergia comptoniana*, *Helichrysum racemosum*, *Hibbertia amplexicaulis*, *Logania vaginalis*, *Orthrosanthus laxus* and *O. multiflorus* at the dry fertile end.

An intermediate species group, at the moister end of the continuum is SOLOAM (southern loams) of *Chorilaena quercifolia*, *Eucalyptus guilfoylei* and *Lepidosperma effusum*. At the dry fertile end, the intermediate species group is HIGRA (high rainfall gravels) of *Leucopogon verticillatus*, *Pteridium esculentum*, *Corymbia calophylla*, *Lomandra drummondii* and *Opepcularia hispidula*.

A gradient also exists from infertile, wet and low radiation, represented by HEATECO, (already described above) to infertile, dry and high radiation, represented by GRAMED (gravels in medium rainfall) group of *Banksia grandis*, *Persoonia*
_longifolia_ and INFEKA (infertile karri) group of _Conospermum caeruleum, Hibbertia cunninghamii, Lomandra integra, Lomandra nigricans_ and _Ricinocarpos glaucus_.

Other studies have provided additional insight into the relationship between vegetation and the underlying environmental factors. Wardell-Johnson _et al._ (1989) defined three broad groups, interpretable in terms of landform and drainage characteristics, 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. 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 of the community types than the landforms themselves. Many of the soil types occur in more than one landform unit. In the swamps, the boundaries are more diffuse. The communities on the aeolian sands occur in a very complex pattern and have greater species richness.

In the study of the southern Swan Coastal Plain, Gibson _et al._ (1994) described a broad relationship between vegetation and landforms. At the level of the four supergroups, the grouping reflected major geomorphological elements, such as plains, swamps and young (Spearwood and Quindalup) and old (Bassendean) dunes. They concluded that although floristic types are broadly correlated with geomorphological / geological units, there is not a direct one to one correspondence. Few community types occur on only one geomorphological unit, though some community types have relatively narrow geomorphological range. There is also negative correlation, in that some community types do not occur on certain geomorphological units.
In comparing the floristically based community groups with vegetation complexes of Heddle et al. (1980), Gibson et al. (1994) concluded that repeatable floristic communities, primarily determined by seasonal water regimes and geomorphology, do occur across the coastal plain, but groups of floristic communities are not restricted to particular vegetation complexes.

3.3.6 Qualitative Matching of Landform Maps and Vegetation Classifications

In this study, the maps of Heddle et al. (1980) have been used, with modifications at the southern margin, as the basis for remapping the northern third of this project. As no studies comparable to those of Havel (1975b) have been carried out for the more diverse and complex south it was necessary to examine alternative approaches to relating vegetation to landforms and climate. Fortunately, the mapping of Churchward and McArthur (1980) had been extended southwards (Churchward et al. 1988; Churchward 1992), and in contrast to the northern study the southern studies included a considerable amount of botanical observation. In addition, the existence of these landform maps has enabled forest ecologists who carried out subsequent ecological studies in the Warren Bioregion (Strelein 1988; Wardell-Johnson et al. 1989,1995) to relate their observations of vegetation to landforms.

It is not possible to detail here all the information utilised and all the analyses carried out to achieve this. Rather, examples will be given of the various sources and methods in view of the importance of this process.
In the description of their mapping units Churchward et al. (1988) included the following information:

**BE (Bevan landform)** - gently undulating surface made up of broad divides with short gentle slopes of less than 5°, extending into minor valleys, underlain by deeply weathered granitic rocks, largely without outcrops and including some unconsolidated sandy deposits.

**BEy** is an edaphic variant, dominated by yellow duplex soils (Dy3.62) with greybrown sand to sandy loam surface incorporating ferrugineous gravel and some duricrust boulders, over a pale A2 horizon and weakly pedal clay B horizon.

BEy is described by them as supporting jarrah and marri tall open forest with an upper tree layer at about 30 m; a sparse small tree layer of *Banksia grandis* and *Persoonia longifolia*; shrub layer (1-2 m) of *Bossiaea linophylla*, *B. aquifolium* subsp. *laidlawiana*, *Xanthosia rotundifolia*, *Agonis parviceps*, *Oперcularia hispidula*, *Synaphea reticulata*, *Acacia obscura*, *A. myrtifolia*, *A. divergens*, *Hakea amplexicaulis* and *Hypocalymma robusta*; creepers *Clematis pubescens*, *Kennedia prostrata* and *K. coccinea*.

In Strelein’s (1988) description of vegetation types the following are considered to occur, partially or wholly, on landform BEy – S, T, V, Y and M.
Type S occurs on moderately dissected uplands in higher rainfall areas, with gravelly duplex soils and many surface lateritic outcrops. Strelein described it as open forest of jarrah and marri with the following species as the primary indicators:

Second storey species Banksia grandis, Persoonia longifolia and shrub storey Bossiaea linophylla, Boronia gracilipes, Gompholobium ovatum, Grevillea brevicuspis, Hakea amplexicaulis, Hovea chorizemifolia, H. elliptica, Leptomeria cunninghamii, Leucopogon verticillatus, Macrozamia riedlei, Petrophile diversifolia, Podocarpus drouynianus, Sphaerolobium medium and Xanthorrhoea gracilis.

The less common associate species included Acacia myrtifolia, A. pulchella, Agonis hypericifolia, Bossiaea aquifolium subsp. laidlawiana, B. ornata, Hakea lasianthoides, Isopogon sphaerocephalus, Lechenaultia biloba, Loxocarya flexuosa, Patersonia umbrosa, Pteridium esculentum and Xanthorrhoea preissii. Strelein also referred to minor inclusion of moister sandy sites with Adenanthes obovatus, Agonis parviceps, Kingia australis and Leucopogon concinnus.

Type T differs slightly edaphically, having less lateritic outcrops and a yellow or reddish brown subsoil, indicative of higher fertility. It is mainly a tall open forest of jarrah and marri. Clematis pubescens, Hakea amplexicaulis, Hovea elliptica, Leucopogon verticillatus, Macrozamia riedlei, Persoonia longifolia, Podocarpus drouynianus and Pteridium esculentum are the primary indicators.

Type V is described as occurring on long sandy slopes, being less adequately drained than S and T and having brown or yellow sandy loams over brown or orange clay subsoil. It is an open forest whose primary indicator species are Acacia extensa, A.
pulchella, A. urophylla, Agonis flexuosa, Bossiaea linophylla and Clematis pubescens, with Leucopogon propinquus, L. verticillatus, Macrozamia riedlei and Persoonia longifolia also present.

Type Y is described as coming from eastern broad flat drainage lines, with impeded drainage and dark grey clayey sand in the upper profile. It is an open forest whose primary indicators are Bossiaea linophylla, B. ornata, Hakea lissocarpha, Hypocalymma angustifolium, Leucopogon propinquus and Desmocladius (formerly Loxocarya) fasciculatus. By comparison with S, T and V, it has a lower rainfall and is less adequately drained, to the point of seasonal water logging. It is not strictly an integral part of the Bevan landform, but may occur within it as enclaves.

Type M is described as occurring on eastern slopes with brown sandy loams over gravelly brown clays. It is a woodland or open forest in which the chief associate of jarrah is wandoo. The primary indicators are Acacia pulchella, Hakea lissocarpha, Leucopogon propinquus and Trymalium ledifolium. Astroloba ciliatum, A. pallidum, Macrozamia riedlei and Desmocladius fasciculatus are also common. By comparison with types S, T and V, this type occurs in a lower rainfall zone; by comparison with Y it is more fertile and better drained to the point of being drought prone. It fits only marginally into the Bevan landform.

The comparison of the two approaches indicates that, although the geomorphologists put greater accent on the abiotic components of the ecosystem, and the ecologists on the biotic components, there is a broad agreement on the range of topographic and edaphic features and on the vegetation associated with them. The wider range of
vegetation, which is strongly subject to climatic influences, indicates that geographically extensive landforms that extend over several climatic zones need to be subdivided.

In the case of the BEy landform, it was found necessary to subdivide BEy into BEy1 and BEy2, and in the extreme case on the eastern periphery of the bioregion, to add BE3. Strelein’s types S, T and V would mainly occupy BEy1 and to a lesser degree BEy2, types Y and M would occupy BEy 2 and type M would mainly occur on BE3.

By comparison with the upland landforms such as the one described above, the valley landforms tend to be more diverse in terms of both soils and vegetation. Churchwood’s (1992) Warren landform is described as valleys that are 60-100 m deep and 0.75 to 1 km wide, having slopes that range from 5° to 20° and floors that sometimes have a narrow terrace. There are few gneissic outcrops and the slopes are usually smooth and partially covered by colluvium. The dominant soils are red earths, though there are some yellow earths and red and yellow duplex soils on slopes and brown sandy loams on terraces.

Churchward describes the vegetation as tall open forest dominated by karri, with marri becoming more prominent with northward decrease in rainfall. The low tree layer is mainly Banksia grandis, Agonis flexuosa and Allocasuarina decussata. There is also a tall dense shrub layer of Acacia pentadenia, Bossiaea linophylla, Hovea elliptica, Clematis pubescens and Chorizema ilicifolium.
The valleys in this subregion are covered by the Inions et al. (1990b) classification of the karri forest, more specifically community types Shea, Stewart, Beggs, McNamara, Havel and White. Inions et al. does not specifically refer to landforms, as their study preceded the landform mapping of Churchward (1992) which covers the prime occurrence of karri. The Stewart and McNamara community types represent the drier northeastern variants. In the moister centre, where the Warren landform is most common, Inions et al. describe the riverine terraces as being occupied by the Havel, the mid slopes by Shea and upper slopes by Beggs community types.

The Havel community type of moist sandy riparian sites has as its key characteristic species *Chorilaena quercifolium*, *Chorizema diversifolium* and *Lepidosperma effusum*, with *Hovea elliptica* and *Veronia plebeia* also present.

The Shea community types of mid-slopes has as its characteristic species *Bossiaea aquifolium* subsp. *laidlawiana*, *Chorilaena quercifolia* and *Tremandra stelligera*, with some *Acacia urophylla* also present.

The Beggs community type of well drained sites high in the profile is described as having a significant component of marri in the overstorey, and *Bossiaea aquifolium* subsp. *laidlawiana*, *Hovea elliptica*, *Leucopogon verticillatus*, *Opercularia hispidula*, *Pteridium esculentum* and *Tremandra stelligera* in the shrub storey. To a lesser degree there are also *Banksia grandis*, *Leucopogon australis* and *Lomandra drummondii*.

With decrease in rainfall in the north, Strelein’s (1988) type Q also enters on to this landform. It has yarri, jarrah and marri as well as some karri in the overstorey. It has
*Persoonia longifolia* in its second storey and its shrub storey includes *Clematis pubescens*, *Hovea elliptica*, *Pteridium esculentum*, *Macrozamia riedlei* and *Tremandra stelligera* and to a lesser degree *Acacia urophylla*, *Bossiaea aquifolium* subsp. *laidlawiana*, *B. linophylla* and *Hakea amplexicaulis*.

Although two strongly contrasting landforms, namely the Bevan landform of the largely undissected uplands and the Warren landform of strongly dissected major valleys were chosen as examples of integration between vegetation and landform, there is still some degree of overlap in terms of the individual species. The dominant vegetation type of the Bevan landform is jarrah-marri open forest and the dominant vegetation type of the Warren landform is karri tall open forest, yet at their interface the edaphic and vegetative differences diminish. There is a significant proportion of species that respond primarily to the climatic differences, such as *Hovea elliptica*, *Leucopogon verticillatus*, *Bossiaea aquifolium* subsp. *laidlawiana*, *Clematis pubescens* and *Pteridium esculentum*, so that they occur at the interface of the Bevan and Warren landforms in the high rainfall zone in the west, but are largely absent from the Bevan landform in the low rainfall zone at the eastern margin.

It will be also seen that within the Warren landform the difference in the composition of the shrub storey between Inions *et al.* (1990b) Havel community type of the valley floor and the Beggs community type of the upper slopes is greater than the difference between the Beggs community type and the T vegetation type of Strelein (1988) on the adjacent Bevan uplands. This is so because within a dissected plateau landscape the maximum variation in soils and vegetation is across valleys, and least on the uplands.
The remainder of the information obtained from matching ecological classifications with landform maps is contained in Appendix 3.3 (toposequences). These are described in section 3.4.

At the map scale of 1:250,000, used here for the mapping of vegetation complexes, the width of the Warren landform ranges from 5 to 10 mm and other valley landforms, such as Pemberton and Wheatley, are even narrower, yet it is common for them to be composed of two or three vegetation types (communities). The width further decreases at the scale of 1:500,000 used for the mapping of vegetation systems, which is the finest scale at which the Jarrah and Warren bioregions can be mapped together. The mapping of homogeneous plant communities is impossible beyond the scales used by Havel (1975b), namely 1:50,000 or 1:83,000. The bulk of detailed floristic mapping in south western Australia, carried out in conjunction with impact assessment for mining and engineering projects, is initially at the scale of 1:10,000 (Mattiske Consulting Pty Ltd 1996), though the scale may be reduced subsequently.

3.4 Construction of Toposequences and Definition of Vegetation Complexes

3.4.1 Construction of Toposequences

In order to tackle the complex task of mapping vegetation at the bioregion scale a framework had to be established that could accommodate the complexity of
environmental and vegetational continua. A format of recording that would make comparison across these continua feasible also had to be found.

Such a format had to provide for the display of all relevant physical and biological factors and of the interaction between them in a compact form. The pictorial component of the format follows the pattern already utilized by Speck (1958), Havel (1968, 1975b) and Beard (1981a) to illustrate the ecological relationships, i.e. the configuration of the land and the structure and composition of the vegetation. This is augmented by a brief description of climate and soils in terms of criteria most relevant to plant ecology, in particular the water balance, and by description of the composition of the dominant stratum, of the second story and of the shrub and herb story. This format makes it possible to get a rapid overview of similarities between the various vegetation, climate, landform combinations. These records, in the form of diagrams and the associated text will be referred to as toposequences in subsequent discussions because of their similarity to toposequences in recent Canadian forest ecology studies (Cartier et al. 1996).

For the bulk of the observations, toposequence information is recorded in triplets. For the landforms that are defined more narrowly, each component of the triplet generally contains one narrowly defined landform, and the triplet thus depicts the interrelationship between neighbouring landforms. Where the landforms are defined more broadly, the entire triplet is sometimes required to depict the full range of variation within one landform. An example of a toposequence is shown in Figure 3.9. The full set of toposequences is contained in Appendix 3.3.
<table>
<thead>
<tr>
<th>Geographic Region</th>
<th>Perarid north</th>
<th>Bindoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphologic catena – VC (EVS)</td>
<td>No – Noonong (Ev2)</td>
<td>Bi – Bindoon (Dso0)</td>
</tr>
<tr>
<td>Landform and Vegetation profile</td>
<td>Terrace of a major valley incised into the Darling Plateau</td>
<td>Lower slope of a major valley incised into the Darling Plateau</td>
</tr>
<tr>
<td>Soil structure, texture and fertility</td>
<td>Red brown alluvial loams and sandy loams</td>
<td>Red brown earths and red brown duplex soils</td>
</tr>
<tr>
<td>Soil hydrology</td>
<td>Seasonally inundated and water logged, but with fair lateral drainage to the stream bed</td>
<td>Strongly water shedding, with moderate infiltration, and variable storage capacity</td>
</tr>
<tr>
<td>Over storey (canopy or emergents)</td>
<td>Low Open Forest of <em>Eucalyptus rudis</em> (Er) and <em>Melaleuca rhaphiophylla</em> (Mr) on streamline and of <em>Casuarina obesa</em> (Co) on terraces</td>
<td>Open Woodland of <em>Eucalyptus loxophleba</em> subsp. <em>loxophleba</em> (Elx) on deeper soil, of <em>Allocasuarina huegeliana</em> (Ah) on shallower soils</td>
</tr>
<tr>
<td>Second storey</td>
<td>No second storey</td>
<td>Some <em>Acacia acuminata</em> (Aa)</td>
</tr>
<tr>
<td>Shrub and herb storey</td>
<td><em>Samolus junceus</em> <em>Halosarcia indica</em> subsp. <em>bidentis</em> but mainly exotic weeds</td>
<td><em>Acacia pulchella</em> <em>Styphandra glauca</em> <em>Dianella revoluta</em> <em>Cheilanthes austrotenuifolia</em> <em>Chamaescilla corymbosa</em> <em>Tetragonia octandra</em> <em>Haemodorus paniculatus</em></td>
</tr>
</tbody>
</table>

**Figure 3.9:** A toposquence from the northern margin of the RFA area.
There was an unavoidable variation in the way that toposquences were compiled. Where the relationships between climate, landform and vegetation were already well documented, such as in the north western Darling Plateau covered by earlier detailed studies of Havel (1975a,b), Heddle et al. (1980) and Bettenay et al. (1980), the toposquences are either representations of the published information, or additional observations at the extremes of the climatic range. Where vegetation classifications and landform maps have been published, but the interrelationship between the physical environment and the vegetation has not been adequately established by quantitative studies, the toposquences aim to illuminate these relationships and establish a link between the ecologist’s brief description of the landforms associated with a given vegetation type and the geomorphologist’s brief description of the vegetation perceived to be associated with a given landform.

This is particularly important for landforms that have a wide geographic spread across several climatic zones, as the tendency has been to focus on the typical or common combination of landform and vegetation, and to overlook that the relationship may be modified by a shift in climate. In this category the toposquences are either interpretations of the published descriptions of vegetation in terms of landform and climate, or new observations of vegetation based on landform and climate maps, the latter being oriented towards exploring the full geographic range.
At the level of the vegetation complexes, the aim was to reduce or eliminate the effect of climate, on a broad zonal scale. This study is too broad to consider microclimatic variation, such as differences between northern and southern slopes of valleys. As described in the previous section, the strategy employed was to subdivide the landforms that were geographically most extensive, into subsets which were as far as possible climatically homogeneous in terms of the annual rainfall/summer evaporation criteria. By doing this it was hoped to reduce the first stage of multiple correlation between factors of the environment and the vegetation to simple correlation between vegetation and landform.

As the climatic boundaries derived by discounting of annual rainfall by summer evaporation are only approximations, excessive fragmentation of the landforms was avoided by subdividing upland landforms along streamlines and valley landforms along divides closest to the boundary. That portion of the landform having the optimum climatic conditions (hyperhumid-perhumid) was given the suffix 1, e.g. BE 1, that with intermediate conditions (humid-subhumid) suffix 2 and that with the greatest climatic stress (semiarid-arid) the suffix 3.

Where no published classification of vegetation existed, or where landform mapping was proceeding concurrently with vegetation mapping and the description of landforms was as yet unavailable, the toposequences represent new observations. In these cases, they were intended to form a basis for the description of new vegetation types, and hence the tendency was to record a greater number of toposequences for each vegetation/climate/landform combination.
The compilation of new toposequences was often, but not always, carried out concurrently with establishment of detailed quadrats or with field checks on landform boundaries. This was done so as to minimise the duplication of risk and of effort in travel, and to provide a sounder taxonomic basis. In such cases, I compiled the toposequences whilst the team was establishing quadrats and collecting botanical specimens. As one member of the team was usually a plant taxonomist who subsequently clarified any doubtful identifications, I had the benefit of the additional expertise.

The proportion of the total number of toposequences that fall into various categories is:

1. Reworking of ground covered by earlier vegetation classification and mapping - 11%.

2. Integration of published landform maps and vegetation classifications for areas not mapped previously, or areas mapped without adequate classification basis - 39%, and

3. Based on field work, without published quantitative classification or ordination of vegetation - 50%.

Category 1 largely comprises the northern half of the Jarrah bioregion, covered by classifications of Havel (1975a,b) and Loneragan (1978) and maps of Heddle et al. (1980).
Category 2 comprises the southern half of the Jarrah bioregion and the Warren bioregion, covered by ecological studies of Christensen (1980), McCutcheon (1980), Strelein (1988), Wardell-Johnson et al. (1989, 1995), Inions et al. (1990a,b), Gibson et al. (1994), Mattiske Consulting Pty Ltd (1996) and Gibson\(^1\) (personal communication). It includes the Blackwood Plateau, the southern Darling Plateau, Scott Coastal Plain, South Coastal Plain and hinterland.

Category 3 comprises the Margaret River Plateau, Blackwood River catchment east of the Darling Scarp, upper reaches of the Frankland, Kent and Gordon Rivers, and eastern and northern periphery of the Jarrah Bioregion drained by the tributaries of the Avon River.

\(^1\) Department of Conservation and Land Management WA, Woodvale
3.4.2 Vegetation Complexes

3.4.2.1 Description by Toposequences

A toposequence is an attempt to capture the essence of the relationship of vegetation to a particular combination of climate and landform, rather like a snapshot. Each toposequence contains verbal description of climatic zone and general location in which it was captured, of the soil structure and hydrology, and of the composition of the understorey, as well as verbal and pictorial description of the topography and of the structure and composition of the overstorey and second storey. As such it gives a basic description of a vegetation complex. The fullest description of a vegetation complex is provided by the sum of the toposequences that describe that combination of climate, landform and vegetation, rather like a folder containing all relevant snapshots. A set of toposequences depicting the same climate/landform combination enhances the description either by reinforcing it or by defining the range of variation within the vegetation complex.

Whereas in System 6 (Heddle et al. 1980) the vegetation complexes were described in terms of the component site-vegetation types, in this thesis the vegetation is described in terms of the component species, that is, the dominant and subdominant trees and characteristic (indicator) or common species of the understorey. The reason for this is that in this project the level of knowledge across all the various underlying landform maps and vegetation classifications is uneven and diverse, and for many of the complexes there is no previous classification to refer to. Whereas vegetation complexes were the highest level of hierarchy in System 6, in this project the
vegetation complexes are ultimately agglomerated into ecological vegetation systems. They are therefore viewed here more as the stepping stones rather than terminals. At the level of the vegetation complex, the observation is made, and at the same time the hypothesis is stated, that for a given combination of climate and landform a certain set of species is likely to occur. The next step in the process is the examination of the vegetation complexes to see which of the vegetation complexes are sufficiently similar to warrant agglomeration into ecological vegetation systems. It is at this more general level of ecological vegetation systems that the various underlying classification units (types, communities, groups) are brought in, if available.

3.4.2.2 Description by Map Legend

Description by map legend is the most concise form of description, as space is at a premium. It is an attempt to summarize the essence of a map category, in this case a vegetation complex, characteristic of a given combination of landform and climate, in a few short lines.

The definition of the mapping units and hence the compilation of the map legend was based on the toposequences illustrating the vegetation/climate/geomorphology combinations. It needs to be realized that at each stage of the process of developing a higher and more complex, yet at the same time more concise concept, such as the fusing of the landform, climate and vegetation information into a toposequence depicting a vegetation complex, there is an inevitable loss of information. This is heightened when a full description of the resulting categories is condensed into a map legend. The risk entailed in that is that the loss of information may be so high as to
make the condensed description too brief and too general and hence open to criticism of imprecision and vagueness. The study of the map therefore needs to be done with this process in view, that is by augmenting the reading of the map legend by the reading of the accompanying text, and if necessary, going back to the underlying level of mapping and description. In the case of the vegetation complex this means going back to the toposequences, and perhaps even back to the underlying landform maps and vegetation classifications.

The legend describing all vegetation complexes described for the Jarrah and Warren bioregions is printed on the maps of the vegetation complexes. An example of a legend item corresponding to Figure 3.9 is given below:

Valley floors and Swamps

Nooning (No)
Mosaic of low open forest of *Casuarina obesa* and open scrub of *Casuarina obesa* - *Acacia* spp. - *Melaleuca* spp. and woodland of *Eucalyptus rudis* - *Melaleuca rhaphiophylla* on major valley systems in the perarid zone.

Valleys

Bindoon (Bi)
Woodland of *Eucalyptus loxophleba* on the slopes, flanked by woodlands of *Eucalyptus wandoo* - *Eucalyptus accedens* on the breakaways and upper slopes in the perarid zone.
The six maps of vegetation complexes are contained in Appendix 3.4 (Mattiske and Havel 1998a,b,c,d,e,f).

\section*{3.5 Agglomeration of Vegetation Complexes into Ecological Vegetation Systems and Their Description}

\subsection*{3.5.1 Definition of the Mapping Units}

The principle of near-equivalence was used in the agglomeration of vegetation complexes into vegetation systems. The definition of the vegetation systems was largely a desktop exercise, as the components of a vegetation system may be scattered over tens of kilometres. Essentially it consisted of a search for similarities between vegetation complexes, and evaluation of these similarities so that a decision could be made whether or not to merge two or more complexes into a ecological vegetation system. The initial search was done on the basis of toposquences, which provide a combined pictorial and textual description of the vegetation complexes. The search was guided by the description of the underlying factors of the physical environment, as the most likely mergeable components are those that share a similar combination of landform and climate. This can be looked upon as the deductive component of the process. The final decision to merge was, however, done on the basis of the structural and floristic features of the vegetation, because what ultimately counts is whether there is sufficient similarity in vegetation to justify the merger. This can be considered the inductive component of the process.
On the whole, the two processes did not lead to divergent conclusions. It was, however, found that if the accent was too much on the underlying physical factors of the environment, the agglomeration proceeded too rapidly and resulted in categories that were too broad and too heterogeneous in terms of vegetation. If the initial accent was too much on vegetation, the process became too laborious and too slow. This is because the differences between vegetation complexes amount to subtle variations in structure and floristic composition. The comparison of floristic composition requires the consideration of a relatively large number of component species. Consequently, after the initial trials the two processes were used jointly.

A further complicating factor arose out of the characteristic of vegetation complexes already discussed, namely that they tend to be continua rather than narrowly defined entities. Whereas it is relatively easy to agglomerate several vegetation complexes into an ecological vegetation system, it is difficult to reverse the agglomeration process if it has gone too far. Ultimately, a cautious approach was adopted. It may be that some vegetation systems that occupy only small areas could have been agglomerated with larger ones, thus reducing the relatively large number of vegetation systems. Such agglomeration would have also reduced the disparity of size between the vegetation systems, some of which occupy much smaller areas than others. The potential risk of eliminating an ecosystem small in extent, but significant floristically, was considered to be too great.

Yet another difficulty encountered was the delineation of the geographic limits of some of the more common combinations of environmental and structural criteria. For
instance, the open forest of jarrah-marri occupies the bulk of the lateritic uplands in
the humid-subhumid zone of the Darling Plateau over a distance of 500 km. Yet the
composition of the understorey varies gradually but significantly. To put all of this
into one vegetation system would defeat the objective of this project. Again, the
potential risk of eliminating floristic variation was considered unacceptable. The
solution ultimately adopted is shown in Table 3.3.

<table>
<thead>
<tr>
<th>Table 3.3 Example of Agglomeration of Vegetation Complexes into Vegetation Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laterite-mantled crystalline uplands, carrying jarrah-marri forest or woodland of jarrah, wandoow and powderbark wandoow.</td>
</tr>
<tr>
<td>$\text{MTy1 + COy1 + BEy1 + CRy + BE1 + CO1 + MT1} = \text{Mp8}$ (that is, all uplands in the perhumid – hyperhumid zone of southern Darling Plateau)</td>
</tr>
<tr>
<td>$\text{BEy2 + BE2 + CO2} = \text{COp2 + COy2 + MT2 + MTp2 + MTy2 + UC3} = \text{Jp5}$ (all uplands in the humid – subhumid zone of southern Darling Plateau)</td>
</tr>
<tr>
<td>$\text{BE3 + FH1} = \text{JP3}$ (all uplands in the semiarid zone of the southern Darling Plateau)</td>
</tr>
<tr>
<td>$\text{C1 + H} = \text{Jp9}$ (all uplands in the perhumid – hyperhumid zone of the Margaret River Plateau)</td>
</tr>
<tr>
<td>$\text{C2 + M} = \text{Jp6}$ (all uplands in the humid – subhumid zone of the Margaret River Plateau)</td>
</tr>
<tr>
<td>$\text{DM1} = \text{Jp4}$ (uplands in the subhumid zone of the Blackwood River catchment)</td>
</tr>
<tr>
<td>$\text{DM2 + SD} = \text{Jp3}$ (all uplands in the semiarid zone of the Blackwood River catchment)</td>
</tr>
<tr>
<td>$\text{BO1 + Dk1 + Fa1} = \text{Jp2}$ (all uplands in the arid zone of the Blackwood River catchment)</td>
</tr>
<tr>
<td>$\text{D1 + HR} = \text{Jp6}$ (all uplands in the humid – perhumid zone of the northern Darling Plateau)</td>
</tr>
<tr>
<td>$\text{D2} = \text{Jp4}$ (uplands in the subhumid zone of the northern Darling Plateau)</td>
</tr>
<tr>
<td>$\text{D3 + D4 + MH} = \text{Jp2}$ (all uplands in the arid to semiarid zone of northern Darling Plateau)</td>
</tr>
</tbody>
</table>
Table 3.3 (Continued)

\[ Y5 = Vp2 \]
(uplands in the arid zone of northern Darling Plateau)

\[ Y6 = Vp1 \]
(uplands in the arid to perarid zone of northern Darling Plateau)

It also proved difficult to relate all of the 300+ vegetation complexes to each other simultaneously, particularly as many of them have no common boundaries with one another, and do not appear together on the toposequences.

For these reasons, several attempts at sub-regionalisation were made, some of which foundered on lack of clear-cut boundaries. The approach ultimately adopted used the two most extensive and most consistent geographic features of the southwest, namely the Darling Scarp and the Blackwood River. The four sub-regions thus are:

- **Western** - west of the Darling Scarp, including the Scott Coastal Plain, Margaret River Plateau, Blackwood Plateau and the Southern Swan Coastal Plain
- **Southern** - east of the Darling Scarp, south of the Blackwood catchment, including the Southern Coastal Plain and Hinterland, the Southern Darling Plateau and the Unicup Basin
- **Central** - Blackwood and Preston catchments east of the Darling Scarp
- **Northern** - north of the Blackwood-Preston Catchments, consisting of the northern Darling Plateau, the Collie Basin and small fragments of the Northern Coastal Plain and the Dandaragan Plateau.

The subregions are shown in Figure 3.10.
Figure 3.10 - Sub regions of the area covered by the Regional Forest Agreement used in the agglomeration process
The process of agglomeration was carried out by sub-regions, commencing at the wettest margin (coast or escarpment) and proceeding inland to the driest margin.

In the legend for the map of the Ecological Vegetation Systems, the Western and Southern sub-regions, which both contain karri forests, coastal dunes and coastal swamps and plains, were dealt with jointly for economy of description. Similarly, the Central and Northern sub-regions, which consist mainly of the dissected western margin of the Darling Plateau carrying jarrah forest, were dealt with jointly.

Within the Southern and Western sub-regions the agglomeration commenced with the hyperhumid foredunes and progressed through the stable older dunes to the sub-coastal swamps and plains, inland swamps and river valleys to the slopes and uplands of the plateau, ending with the semi-arid uplands at the eastern margin of the project area. Within the Central and Northern sub-regions, which occur inland, the agglomeration commenced with the steeply sloping escarpment and major valleys at the wet western margin of the Darling Plateau, through progressively milder inland valleys to swamps in the headwaters of the streams and finally to uplands of increasing aridity, ending with semi-arid to perarid uplands on the northeastern margin of the project area. The sedimentary basins or plateaus were dealt with separately from the crystalline plateaus, from which they differ in sandy infertile soils and subdued topography.
3.5.2 Examples of the Agglomeration Process from the Southern Subregion

3.5.2.1 Coastal Vegetation Systems

Basically, the first step in agglomeration was to search for a possible match between the landform categories defined by the various surveys on which this study was based, that is, whether categories defined by different geomorphologists were sufficiently similar in terms of vegetation to warrant agglomeration. For instance, the dune systems at the southwestern margin of the project area were named Meerup east of the southern tip of the Darling Scarp by Churchward et al. (1988) and D’Entrecasteaux by Tille and Lantzke (1990) west of it. Within each dune system several subsets (landforms) were defined on the basis of degree of stabilisation and soil formation, e.g. Mu, Mc, Mr, My, Ms and Mf in the case of Meerup and D5, Dd5, DE5, Drd and Dr in the case of D’Entrecasteaux. Further to the west, north and west of the Blackwood River estuary, yet another two dune systems were described, namely Kilcarnup and Gracetown, subdivided into Kef, Kf, Kr, Ge, GE, G2, G3, Gv and Gk. Whilst the four dune systems differ in terms of geomorphology and geographical setting, the subsets (landforms) within each dune system often have less in common in terms of plant cover than they have with the corresponding subsets of the neighbouring systems. The sources available on vegetation classification and mapping, namely Smith’s (1972, 1973) and Beard’s (1981a) maps based on structural criteria, and Gibson’s (personal communication) floristic classification, do not make a clear distinction between the four dune systems. The classification of Wardell-Johnson et al. (1995) is confined to a relatively small portion of the coast near Walpole.
Churchward's (1992) landform maps straddle the Meerup and D'Entrecasteaux systems, and hence form a link between Churchward et al. (1988) and Tille and Lantzke (1990). They also have a reasonable description of the vegetation associated with the various subsets. Churchward (1992) was therefore used as the basis for linking the landforms across systems and landforms and vegetation within and across systems.

At the first level of agglomeration, vegetation complexes Mc, Mp, Mr and My within the Meerup dune system, were combined into vegetation system Py9, which stands for mixed coastal heath or low woodland of Agonis flexuosa (P-peppermint) on young but stabilised dunes (y) of the hyperhumid (9) south coast. This contrasts with the vegetation system Qu9, consisting of vegetation complex Mu, which occurs in the same dune system but differs in being a mosaic of bare sand, sometimes stabilised with Ammophila arenaria (exotic), and of mixed coastal heath (Q) on unstable dunes (u) in hyperhumid zone (9). It also contrasts with Po9, which combines Ms and Mf vegetation complexes and describes woodland of Agonis flexuosa, Eucalyptus cornuta, Eucalyptus megacarpa and Banksia attenuata or open forest of Eucalyptus marginata subsp. marginata and Corymbia calophylla with Agonis flexuosa second storey. It occurs on old (o) leached stable dunes and in swales, generally further inland than Py9, but still in the hyperhumid zone (9).

The degree of generalisation involved is best seen by comparing it with floristic classifications of Gibson (personal communication) and Wardell-Johnson et al. (1995). In terms of geographic position and description of structure, several of Gibson's community groups occur in the Py9 vegetation system, namely communities 4, 5, 7
and 9. Between them they contain many tens of species of shrubs and herbs and a few
trees, some of them shared across several communities, others specific to one
community. The common coastal species occurring in most of these communities are
*Agonis flexuosa, Acacia littorea, Olearia axillaris, Spyridium globulosum, Poa
poiformis, Leucopogon parviflorus, Rhagodia baccata, Hibberia grossulariifolia,
Lepidosperma angustatum, Loxocarya flexuosa* and *Phyllanthus calycinus*. The
differences between the groups reflect edaphic variation that occurs within the stable
younger dunes, from group 4 on skeletal limestone containing *Lepidosperma
gladiatum, Podotheca angustifolia, Poa drummondii, Austrostipa flavescens,
Thomasia triphylla, Olax phyllanthes* and *Melaleuca acerosa* through community
group 7 on deeper sands containing *Hibbertia cuneiformis, Hardenbergia
comptoniana, Tetrarrhena laevis* and *Macrozamia riedlei* to community group 9
containing *Jacksonia horrida, Lobelia tenuior, Levenhookia pusilla, Waitzia citrina,
Brachysema praemorsum, Amperea ericoides, Xanthosia huegelli* and *Sollya
heterophylla*. Similarly, this vegetation system corresponds to the Wardell-Johnson *et
al.* (1995) community groups 14 to 17, containing a smaller (30-40) group of species
of high constancy, including *Agonis flexuosa, Sollya heterophylla, Leucopogon
parviflorus, Hibbertia cuneiformis, Hibbertia grossulariifolia, Lobelia tenuior,
Lepidosperma squamatum, Waitzia citrina, Olearia axillaris, Spyridium globulosum*
and *Acacia littorea*.

At the second level of agglomeration, carried out by colour and legend of the map,
Py9 was grouped, but not merged with Py8 of the D’Entrecasteaux dune system and
Py7 of the Kilcarnup and Gracetown dune systems on the basis that they all carry
mixed coastal heath and low woodland of *Agonis flexuosa* on young but stabilised
dunes. The numerical affixes reflect the climatic zone, namely perhumid (7), broadly perhumid (8) and hyperhumid (9).

3.5.2.2 Inland Vegetation Systems

There appears to be no clearcut division, from the point of view of geomorphology or vegetation, between some of the southern valley landforms described by the various authors. The vegetation at the extremes is distinct, e.g. the presence of the tinges in the southeast near Walpole only. The vegetation complexes Vh2 and Vh3 north of Northcliffe, based on the V2 and V3 landforms of Churchward et al. (1988) have, in terms of overstorey, more in common with the Warren and Lefroy vegetation complexes based on Churchward (1992), to the north and west of them, than with the vegetation complexes Vh2 and Vh3 near Walpole. For this reason, the four vegetation complexes were agglomerated on the basis that they all carry tall open forest of *Eucalyptus diversicolor* - *Corymbia calophylla* on moderate to steep slopes with red earths and red duplex soils in perhumid-hyperhumid climate. They also have a similar second storey of *Allocasuarina decussata* and *Agonis flexuosa* and similar understorey vegetation of *Trymalium floribundum*, *Chorilaena quercifolium*, *Tremandra stelligera*, *Hovea elliptica*, *Bossiaea aquifolium* subsp. *laidlawiana*, *Lasiopetalum floribundum*, *Clematis pubescens*, *Chorizema diversifolium*, *Pteridium esculentum* and *Opearcularia volubilis*. The Walpole occurrences of the Vh2 and Vh3 complexes also have *Eucalyptus jacksonii* and *Eucalyptus guilfoylei* as associates. The Donnelly vegetation complex, which is restricted to a steeply dissected valley close to the western margin of the Darling Plateau, and the V1 complex restricted to steep valleys in the south coast hinterland, were also added to this vegetation system.
In the inland of the Southern sub-region vegetation classifications of Strelein (1988) and Wardell-Johnson et al. (1995) were utilised in interpreting the landform mapping of Churchward et al. (1988) in the southeast, Churchward (1992) in the west and Stewart-Street & Smolinski\(^2\) (personal communication) in the northeast. The classification of Inions et al. (1990b) was only relevant for the more humid south and west and the classification of Christensen (1980) was only relevant for the drier centre and east. Whilst there was some degree of overlap between the vegetation classifications in the southwest and centre, none of the classifications adequately covered the northeast, and the fieldwork done there was consequently at a higher level of intensity to compensate for this deficiency.

3.5.3 Agglomeration in the Western, Central and Northern Subregions

In the Western sub-region the aim was to bring together similar vegetation complexes based on the Mc Cutcheon (1980) classification of the northern Blackwood Plateau, on Gibson’s (personal communication) classification of the western and southern coasts and adjacent coastal plains, on Gibson et al.’s (1994) classification of the southern Swan Coastal Plain and its transition to the Blackwood Plateau and on Mattiske Consulting Pty Ltd’s (1996) surveys of parts of the Scott Coastal plain. The main deficiency was the lack of vegetation classification for the ecologically very diverse Margaret River Plateau, and consequently the fieldwork was more concentrated there, hindered by high level of land alienation and conversion to agriculture.

\(^2\) Agriculture WA, South Perth.
This was compensated for, to a degree, by Griffin’s (1995) surveys of remnant vegetation on private land. The Margaret River Plateau proved, in ecological terms, to be a miniature outlier of the western margin of the southern Darling Plateau, having forests dominated by both jarrah and karri. In the agglomeration process, the vegetation systems of the Margaret River Plateau were grouped with, but not merged with vegetation systems of the southern Darling Plateau.

In the Central sub-region, no previous quantitative vegetation classification could be referred to, though it was known from earlier mapping of System 6 (Heddle et al. 1980) which covered part of the sub-region, that it is largely an extension of the Northern sub-region. However, it has a higher degree of dissection and hence a higher proportion of fertile soils. It is also much more highly disturbed by agriculture, and it proved difficult to find undisturbed examples of adequate size for many of the landforms which are attractive to agriculture because of their higher soil fertility. Havel’s (1975a) classification from the north of the sub-region and Strelein’s (1988) classification from south of the sub-region were therefore utilised and supplemented by intensive field sampling of residual vegetation. This was further supplemented by Griffin’s (1995) surveys of remnant vegetation on private land. Because of the wide climatic range and great fragmentation of the sub-region, a higher number of vegetation systems per unit area was retained than in the neighbouring sub-regions.

In the Northern sub-region, less agglomeration was carried out than in the other three sub-regions. The primary reason for this is that this region was the first to be mapped in terms of landforms, at a coarser level than the other sub-regions (Mulcahy et al. 1972; McArthur et al. 1977; Churchward and McArthur 1980). Consequently, the
landforms and the vegetation complexes based on them are broader in concept and
more extensive in area than in the later surveys. Although more detailed landform
mapping was subsequently carried out on the north western (King and Wells 1990)
and north eastern (Lantzke and Fulton 1992) periphery, it did not cover the entire
northern sub-region and it was not possible to use it in the mapping of the vegetation
for the sub-region as a whole. Secondly, in the earlier mapping of Heddle et al.
(1980) a great deal of on-the-ground reconnaissance was carried out in the northern
sub-region, which could not be matched in the present round of mapping, particularly
as the focus was on the central, southern and western sub-regions which lacked earlier
maps. The tendency has therefore been toward minimal modification of the mapping
of Heddle et al. (1980). However, much fieldwork was carried out in the eastern
margin of the sub-region not covered by earlier mapping, and the detailed vegetation
classification in the extreme north of the sub-region by Griffin (1992) was utilised.

The vegetation systems of the Northern sub-region tend to be more extensive in terms
of area/system, and less precisely defined than those of the other three sub-regions.
On the positive side, much greater proportion of the Northern sub-region is covered
by detailed vegetation mapping at the level of site-vegetation type of Havel (1975a,b),
carried out in conjunction with research, reserve establishment, disease control,
moving and water resource development (Mattiske, E.M. and Associates 1991;
Worsley Alumina Pty Ltd 1999; Havel Land Consultants 1987; Shearer et al. 1987).
Some of this is now historical information, as the natural vegetation was subsequently
eliminated by surface mining or flooding or significantly altered by the impact of
dieback disease.
3.5.4 Description of Ecological Vegetation Systems

The nomenclature of the ecological vegetation systems is based on alpha numeric combination (two letters, one number) based on the minimal description of tree stratum, generalised description of landform and numerical zonation of the climate, for example:

Ds0 stands for D woodland of Allocasuarina huegeliana
    s on strongly dissected crystalline slopes
    0 in perarid zone.

The classifiers are listed in Table 3.4.

The most concise form of description is the legend incorporated into the map of vegetation systems (Appendix 3.5) (Havel and Mattiske 1998).

The understorey is briefly covered in the mid-length legend (Appendix 3.6).

The full description of all component species, derived from the original vegetation studies (where available) is only available in draft form and is not included in this thesis. It is too lengthy (up to 3 pages per vegetation system) and requires further taxonomic checks. An example is given in Appendix 3.7.
Table 3.4: Nomenclatural Code for Ecological Vegetation Systems (EvS)

**Composition of Overstorey**

<table>
<thead>
<tr>
<th>Code</th>
<th>Species/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td><em>Banksia attenuata</em> low woodland</td>
</tr>
<tr>
<td>B</td>
<td><em>Banksia ilicifolia</em> low woodland</td>
</tr>
<tr>
<td>C</td>
<td><em>Casuarina obesa</em> woodland or thicket</td>
</tr>
<tr>
<td>D</td>
<td><em>Allocasuarina huegeliana</em> woodland or low forest</td>
</tr>
<tr>
<td>E</td>
<td>Flooded gum (<em>Eucalyptus rudis</em>) with <em>Casuarina obesa</em></td>
</tr>
<tr>
<td>F</td>
<td>Flooded gum (<em>Eucalyptus rudis</em>) with <em>yarri (Eucalyptus patens)</em></td>
</tr>
<tr>
<td>G</td>
<td><em>Melaleuca preissiana</em> - <em>Banksia littoralis</em> woodland</td>
</tr>
<tr>
<td>H</td>
<td>Bullicher (<em>Eucalyptus megacarpa</em>) woodland or forest</td>
</tr>
<tr>
<td>I, J</td>
<td><em>Jarrah (Eucalyptus marginata)</em> woodland or open forest</td>
</tr>
<tr>
<td>K</td>
<td><em>Karri (Eucalyptus diversicolor)</em> tall open forest</td>
</tr>
<tr>
<td>M</td>
<td><em>Marri (Corymbia calophylla)</em> tall open forest</td>
</tr>
<tr>
<td>N</td>
<td><em>Marri (Corymbia calophylla) - yarri (Eucalyptus patens)</em> open forest</td>
</tr>
<tr>
<td>P</td>
<td>Peppermint (<em>Agonis flexuosa</em>) woodland</td>
</tr>
<tr>
<td>Q</td>
<td>Coastal complex of shrublands</td>
</tr>
<tr>
<td>R</td>
<td>Rocky outcrop with herland and shrubland</td>
</tr>
<tr>
<td>S</td>
<td>Swampy shrub and sedgeland</td>
</tr>
<tr>
<td>T</td>
<td><em>Tingles (Eucalyptus jacksonii, E. guilfoylei)</em> tall open forest with <em>karri (Eucalyptus diversicolor)</em> and <em>marri (Corymbia calophylla)</em></td>
</tr>
<tr>
<td>V</td>
<td>Powderbark wandoo (<em>Eucalyptus accedens</em>) woodland</td>
</tr>
<tr>
<td>W</td>
<td>Wandoo (<em>Eucalyptus wandoo</em>) woodland</td>
</tr>
<tr>
<td>Y</td>
<td>Flat-topped yate (<em>Eucalyptus occidentalis</em>) woodland</td>
</tr>
<tr>
<td>Z</td>
<td><em>Melaleuca cuticularis</em> low woodland</td>
</tr>
</tbody>
</table>

**Landforms**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Crystalline hills</td>
<td>0</td>
</tr>
<tr>
<td>p</td>
<td>Crystalline plateau uplands</td>
<td>1</td>
</tr>
<tr>
<td>g</td>
<td>Sedimentary plateau uplands</td>
<td>2</td>
</tr>
<tr>
<td>s</td>
<td>Strongly dissected crystalline slopes</td>
<td>3</td>
</tr>
<tr>
<td>m</td>
<td>Moderately dissected crystalline slopes</td>
<td>4</td>
</tr>
<tr>
<td>n</td>
<td>Moderately dissected sedimentary slopes</td>
<td>5</td>
</tr>
<tr>
<td>l</td>
<td>Mildly dissected crystalline slopes</td>
<td>6</td>
</tr>
<tr>
<td>k</td>
<td>Mildly dissected sedimentary slopes</td>
<td>7</td>
</tr>
<tr>
<td>w</td>
<td>Waterlogged coarse textured deposit</td>
<td>8</td>
</tr>
<tr>
<td>v</td>
<td>Waterlogged fine textured deposit</td>
<td>9</td>
</tr>
<tr>
<td>u</td>
<td>Unstable coastal dune</td>
<td></td>
</tr>
<tr>
<td>y</td>
<td>Young stable coastal dune</td>
<td></td>
</tr>
<tr>
<td>o</td>
<td>Old stable coastal dune</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>Loamy well drained deposit</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>Sandy well drained deposit</td>
<td></td>
</tr>
</tbody>
</table>

As p, m and n are dominant landforms, capital as well as lower case letters had to be used to accommodate the full range of combinations.
3.5.5 Relation of Vegetation Complexes and Ecological Vegetation Systems to other Mapping Units.

It is appropriate to consider how the maps generated by this process relate to other forms and scales of mapping available for south western Australia.

In Beard's (1990) coverage of vegetation of Western Australia as a whole at 1:10,000,000, the area covered by these maps falls into the South West Botanical Province and into three primary vegetation types:

a. Tall forest - Karri
b. Forest - Jarrah
c. Eucalypt woodlands - Tuart, marri, wandoo

A comparable level of detail, but at a larger format, is contained in the 1:3,000,000 map of vegetation of Western Australia (Beard 1981b). It is the most detailed map, of the vegetation of the state as a whole, that has been published so far.

The next layer of higher detail is only available for portions of the state, such as the Swan Area which covers the south west of the state (Beard 1981a). It is a part of the 1:1,000,000 series. Even at this scale the forested areas of the south west fall into three main categories (plant formations):

a. Tall forest with karri as the primary species
b. Forest with jarrah and marri as the primary species
c. Woodland with marri and wandoo as the primary species.
However, the map also includes a number of minor plant formations:

d. Woodland of powderbark wandoo and wandoo

e. Woodland of wandoo and *Eucalyptus loxophleba*

f. Woodland of wandoo and *Eucalyptus occidentalis*

g. Woodland of jarrah and *Allocasuarina fraseriana*.

Most of these occur along the eastern periphery, in climatically marginal (arid to perarid) zones. Other minor plant formations described by Beard from the south west forest region are:

h. Low forest of jarrah

i. Low woodland of peppermint

j. Low woodland of *Melaleuca* spp.

k. Low woodland of jarrah and *Banksia* spp.

l. Thickets of *Acacia* spp.

m. Heath

n. Reed swamp.

These occur primarily on edaphically marginal landforms along the south coast, such as coastal dunes, swamps and poorly drained flats.

The map of forest associations of the south west of Western Australia by Bradshaw *et al.* (1997) uses comparable criteria (structure and dominance of the overstorey). Because it utilises a considerable amount of ground surveys in addition to photo interpretation, it is more precise in the delineation of map polygons and their characterisation than Beard (1981a). However, in common with other maps based on
structure and composition of the overstorey, it places the bulk of the publicly owned land into one category of jarrah - marri forest (1,571,000 ha out of 2,628,000 ha mapped). However, it also gives 21 other associations, some of which are dominated by other species such as wandoo forest and woodland, karri forest, bullich and yate (Eucalyptus megacarpa and Eucalyptus cornuta) woodland, banksia woodland, peppermint and coastal heathlands. There are also other structural formations such as shrublands and sedgelands, and vegetational mosaics of extreme sites such as rock outcrops, swamps and sand dunes.

The map also defines mixtures of jarrah and karri with the tingles (Eucalyptus jacksonii, Eucalyptus guilfoylei and Eucalyptus brevistylis) and mixtures of karri with marri and jarrah. The definition of wandoo associations is loose, incorporating Eucalyptus laeliae in addition to wandoo and powderbark. Eucalyptus patens (referred to as blackbutt rather than yarri) stands are incorporated into jarrah - marri forest and jarrah - marri open woodland.

The map of Havel and Mattiske (1998) at 1:500,000 and the maps of Mattiske and Havel (1998a,b,c,d,e,f) at 1:250,000 are comparable to the maps of Bradshaw et al. (1997) in scale, but differ radically in concept.

There are no maps of the south western forests as a whole at finer scale than 1:250,000. However, there are localised maps at markedly finer scales of 1:83,000 to 1:10,000, which utilise Havel's (1975a) site-vegetation types (Havel 1975b; Bettenay et al. 1980, Mattiske, E.M. and Associates 1979-1994, Mattiske Consulting Pty Ltd
1994-2000 and Worsley Alumina Pty Ltd 1999). Most of the categories in the above
maps approach floristic homogeneity.

The increase in detail in progress from the plant formations of Beard (1981a) at
1:1,000,000, through the vegetation systems of Havel and Mattiske (1998) at
1:500,000 and the forest associations of Bradshaw et al. (1997) at 1:250,000 to the
site-vegetation types of Havel (1975b) at 1:83,000 and 1:50,000 can be demonstrated
by reference to the test survey areas surveyed by Havel (1975b) in the northern jarrah
forest (Table 3.5). The test areas are described in Appendix 1.2.

Table 3.5 : Comparison of Map Scales

<table>
<thead>
<tr>
<th>Test Area</th>
<th>Number of Map Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beard</td>
</tr>
<tr>
<td>Name</td>
<td>1:1,000,000</td>
</tr>
<tr>
<td>Ashendon</td>
<td>1946</td>
</tr>
<tr>
<td>Cooke</td>
<td>2234</td>
</tr>
<tr>
<td>Leona</td>
<td>2789</td>
</tr>
<tr>
<td>Flint</td>
<td>1823</td>
</tr>
</tbody>
</table>

Along the southern coast, the ratios between the maps of Beard and the other map
compilers would decrease because of the greater structural diversity of vegetation.
However, the vegetation maps at scales finer than 1:250,000 are lacking and
quantitative comparison is not possible.

3.6 Conclusions

The compilation of the maps and the supporting legends, descriptions and illustrations
brings the process of integrating the various vegetation classifications and landform
and climate maps into one ecological map of the entire forested area of south western
Australia to conclusion. Because the information sources are so diverse, the process was unavoidably complex, cumbersome and subjective.

The resulting six maps of vegetation complexes (Appendix 3.4), and one overall map of ecological vegetation systems (Appendix 3.5), match the definition for an ecological map, in that they combine vegetation and the underlying environmental factors. They are somewhat unique in that they are essentially maps of continua. At the highest level, the broad patterns are determined by climatic zones, which range from hyperhumid on the south coast to perarid inland north east. This continuum is broadly expressed in a range of colours from blue and mauve through green and yellow to red. Although the individual vegetation complexes are discrete polygons on the map, together they represent several continua, such as that from steep slopes with shallow loamy soils (He2) to near level swampy depressions (Swd). This continuum is broadly expressed in intensity of colouring, in that steep slopes are dark coloured and level depressions light coloured.

The map of the vegetation systems is the first overview of the south western forests (Jarrah and Warren bioregions) that combines structure and floristics of the vegetation with the underlying environmental factors.

The process whereby the maps were developed, that is through a “bottom-up” approach of inductive agglomeration, differs from the usual “top-down” approach of deductive definition of map categories through division of the whole into hierarchically arranged sub-units.
The success of the project needs to be tested through assessing how accurately the maps predict the floristic composition of vegetation in the field. This is attempted in Chapter 4 by comparing the predicted composition of the map categories with the records of FloraBase of the Western Australian Herbarium.
Chapter 4: Validation of the Maps Against Floristic Data

4.1 Introduction – Need For Validation

Although the maps discussed in the previous chapter were, as far as possible, based on quantitative studies of the floristic composition of plant communities, the compilation of the maps unavoidably involved a considerable amount of subjective judgement. It was necessary to match the climate and landform combinations with vegetation categories (types, communities or site groups). Only in one case was the classification previously taken to a mapping stage and the predictive capacity of the maps tested quantitatively (Havel 1975b). In all other cases, it was necessary to link the vegetation categories with the landform maps subjectively, using the information provided by the ecologists on the location of the vegetation categories within the landscape and that provided by the geomorphologists on the vegetative cover of the landforms. It is therefore desirable to assess the capacity of the maps to predict the composition of the vegetation representative of individual map polygons.

4.2 Availability of Databases

There are basically three main sources of information against which the maps could be validated. These are FloraBase (Western Australian Herbarium 1999), Banksia Atlas
(Taylor and Hopper 1991) and Flora of the Perth Region (Marchant et al. 1987). Their nature and their likely use in the validation process will now be discussed.

4.2.1 FloraBase

FloraBase is essentially a plant specimen database linked to a geographic reference system. It has been developed by the Western Australian Herbarium, which is its custodian. It covers all vouchered specimens held by the Herbarium and is regularly updated as new collections are added and as the taxa are revised, both of which are on-going processes. The vouchered specimens currently number approximately half a million. Given the large size of Western Australia (2,225,000 km²), this amounts to only to 0.2 specimens /km² (Gioia¹, personal communications). The disparity between the need and the capacity is accentuated by the fact that Western Australia is floristically quite rich. For instance, the area of 42,000 km² covered by this study contains in excess of 3,000 species (RFA 1998a). Many past ecological studies have not adequately budgeted for the processing of the botanical specimens that they generated and consequently these have not been incorporated into the Herbarium or the FloraBase records (Gioia, personal communications). However, most of the recent studies covered by this thesis are well represented.

Many of the families and genera represented in the database either are in the process of, or in need of taxonomic revision, so that the taxonomic correctness of all FloraBase records cannot be guaranteed (Gioia, personal communications; Gibson²,

¹ Department of Conservation and Land Management WA, Herbarium WA, Kensington
² Department of Conservation and Land Management WA, Woodvale
personal communications). The outcomes of some recent taxonomic revisions have not flowed through to the entire collection, so that original taxa are still present alongside new subspecific taxa, such as *Eucalyptus rudis* alongside *Eucalyptus rudis* subsp. *rudis* and *Eucalyptus rudis* subsp. *cratyantha*.

The representativeness and the accuracy of the FloraBase records are determined by the collections on which the database is based. Because FloraBase is the repository of what botanical collectors have chosen to submit to the Herbarium, it reflects the biases of the individual collectors, such as oversampling of favoured or readily accessible sites and inadequate sampling of less accessible sites (Gioia, personal communications). As will be seen in subsequent discussions, some of the more extensive and more accessible vegetation complexes such as D1 and D2 of the mildly undulating uplands close to the capital have as many as 29 entries for the common shrub species. The more distant and less accessible complexes such as DO of a deeply incised valley 400 km from the capital had, until very recently, no entries.

Another limitation, not recognised until the validation process was initiated, is that on the whole the level of collection for the trees is much lower, often only a third of that for associated understorey shrub species. This can be probably attributed to greater effort needed to obtain flowering or fruiting specimens of trees as compared with shrubs, but also to the assumption that the tree species, which are fewer, are better known than the numerous shrub species. This is not always justified, as many of the current tree taxa were not known 35 years ago when the detailed ecological studies commenced.
The precision of geographic referencing is influenced by the facilities available to, and the effort made by, individual collectors. The descriptions of sites range from vague comments about a district, a range or a catchment in the case of some of the early collectors, to relatively precise definition utilising satellite technology in the case of the more recent collectors.

The data within FloraBase have been enhanced by combining them with vegetation complex and vegetation system data using a Geographic Information System. The combined data were then analysed within a statistical package to generate two-way tables showing the number counts of species within each ecological category (Gioia, personal communications). Despite the limitations described above, FloraBase is a by far the best criterion against which the maps can be validated, in that it covers all taxa and assigns them geographical references.

4.2.2 Banksia Atlas

The Banksia Atlas is more narrowly focused, in that it deals with just one genus – *Banksia*. However, it is not tied to vouchered specimens in the herbarium, so that there are many more entries against individual species. It also appears to have a stronger ecological orientation than FloraBase and the geographic referencing seems to be sounder because it is more recent, and hence more accurate. It is not entirely free of bias, in that certain vegetation complexes that are geographically not extensive, such as the Blackwood well drained alluvial flats (B), nevertheless have a higher number of entries of the common species *Banksia grandis* against them than the very
extensive lateritic uplands of the northern jarrah forest (D1 and D2), which are the ecological heartland of the species. The data within the Banksia Atlas were also related to ecological categories.

4.2.3 Outputs from FloraBase and the Banksia Atlas Database

The format of the most basic output from the data bases is a line giving the identification of the taxon, the code of the vegetation complex as used on the map, its number and its name and the name of the vegetation system of which the complex is a component, for example:

_Banksia attenuata_ A 71 Angove Bw8

which means that _Banksia attenuata_ is recorded once for vegetation complex A numbered 71 (Angove) and that this corresponds to vegetation system Bw8 (banksia woodland on swampy sites with coarse textured soils in perhumid zone).

Similarly,

_Banksia grandis_ B 97 Blackwood Mk8

describes a single occurrence of _Banksia grandis_ in vegetation complex B numbered 97 (Blackwood), corresponding to marri open forest on well drained, fine textured deposit in perhumid zone.

The above examples are from the Banksia Atlas database. The same output can be obtained from FloraBase, but a more structured output in a tabular form has also been
made available from this database. It gives the generic and specific name and number of occurrences of that species for a set of vegetation complexes, as for example:

<table>
<thead>
<tr>
<th></th>
<th>FH2</th>
<th>Sd</th>
<th>PM1</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banksia attenuata</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Banksia grandis</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Banksia littoralis</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Banksia seminuda</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>

This means that *Banksia attenuata* occurs three times in this bracket of vegetation complexes from the south coast and hinterland, namely twice in complex Sd (Scott sandy) and once in complex A (Angove)

After the full enumeration of the banksia species, the total number of records of all banksia species on the four vegetation complexes is given:

<table>
<thead>
<tr>
<th></th>
<th>FH2</th>
<th>Sd</th>
<th>PM1</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column Totals</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>22</td>
</tr>
</tbody>
</table>

This indicates that complexes FH2 (Frankland Hills 2) and PM1 (Pemberton 1) are inadequately covered and that the coverage for complex Sd (Scott sandy) may be just satisfactory. Vegetation complex A (Angove) appears to be amply covered by past collections. However, it may merely mean that there is a bias, with *Banksia seminuda* having been heavily collected for taxonomic studies, as its name has been changed twice in relatively recent times, from *Banksia littoralis* through *Banksia littoralis* subsp. *seminuda* to *Banksia seminuda*. In early forestry reports it was erroneously referred to as *Banksia verticillata*. 
The example illustrates the difficulties of vegetation mapping in a region under active taxonomic research, as it would be impossible to determine whether *Banksia littoralis* described from the region in an ecological study thirty years ago was in fact *Banksia littoralis* or *Banksia seminuda*, as the ranges of the two species overlap.

In addition to the printed output described above, it is also possible to question FloraBase for details about individual taxa. Two kinds of information are relevant to this study:

Firstly, the distribution map for the taxon, which is particularly useful for assessing the influence of broadscale factors such as climate and geology. The distribution maps are only broad, so that it is not possible to assess finer climatic differences, such as between humid and subhumid zones, but it is possible to assess whether the taxon primarily occurs in the perhumid-hyperhumid zone, in the humid-subhumid zone, in the semiarid to perarid zone, or whether it is largely independent of climatic factors within the range of this study. Distribution maps are not precise enough to assess finer scale information such as landform.

Secondly, it is possible to view the information submitted with individual specimens of the taxon, and to compare it with that obtained from the broad questioning of FloraBase with respect of the taxon as a whole. Many entries carry no ecological information, whereas others give considerable detail of the ecological setting such as topographical position, soils and associated species. Such information makes it
possible to check seemingly anomalous records at the finer scale of landforms. Examples of both options will be given in discussion of individual tree species.

4.2.4 Additional Sources

**Flora of the Perth Region**  (Marchant *et al.* 1987)

This not a data base but a Flora, in that it does not give quantitative geographic referencing. It covers only the northern quarter of the RFA project area (Figure 1.1). It does, however, provide, in addition to its main focus on taxonomy, notes on the geographic distribution and ecological setting.

*Banksia attenuata*  -  *Occurs in sandy woodlands on the Coastal Plain. Extends from Murchison River to Bremer Bay.*

*Banksia grandis*  -  *Occurs in sand on the Coastal Plain and on laterite on the Darling Scarp and Range, in both areas usually associated with Jarrah.*

*Banksia seminuda*  -  *In the Perth Region known only from Dwellingup, occurring along a watercourse in Jarrah forest on the Darling Range. Extends to the south coast and Albany, associated with watercourses and, less frequently, with other wetlands.*

The Flora of the Perth Region cannot be used directly for the validation process, but it can be used as a second reference in those cases where the FloraBase records appear
to be at odds with known ecological setting of a species, such as when a swamp or riparian species is recorded from well-drained plateau uplands. This is the case with both Banksia littoralis in the D2 complex and Banksia seminuda in the D1 complex. D1 and D2 are upland complexes. It suggests a drift in geographic referencing, as Banksia seminuda referred to in the Flora of the Perth Region occurs in the Yg1 vegetation complex of the valleys.

Eucalypt Field Guides

For eucalypts (Eucalyptus, Corymbia) additional ecological information is also available from the field guide series of Brooker and Kleinig (1990). The series gives both distribution maps and notes on ecology for individual taxa.

4.3 Availability of Map Criteria

4.3.1 Map Legends

There are several map criteria that could be used for the comparison of the maps with other sources. The legend on the map itself is the logical candidate. However, map legends have to fit into a limited space, and are concise in the extreme, generally only giving a brief description of the environmental setting, the structure of the vegetation and floristic description of the dominant stratum and the second storey such as:
HI6 Valleys mildly incised into the northern and central Darling Plateau in the humid-subhumid zone, with woodland of *Eucalyptus megacarpa*, *Eucalyptus patens* and *Banksia littoralis* on the valley floor to open forest of *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla* with a second storey of *Banksia grandis*, *Persoonia longifolia* and *Allocasuarina fraseriana* on the slopes.

There is a limited scope for describing the floristic composition of the understorey, in which the bulk of the variation resides, and for which the FloraBase record is better than for the overstorey. These condensed legends have been derived by a process of reduction, from a set of toposequences in the case of the vegetation complexes, and from a set of vegetation complexes in the case of vegetation systems. In the case of the vegetation complexes the fullest description is given by the sum total of the toposequences covering the particular complex. It suffers from the limitation that the toposequences are, in themselves, reductions of the full information, in order to fit the format.

### 4.3.2 Full Description of Vegetation Systems

In the case of vegetation systems, the loss of information resulting from the condensation could be offset by incorporating into the description the information developed for that particular combination of landform and climate by earlier ecological studies. In the case of ecological systems that have been subject to a number of ecological studies, such as Bw8 (Strelein 1988; Wardle-Johnson *et al.*
1989; Wardle-Johnson et al. 1995; Gibson, personal communication), this amounts to two or more pages and many tens of species, which is to be expected given the floristic richness of south western Australia.

An example of a full description of a vegetation system is given in Appendix 3.7. Such descriptions are too bulky for publication, too unwieldy for comparison, and require more scrutiny than has been possible to give them.

4.3.3 Criterion Chosen

The intermediate stage of condensation, in which the description of individual systems is reduced to a paragraph, has been chosen as the best compromise. It represents the stage of the legend at the time of the printing of the map in 1998, except for subsequent minor taxonomic and typographic corrections. It incorporates a limited number of understorey species, judged at the time to give the most economic floristic description of the vegetation system. It will be referred to as the mid-length map legend.

An example of a single item, describing the same vegetation system as used in the example of a full description above, is given below:

NM6 Component vegetation complex, *MyI*.

Major valleys moderately incised into the humid zone of the northern Darling Plateau, with red brown earths and red and yellow duplex soils. Vegetation
ranges from Woodland of *Eucalyptus patens* over *Banksia seminuda*, *Callistachys lanceolata* and *Agonis flexuosa* on valley floor to Open Forest of *Corymbia calophylla* and *Eucalyptus marginata* subsp. *marginata* with second storey of *Banksia grandis* and *Persoonia longifolia* on slopes. Shrub and herb storey of *Grevillea diversifolia*, *Trymalium floribundum*, *Hypocalymma cordifolium*, *Lepidosperma tetraquetrum* and *Chorizema ilicifolium* on valley floor to *Bossiaea aquifolium* subsp. *aquifolium*, *Leucopogon verticillatus*, *Leucopogon capitellatus*, *Macrozamia riedlei*, *Acacia urophylla* and *Pteridium esculentum* on slopes.

A full set is contained in Appendix 3.6.

### 4.4 Methodology of Evaluation

#### 4.4.1 Statistical Evaluation

The ideal situation would be to carry out the validation by means of statistically sound methods, such as the homogeneity analysis of Bedward *et al.* (1992) and the resemblance coefficient of Belbin (1992). A quantitative multi-variate measure of homogeneity, which can be used to measure the information of maps, has been developed by Bedward *et al.* (1992). It is based on the average group association of samples. The specific questions addressed by this measure are the questions of scale and of the choice of attributes. Bedward *et al.* used it to define the coarsest acceptable scale and to quantify benefits of mapping at finer scale. They also used it to compare
maps based on various attributes with a map based on the whole flora. In this study, it is not the comparison of differing classifications, but of a map legend against two databases.

An objective method comparing two sets of community data was proposed by Belbin (1992) as a means of testing reserve adequacy. He considered a comparison of a set of new observations to an existing classification as easier than creating a new combined classification, in that the new observation may cause a significant departure from the original. In discussing the problem, Belbin pointed to a number of assumptions made when using discriminant analysis, such as those about multi-variate normality, and about linear response of species to environmental gradients, which may not be appropriate. In addition, in order that discriminant analysis may be used, there must be a predefined classification. He therefore proposed a new approach, in which a set of original observations is established as reference points as a first step, followed by definition of the level of resemblance that can be used to judge a significant difference. The final step is to test the resemblance coefficient between each new observation and all the reference points, on the basis of which each new observation is either allocated to its closest reference points, or, if the minimum difference exceeds the nominated threshold, the new observation becomes a new reference point. The implementation of this proposal was achieved by using the ALOC procedure in Belbin’s (1990a,b) PATN set of classification programs. The procedure was tested on a set of floristic data from southern coastal New South Wales. It was concluded that it provided an effective and efficient way of quantifying differences between a set of new observations and a reference set, and that it was ecologically robust, being free of
the assumptions implicit in discriminant analysis. Its use in this study is hindered by
the disparity of the data sources, and their in-built biases.

Unfortunately the advice received (Goodall, Hopper and Hobbs - all personal
communications) is that neither the data to be validated (the maps and their legends)
nor the data that could be used as the basis for the validation (the records in the
databases) meet the necessary criteria of randomness, normality and freedom from
bias.

4.4.2 Tabular Comparison

The obvious limitation of the tabular comparison are those enumerated above, namely
that they lack statistical validity and can therefore only be taken as an indication rather
than a proof of the validity of the maps. Obviously, the higher the departure from
randomness, such as an overwhelming concentration of a taxon in those vegetation
complexes of which it was predicated to be a key component, the greater confidence
that can be placed in the maps. The comparisons to be discussed fall basically into
two main categories:

a) comparison of the actual occurrence of a taxon in a set of vegetation
complexes, as recorded in the FloraBase or in the Banksia Atlas, against the
occurrence of the same taxon as predicted in the map legend, and

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3 Formerly at CSIRO Australia, Floreat WA. Now at Edith Cowan University, Joondalup Campus WA
4 Formerly at Department of Conservation and Land Management WA, Woodvale. Now at Kings Park
and Botanic Garden, Perth WA
5 Formerly at CSIRO Australia, Floreat WA. Now at Murdoch University, Murdoch Campus WA
b) comparison of the set of taxa predicted in the map legend to be associated with a particular vegetation complex or vegetation system, with the actual set of taxa recorded in the FloraBase.

4.5 Results and Discussion

4.5.1 Validation of Prediction on the Occurrence of Individual Taxa

Given that there are reservations about the accuracy and freedom from bias of not only the maps, but also of the data bases against which the validity of the maps is to be tested, the logical start is a three way comparison of the distribution patterns of Banksia species, for which information is available both from FloraBase and Banksia Atlas.

To facilitate the comparison, a tabular format has been developed which summarizes the database output. Its structure is described and illustrated in Table 4.1. Its primary purpose is to identify for each species those vegetation complexes in which it is recorded at the highest level. It also extends that to corresponding vegetation systems, of which those complexes are subsets.
### Table 4.1: Enumeration of FloraBase Records of Individual Species Against Map Categories (Vegetation Complex and Vegetation System)

#### Significance of the Columns

<table>
<thead>
<tr>
<th>Species</th>
<th>N</th>
<th>Veg. Complex</th>
<th>E</th>
<th>Veg. System</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia acuminata</em></td>
<td>18</td>
<td>Bi (9)</td>
<td>V</td>
<td>D E W V</td>
<td>rock sheoak - flooded gum - wandoo - powderbark</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wi (3)</td>
<td>L</td>
<td>s v m p</td>
<td>dissected crystalline plateau</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mi (2), Y6 (2)</td>
<td>C</td>
<td>0 2 1 1</td>
<td>arid - perarid</td>
</tr>
</tbody>
</table>

#### Column 1
Species
- Gives the current name of the taxon, that is either species or subspecies, e.g. *Acacia acuminata*.

#### Column 2
N
- Gives total number (e.g. 18) of FloraBase records of that taxon within the area covered by the maps.

#### Column 3
Veg. Complex
- Lists those vegetation complexes with highest records of the particular taxon, with number of records in bracket, e.g. Bi (Bindoon) with (9) records; Wi (Williams) with (3) records; Mi (Michibin) and Y6 (Yalanbee) with 2 records.
- No number is entered for single records.

#### Column 4
E
- Specifies the code component of the vegetation systems equivalent to the vegetation complexes with highest number of records. V - vegetation; L - landform; C - climatic zone.

#### Column 5
Veg. System
- Gives codes of the vegetation systems arranged vertically, e.g. Bi (Bindoon) is a component of Ds0 vegetation complex.
- D - *Allocasuarina huegeliana* woodland or low forest
- s - strongly dissected crystalline slopes
<table>
<thead>
<tr>
<th>Column 6</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>line 1</td>
<td>Translates the codes into verbal terms, e.g.</td>
</tr>
<tr>
<td></td>
<td>D - rock sheoak (<em>Allocasuarina huegeliana</em>) woodland</td>
</tr>
<tr>
<td></td>
<td>E - flooded gum (<em>Eucalyptus rudis</em>) woodland</td>
</tr>
<tr>
<td></td>
<td>W - wandoo (<em>Eucalyptus wando</em>) woodland</td>
</tr>
<tr>
<td></td>
<td>V - powderbark wandoo (<em>Eucalyptus accedens</em>) woodland</td>
</tr>
<tr>
<td>line 2</td>
<td>s - strongly dissected crystalline slopes</td>
</tr>
<tr>
<td></td>
<td>v - waterlogged fine textured deposit, usually on valley floors</td>
</tr>
<tr>
<td></td>
<td>m - moderately dissected crystalline slopes</td>
</tr>
<tr>
<td></td>
<td>p - crystalline plateau uplands, usually laterite mantled</td>
</tr>
<tr>
<td>line 3</td>
<td>0 - perarid</td>
</tr>
<tr>
<td></td>
<td>1 - arid</td>
</tr>
<tr>
<td></td>
<td>2 - broadly arid</td>
</tr>
</tbody>
</table>

For treeless vegetation system of extreme sites the first line describes the ecological setting and structure without specifying the dominant species, such as:

- Q - coastal scrub
- R - rocky outcrops with herblands and shrublands
- S - swampy shrubland and sedgeland
- L - Lakes and estuaries
4.5.1.1 Comparison of Map Legend, FloraBase and Banksia Atlas

The enumeration of the occurrence of the individual *Banksia* species in vegetation complexes and the corresponding vegetation systems is given in Appendices 4.1 for FloraBase and 4.2 for the Banksia Atlas. The tabular comparison of the databases with the map legend is contained in Appendix 4.3. A brief resume of these findings is:

- **For *Banksia attenuata*** there is a broad agreement that the species mainly occurs on sandy deposits, on sandy slopes of sedimentary plateaus, on old leached dunes and on sandy margins of swamps, across a wide range of climatic zones. Both databases also record a low level occurrence on laterite-mantled crystalline plateaus.

- **For *Banksia grandis*** there is an agreement on a very wide range of occurrence in association with jarrah across vegetation complexes, with the strongest development on the laterite-mantled uplands of crystalline plateaus. FloraBase also has a low level of occurrence in wandoo woodlands of the valley slopes, which are not predicted in the map legend or recorded in the Banksia Atlas. The Banksia Atlas has a high occurrence on a geographically limited loamy deposit on a coastal plain (B – Blackwood) which is not matched in FloraBase or the map legend.

- **For *Banksia ilicifolia*** there is an agreement that the species occurs mainly on moist sandy deposits on the coastal plains and on sandy margins of swamps, mainly but not exclusively in the high rainfall zones. The records of the two databases cover a wider landform range than the map legend, such as valleys and slopes of sedimentary plateaus, old dunes and even crystalline slopes in
perhumid climate. The map legend is too restrictive compared to the records of FloraBase and the Banksia Atlas. FloraBase also records the species on the shallow slopes of the Darling Scarp in the semiarid zone, which is almost certainly due to drift in geographic references from the adjacent coastal plain.

- For *Banksia littoralis* there is an agreement that it occurs mainly in swampy complexes in depressions and valley floors, irrespective of climate. In FloraBase, and to a lesser degree in the Banksia Atlas, it is also recorded from laterite mantled crystalline uplands, which is at odds with known ecological patterns. The map legend fails to cover adequately its occurrence on coastal dunes recorded in the data bases.

- The Banksia Atlas and the map legend both describe the main occurrence of *Banksia menziesii* on sandy deposits on uplands of both crystalline and sedimentary plateaus and on the coastal plain, in the arid zone. FloraBase also records it from a valley of the crystalline plateau in the humid zone, which seems likely to be a drift in geographic referencing from the nearby coastal plain, which is climatically drier and edaphically sandier.

- *Banksia prionotes* is predicted in the map legend from sandy lunettes in depressions of the Darling Plateau and from uplands of the Dandaragan sedimentary plateau. In the Banksia Atlas and in FloraBase it is recorded from sandy deposits of the Darling Plateau, in both cases from the arid zone. In FloraBase it is also recorded from laterite-mantled uplands in the subhumid zone, which is at odds with the known occurrence of the species (Marchant *et al.* 1987).
• *Banksia quercifolia* is described in the map legend as occurring on the margins of swamps in the humid to perhumid zone of the south coast and hinterland. This is too restrictive compared with the records of both FloraBase and the Banksia Atlas, which in addition record it from hill slopes, plateaus and coastal dunes in the same climatic zone.

• *Banksia seminuda* is described in the map legend as occurring mainly on floors of valleys in the humid to perhumid zone. In both FloraBase and the Banksia Atlas it is also described from uplands, upland-swamp mosaic and swamps in humid to hyperhumid zone. In addition, FloraBase also records it from coastal dunes. The map legend is too restrictive.

• *Banksia verticillata* is primarily recorded from hillsides with shallow soils in the perhumid zone of the south coast hinterland, in both the map legend and the two databases. The Banksia Atlas also records it from sandy saddles in the same zone. FloraBase also reports it from hillslopes with loamy soils, from swamps and coastal dunes in the perhumid zone and from shallow valleys and depressions in the subhumid zone. The last item appears to be an error in geographic referencing between Mt Frankland (perhumid) and Frankland Hills (subhumid).

The comparison of the mid-length map legend with the two databases can be summarised as follows: There is a general agreement between the three sources, though the predictions of the map legend tend to be narrower and focused on that combination of climate and landform on which the particular species reaches its optimum development or is ecologically most significant. In this it is supported by the
general description of the ecological setting of the species in the Flora of the Perth Region. However, there are additional records from other combinations of climate and landform for many of the species in both FloraBase and the Banksia Atlas. Some of these may be due to drift in geographic referencing, to which FloraBase appears to be more vulnerable than the Banksia Atlas. In other cases the discrepancy between the prediction and the record appears to be due to excessively narrow definition of the ecological setting for the species by the map legend. This is to be expected, as the legend attempts to define only species of significance for each combination of climate and landform, whereas the databases record all vouchered collections of any species found on any combination of climate and landform, without making any judgement about their ecological significance.

4.5.2. Comparison of Map Legend and FloraBase for Genera Other than Banksia

The validation will now be extended to those genera which are only recorded in FloraBase, such as *Acacia*, *Agonis*, *Allocasuarina*, *Casuarina*, *Corymbia*, *Eucalyptus*, *Melaleuca* and *Pepsonia*. The comparison is largely focused on those species capable of reaching small tree size, and especially on the tree species that contribute to the canopy and second storey of woodlands and forests.

The full tabular output is available in Appendices 4.4 and 4.5. Appendix 4.4 gives the quantitative record of the occurrence of the various taxa in the ecological framework of the vegetation complexes and vegetation systems. Appendix 4.5 gives a qualitative
comparison of the predictions of the mid-length map legend regarding the occurrence of the various taxa in the vegetation systems network with the actual records in FloraBase.

In summarizing this output, the focus will be on two aspects of the taxon’s distribution – its breadth and its focus: There is general agreement between the map legend and FloraBase record on the breadth of distribution of most of the taxa. For those taxa that have a narrow range of distribution confined to a small number of similar climate/landform combinations, such as Acacia acuminata, A. cyclops, A. littorea, A. microbotrya, A. pentadenia, Actinostrobus pyramidalis, Agonis juniperina, Casuarina obesa, Corymbia ficifolia, C. haematoxylon, Eucalyptus astringens subsp. astringens, E. decipiens subsp. chalara, E. drummondii, E. jacksonii, E. laeliae, E. lanepoolei, E. loxophleba subsp. loxophleba, E. marginata subsp. elegantella, E. marginata subsp. thalassica, E. staeri, E. todtiana, Callistachys lanceolata, Melaleuca cuticularis and Melaleuca rhaphiophylla, the records in FloraBase broadly match the predictions in the map legend.

The predictions about those taxa that have broad distribution patterns over a wide range of climate/landform combinations, such as Corymbia calophylla, Eucalyptus marginata subsp. marginata and Persoonia longifolia, are also broadly matched by the records for these taxa in FloraBase. The same is true of taxa that have a intermediate pattern of distribution, that is either over a considerable range of landforms within a particular climatic zone (Allocasuarina decussata, Eucalyptus wandoa, E. diversicolor, E. brevistylis, E. guilfoylei, Agonis flexuosa) or over a wide climatic
range but on a particular set of landforms (*Allocasuarina fraseriana*, *Eucalyptus rudis*, *Melaleuca preissiana*).

For the taxa with narrow ranges, there is generally also agreement on the particular narrow range of climate/landform combinations, such as fertile slopes in the arid region (*Acacia acuminata*, *A. microbotrya*, *E. loxophleba* subsp. *loxophleba*), lime-rich coastal dunes (*A. cyclops*, *A. littorea*, *Eucalyptus calcicola*), swampy depressions (*Actinostrobus pyramidalis*, *Melaleuca cuticularis*) or rocky slopes in the subhumid to arid zone (*Eucalyptus laelieae*, *Allocasuarina huegeliana*). The agreement is not perfect, with the map legend predictions being generally narrower than the FloraBase records. There are exceptions to this generalisation, such as *Eucalyptus astringens* subsp. *astringens*, *E. occidentalis* and *Casuarina obesa*, for which the narrow prediction is not matched by the very poor record in FloraBase. A similar under-representation also tends to occur among overstorey species with a wide distribution, such as *Corymbia calophylla* and *Eucalyptus marginata* subsp. *marginata*.

For the more common situation, where the map legend prediction is narrower than the FloraBase record, there is a need to check for drift in geographic referencing, as many of the cases go against the known pattern of distribution. This is particularly so for species predicted to occur in vegetation systems that are either narrow in shape (Rs4, Rs7, Ev2) or limited in extent (Ac8, Ra8, Ja4).
4.5.3. Validation of Predictions about Vegetation Complexes

4.5.3.1. Methodology of the Validation

The main validation carried out was that between the medium length map legend and the FloraBase record for 381 taxa of trees, shrubs and perennial herbs. In view of the large number of records (10,000), the comparison was restricted to three groups of vegetation systems from the arid north, humid mid-north and perhumid south. The humid central subregion could not be used because of the high level of disturbance by agricultural clearing and the resulting paucity of FloraBase records. Each group represents a range of landforms ranging from swampy depressions or valley floors to well-drained uplands. In the two northern groups, the information is presented at the level of both the vegetation systems and vegetation complexes. In the southern group, only vegetation systems are considered as many of the vegetation complexes have very inadequate records. Even some of the southern vegetation systems are inadequately represented in FloraBase because of their relatively poor accessibility (500 km plus from metropolis, in a hilly and swampy terrain).

The questions that it is intended to answer through the validation process are:

- Do the map legends adequately define the individual map categories?
- Are the members of a group that share the same climatic conditions adequately differentiated from one another on the basis of landforms?
- Are the groups occurring on comparable landforms adequately differentiated from one another on the basis of climate?
The validation process was carried out through two-way tables (Tables 4.2, 4.3 and 4.4), which list the FloraBase records of the taxa that are predicted by the map legend to occur in the vegetation systems comprising each subregional group. The comparison was further limited to those taxa for which FloraBase output had been obtained. The taxa (rows) were entered in sets which sequentially correspond to the vegetation systems (columns). Those taxa predicted in the legend for a particular vegetation system were entered in bold print in the column representing that system.

4.5.3.2. Outcomes of the Validation

Validation at the Vegetation Complex Level

At the vegetation complex level there are usually insufficient records in one or both of the vegetation complexes that contribute to the same vegetation system. In the northern arid group, only the Ev2 vegetation system (flooded gum woodlands of the loamy valley floors) has two components, No (Nooning) and Wi (Williams). The Nooning complex is inadequately represented in the FloraBase record, with 0 or 1 entry per species. The Williams complex has slightly better entries for some of the key species, but it cannot be reliably distinguished from the Nooning complex.

Similarly, in the northern humid group the D1 (Dwellingup) complex of the JP6 system (jarrah forest on laterite-mantled uplands in the humid zone) is amply represented in the FloraBase (10-20 entries per species), but its distinctiveness from
Table 4.2: Comparison of the Map Legend and FloraBase Records for the Vegetation System of the Arid North

Note: The numbers are the records in FloraBase

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Table 4.3: Comparison of the Map Legend and FloraBase Records for the Vegetation Systems of the Subhumid to Humid North  
Note: The numbers are the records in FloraBase

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Table 4.4: Comparison of Map Legend and FloraBase Records for Vegetation System of the Perhumid - Hyperhumid Zone of South Coast and Hinterland

Note: The numbers are the records in FloraBase

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the HR (Hester) complex, which has entries at only 0 or 1 level, cannot be established. The situation is slightly better in the HI6 system (bullich woodland in mildly incised valleys in the crystalline plateau in the humid zone), where the two components, Yg1 and Yg2 (Yarragil), have FloraBase records for the key species at moderate level (0-7). Even so, they cannot be separated on the key indicator species. The species in which they differ most, such as *Leucopogon capitellatus* (9/0), *Acacia urophylla* (5/1), *Banksia seminuda* (3/0) and *Darwinia citriodora* (4/1), are species characteristic of other vegetation systems. This indicates that the Yg1 complex is more deeply incised and has more fertile soils than the Yg2 complex, which in fact is the case.

**Validation at the Vegetation System Level**

The differentiation between the vegetation systems is stronger, particularly in response to differences in landforms. In the northern arid group the Cw0 system of swampy depressions has a set of species associated with it that is largely absent from all other members of the group, with the exception of the anomalous occurrence of *Melaleuca teretifolia*, a swamp species, in the upland system Vp1. Similarly the valley floor system (Ev2) has a set of species associated with it, though many of these extend on to the slopes of major valleys (Ds0), on to lesser valleys in which the floor and slopes are not separated (Wm1 and W11), and even on to the upland systems (Vp1 and Vp2).

The upland systems (Vp1 and Vp2) share many species with the valley systems, but have some species which are largely confined to them. The FloraBase record of the
Vp1 vegetation system includes within it taxa that are not normally considered to be associated with laterite-mantled uplands, such as *Eucalyptus loxophleba* subsp. *loxophleba*, *Acacia acuminata* and *Cheilanthes austrotenuifolia* of steep valley slopes with fertile but shallow soils, and the earlier mentioned *Melaleuca teretifolia* of swampy depressions. These anomalous records suggest drift in geographic referencing, as these distinct landforms are not likely to be confused in photo-interpretation.

Similarly within the northern humid group of vegetation systems there is clear differentiation in FloraBase records between those associated with laterite-mantled upland (JP4 and JP6), with steep slopes (Rs4 and MS5), with moderately incised valleys (NM6), with mildly incised valleys (Hl6) and with swampy depressions (Sw3). The differentiation is clearest at the extremes, and overall there is a continuum in the FloraBase record which corresponds to the ecological continuum. The vegetation systems with the largest number of records, namely JP4 and JP6, also have the largest number of anomalous records. They contain taxa characteristic of swamps and valley floors (*Agonis linearifolia*, *Banksia littoralis*, *Grevillea diversifolia* subsp. *diversifolia*, *Hypocalymma cordifolium*) and of steep rocky slopes (*Borya sphaerocephala*, *Hakea trifurcata*, *Eucalyptus laeliae*, *Cheilanthes austrotenuifolia*), which are here recorded against well drained but mildly sloping uplands with deep soils, again suggesting a drift in geographic referencing.

Differentiation between vegetation systems that are similar in landform but differ in climate is proportional to the magnitude of the climatic difference. Whereas the
FloraBase records for the Vp1 and Vp2 vegetation systems of the northern arid group differ from one another only in the proportion of the key taxa such as *Eucalyptus wandoo* subsp. *wandoo*, *Eucalyptus marginata* subsp. *thalassica* and *Eucalyptus accedens*, they differ markedly from the FloraBase records for northern humid group JP6 and JP4, in which these three taxa are largely displaced by *Eucalyptus marginata* subsp. *marginata*. The FloraBase record for that group again differs from the edaphically similar Ja8 system of the southern perhumid group, which in addition to *Eucalyptus marginata* subsp. *marginata* also has significant contributions to the overstorey of *Eucalyptus guilfoylei* and *Eucalyptus brevistyli*. Despite these dissimilarities, the FloraBase records for the three sets of laterite-mantled upland systems share *Corymbia calophylla* in the overstorey, *Persoonia longifolia* in the second storey, as well as some shrubs and perennial herbs.

The maximum differentiation attributable to climate occurs in the vegetation systems of the slopes. *Eucalyptus loxophleba* subsp. *loxophleba* (Wm1, W11) and *Acacia acuminata* (Dso, Wm1) are recorded in the FloraBase records and the map legend predictions only in the arid north group. Similarly *Eucalyptus jacksonii*, *Eucalyptus diversicolor*, *Eucalyptus guilfoylei*, *Allocasuarina decussata* and *Acacia pentadenia* are predicted and recorded from the southern perhumid group only. Both sets of species are absent from the vegetation systems of the northern humid valleys (MS5, NM6 and H16). By contrast *Eucalyptus rudis* (including *Eucalyptus rudis* subsp. *rudis*) has a bias toward the vegetation systems of the northern arid valleys (Ev2, Wm1, W11), being less prominent in the vegetation systems of the southern perhumid zone. There are also some tree taxa, such as *Eucalyptus patens* and *Corymbia calophylla*
that are recorded in FloraBase from the arid north to the perhumid south (Wm1, Wl1, NM6, Hl6, Bw8, Ta8).

By contrast to the vegetation systems of the valley slopes, those of the swampy depressions share a number of species which are largely unresponsive to climate. *Banksia littoralis* and *Melaleuca rhaphiophylla* occur in the vegetation systems of swampy depressions from Cw0 in the northern arid group to Qw9 and Bw8 of the southern perhumid group. Although *Melaleuca preissiana* is not recorded in FloraBase as a component of Cw0, it does extend into the arid zone. It is an important component of Sw3 and enters into both Gw9 and Bw8. There are, however, tree species of swampy vegetation systems that are more specific in their response to climate, such as *Agonis juniperina* of swamps in the perhumid zone (Bw8, Gw9) and *Casuarina obesa*, whose inadequate record in FloraBase fails to show its association with swampy depressions and valley floors in the arid zone, as predicted in the map legend (Cw0, Cv2, Ev2 and Cv1).

Whilst in the above discussion the focus has been on tree species, similar patterns are also observable in the shrubs and perennial herbs.

**Possible Reasons for the Absence of Predicted Species from the FloraBase Record**

The emphasis in the discussion so far has been on species predicted in the map legend to be present in various vegetation systems, specifically on whether or not they are recorded in the FloraBase output for these same systems. As yet the possible reasons
for the absence of some of the predicted species from the FloraBase output have not been considered. This will be done now as it has a bearing on the comparison. The comparison will be focused on the northern humid group, which has the largest number of records.

- The JP4 vegetation system of jarrah-marri open forest on laterite-mantled uplands of the subhumid zone has only two species that have been predicted but are not present in the FloraBase output, namely *Adenanthes barbiger* and *Lechenaultia biloba*. They were not included in the limited opportunity to question the FloraBase, so that their absence is artificial.

- The JP6 vegetation system of the humid zone also has only two species that were predicted, but not recorded, namely *Adenanthes barbiger* and *Pteridium esculentum*. Both were omitted in the questioning of FloraBase.

- The Rs4 vegetation system of herbland, shrubland and woodland mosaic of the steep rocky slopes of the Darling Scarp has four species that were predicted but not recorded. Of these, *Allocasuarina huegeliana* is definitely present and is visually prominent, but in terms of geographic extent it is limited. *Calothamnus graniticus* is also limited in its geographic extent, but *Grevillea bipinnatifida* is a relatively common species. Both have been omitted from FloraBase questioning. *Trymalium ledifolium* is a common species that has been predicted but not recorded, because there are only four entries at specific level, the remainder being allocated to subspecies.

- The MS5 vegetation complex of deeply incised valleys with steep rocky sites has a number of species that were predicted but not recorded, including a number shared with Rs4 such as *Allocasuarina huegeliana, Eucalyptus laeliae,*
Grevillea bipinnatifida, Hakea undulata and Hakea trifurcata, as well as Bossiaea aquifolium subsp. aquifolium, Eucalyptus rudis and Hovea elliptica. The likely reasons for the absence of Allocasuarina huegeliiana and Grevillea bipinnatifida have already been given in relation to Rs4. Pteridium esculentum was erroneously omitted from the FloraBase questioning, and Bossiaea aquifolium subsp. aquifolium was questioned at the specific level, not the subspecific level where most of the records presumably are. The absences of Eucalyptus rudis, Eucalyptus laeliae, Hakea undulata and Hakea trifurcata in the FloraBase output are possibly due to the overall low level of documented collections for this system, and to the drift in geographic referencing. Most of these species are recorded from nearby undulating uplands (JP4, JP6) for which they are environmentally unsuited. Hovea elliptica is mainly a southern species, though it has 4 records from Ms5, which adjoins MS5 at its southern extreme.

The NM6 vegetation system of moderately incised valleys with fertile soils of adequate depth has four taxa that were predicted but not recorded. The reasons for the absence of two of these, Pteridium esculentum and Bossiaea aquifolium subsp. aquifolium have already been given. Chorizema ilarifolium was not included in the FloraBase questioning. The absence Callistachys lanceolata is difficult to explain as it definitely occurs in NM6 and is recorded for edaphically equivalent systems that are both more arid (WM2) and more humid (Km8). All four taxa have been recorded in this climate/landform combination in environmental impact studies (Havel Land Consultants 1987).
The HI6 vegetation system of shallowly incised valleys has only two species that were predicted but not recorded, *Adenanthis barbiger* and *Lechenaultia biloba*. Both of these were erroneously omitted in the questioning of FloraBase.

The Sw3 vegetation system of swampy depression in arid to humid climatic zones has a number of species that were predicted but not recorded, namely *Baumea articulata*, *Hakea ceratophylla*, *Meeboldina scariosa*, *Melaleuca pauciflora*, *Melaleuca vimeina* and *Melaleuca lateriflora*. Only the last was omitted from FloraBase questioning. *Meeboldina scariosa* and *Melaleuca pauciflora* have been recorded against the HI6 system, within which Sw3 is commonly a narrow enclave. *Hakea ceratophylla* and *Melaleuca pauciflora* have been recorded against the WI2 system, within which Sw3 is commonly a narrow enclave. The remaining species, *Melaleuca vimeina*, has been recorded from other swampy sites in the same climatic zone. The contributing factors to the absence of these species from the FloraBase output for Sw3 may be geographic drift of less than a kilometre and overall low level of documented collections for this system.

The absence of species that were predicted in the map legend but not recorded in the FloraBase output is thus mainly due to failure to specify the species in the questioning of FloraBase, failure to specify subspecies and a low level of documented collection in some of the vegetation systems.
Occurrence of Taxa not Predicted in the Map Legend

Some taxa are recorded at substantial levels in the FloraBase record of many vegetation systems, although they are not predicted in the map legend. The possible reasons for this are examined in relation to the NM6 vegetation system, of moderately incised valleys in humid zone, for which a full description drawing on several earlier studies has been listed in Appendix 3.7. Most of the species recorded in FloraBase but not listed in the legend, such as Acacia extensa, Agonis linearifolia, Banksia littoralis, Bossiaea ornata, Clematis pubescens, Daviesia decurrens, Hypocalymma angustifolium, Lasiopetalum floribundum, Leucopogon propinquus and Phyllanthus calycinus, have been recorded for this climate/landform combination in earlier studies. They have been omitted from the map legend for the sake of compactness.

There are, in addition, records for species characteristic of neighbouring vegetation systems such as Grevillea wilsonii and Hibbertia commutata of the uplands and Darwinia citriodora and Daviesia horrida of rocky slopes, which would only require a minor drift in geographic referencing. Finally, there are records that appear to be misplaced both in term of landform and climate, such as Eucalyptus marginata subsp. thalassica and Banksia menziesii.
Summary of Comparisons

The outcome of the tabular comparisons between map legend predictions and FloraBase records regarding the relationship between vegetation systems can be summarised as follows:

The responsiveness of vegetation to climate varies with landform, being greatest on valley slopes and least in swamps, with laterite mantled uplands being intermediate.

However, it is possible to differentiate between edaphically analogous vegetation systems in different climatic zones, and between vegetation systems of a specific climatic zone which occupy different landforms.

4.6. Conclusions

In general, there is a good correspondence between what is predicted in the mid-length map legend and what is recorded in FloraBase, but there are taxa which, for various reasons, occur in one source but not in the other. In such cases the FloraBase record can taken as being different from, but not necessarily always superior to the map legend.

The map of the vegetation systems can therefore be used as a basis for considering the influence of environmental factors, in particular landform and climate, on the vegetation patterns in the south western Australia (Chapter 5).
Chapter 5: Falsification of Hypotheses on the Effect of Climate and Landform on the Vegetation Patterns

5.1 Introduction

In the preceding chapter, the maps and legends developed through the integration of the various early classification systems with climate and landform maps were validated against the botanical data bases. Whilst the records in the database did not precisely match the predictions of the maps and the legends, there was an agreement between the various sources of information on the basic vegetation patterns in the forests of south western Australia. The agreement was better at the broader pattern of climate than at the finer pattern of landforms, where inadequate precision of geographic referencing appeared to cause significant drift across the boundaries. The validation of more detailed maps of vegetation complexes was also hindered by the fact that the FloraBase records were inadequate for many of the vegetation complexes, particularly those geographically more remote and less extensive in terms of area. The combination of the maps and the databases opens the way for the validation of the hypothesis on which maps were constructed, namely that the vegetation patterns are the product of interaction between climate and landform. In a sense the maps themselves were hypotheses, as pointed out by Rowe (1996).
It may be appropriate at this point to define or restate some of the terms used in subsequent discussions. When discussing vegetation patterns, reference is frequently made to regional scale or macro-scale. This refers to patterns occurring at the scale of tens, and in some cases, hundreds of kilometres. Most frequently these patterns are attributable to climate and are mappable at the scales of 1:250,000 or 1:500,000. References to local scale or micro-scale are those dealing with patterns occurring on the scale of hundreds of meters to less than ten kilometres. Most frequently these patterns are attributable to landform features, such as topography and soils. They are barely mappable at the scales of 1:250,000 and lend themselves best to mapping at scales of 1:10,000 to 1:100,000. In this study they are primarily described by toposquences.

In addition to examining the hypothesis in the light of the information generated in this study, reference is also to other relevant studies, primarily but not exclusively from eastern Australia. This helps to define whether the hypothesis has applicability to other regions.

Originally it was anticipated that the main hypothesis would be too broad to lend itself to falsification, and a set of subsidiary hypothesis, each of them covering a subset of the total concept, was developed. This set will now be examined.
Subsidiary Hypothesis 1:

Statement

The vegetation of south western Australia forms a lumpy continuum rather than discrete categories.

Discussion

This subsidiary hypothesis has been discussed at length in Chapter 2, as the question was basic to the linking of the various localised classifications. The opinion on this issue ranged from the view of vegetation as discrete categories to that of vegetation as a continuum. The perception of vegetation as discrete categories was given the clearest expression by Speck (1958) in his use of association and consociations as the basic categories. The most clear-cut perception of vegetation as a continuum, composed of species each of which has its own range of distribution governed by environmental factors, in particular climate, was that of Churchill (1961). The thorough quantitative analysis of this issue by Loneragan (1978) indicated that the forests and woodlands of the north eastern Jarrah bioregion conform more closely to the continuum concept than the discrete categories concept, particularly if the common species of the understorey are used as a criterion. The review of the more recent studies presented in Chapter 2 (Strelein 1988; Wardell-Johnson et al. 1989,1995; Inions et al. 1990b;) has shown that, irrespective of what method of classification or ordination is used, the vegetation of south western Australia can be arranged in a continuum, held together by species with wide tolerance to environmental factors, such as Eucalyptus marginata subsp. marginata, Corymbia calophylla and Persoonia longifolia. However, Chapter 2 concluded that the continuum can be broken into
meaningful segments ("lumps") by using species more narrowly responsive to the environment and occupying only a portion of the environmental range, such as *Eucalyptus accedens*, *Eucalyptus wandoo* subsp. *wandoo*, *Eucalyptus diversicolor* and *Eucalyptus jacksonii*.

**Conclusion**

On the basis of available information, this hypothesis has not been falsified.

**Subsidiary Hypothesis 2:**

**Statement**

As there are relatively few tree species and very many shrub and herb species in the region, the variation in response to environmental conditions is less in the tree stratum than in the shrub and herb stratum. There will therefore be a greater number of vegetation communities defined by the composition of the shrub and herb stratum than would be possible to define on the structure and composition of the tree stratum alone.

**Discussion**

This subsidiary hypothesis has been discussed at length in Chapter 2. The clearest statements on this issue are the studies of Strelein (1988) of the southern jarrah forest and Inions *et al.* (1990b) of the karri forest. Each study was focused on forests dominated by a particular tree species, yet was able to define a number of distinct categories, which, whilst sharing basically the same simple overstorey, had a widely divergent understorey that reflected the underlying environmental conditions.
Although the studies of Havel (1975a) and Wardell and Johnson et al. (1989,1995) were less focused on single overstorey species, they nevertheless identified the same pattern of many segments of the continuum being dominated by the same overstorey but differing in understorey responsive to the underlying environmental conditions. The studies of Wardell-Johnson et al. (1989,1995) are particularly illuminating in that they demonstrated that even in a region in which forests and woodlands are the dominant structural formations and occupy the bulk of the region (south eastern part of the study area), the floristic diversity is resident in the shrublands, heathlands and sedgelands of edaphically extreme sites on which trees are unable to exercise their dominance. By comparison with these, not only the overstorey but even the understorey of the forest may be floristically poor.

Conclusion

This hypothesis is well supported by available evidence. Given the great disproportion between the number of tree taxa and understorey taxa in the forests of south western Australia, it is almost a tautology.

By contrast, Bedward et al. (1992) concluded, from their homogeneity analysis of vegetation maps from New South Wales, that, within a certain range of map scales, classifications derived from canopy species composition can be as informative as those derived from full floristic composition, and more informative than environmental classifications. This reflects floristically richer forest overstorey in eastern Australia.
Subsidiary Hypothesis 3:

Statement

The effect of climate on vegetation is more likely to be discernible on a regional scale rather than a local scale. It will be primarily reflected in the structure and composition of the overstorey.

Discussion

This hypothesis can be best discussed by reference to the map of the vegetation systems, the colour scheme of which is designed to reflect the effect of climate on vegetation. Whilst the map itself cannot be considered a criterion for falsification of the hypothesis, the search of FloraBase based on this map can. Much of Chapter 4 was devoted to comparison of the prediction of the map legend with the output of the databases, in particular FloraBase. Comparison was done both at the level of individual taxa and at the level of sets of vegetation systems from across the climatic range. In FloraBase, the components of the tall open forest, such as Eucalyptus diversicolor, Eucalyptus jacksonii, Eucalyptus guifoylei and Eucalyptus brevistyris, are recorded against the vegetation systems of the perhumid-hyperhumid zone such as Ta8, Bw8, Gw9, KI9, Ia8, Ks8, Km8, Km9, Jp8 and Ja8. By contrast, the components of woodlands, such as Eucalyptus loxopleba subsp. loxopleba, Eucalyptus accedens, Eucalyptus wando subsp. wando, Eucalyptus todtiana and Acacia acuminata are mainly recorded against vegetation systems of the arid-perarid zone such as Vp1, Vp2, Ds0, Wm1, WM2, W12, W11, Ev2, Cw0 and Ic2. Some of
them do, however, extend on to edaphically marginal sites in moister zones, such as Rs3 and Rs4.

The main exception to the above statement is Corymbia calophylla, which is recorded as a component of the overstorey of many vegetation systems from the arid (W11, W12, Vp1) to the perhumid-hyperhumid (K19, Ta8) zone. Eucalyptus marginata subsp. marginata extends over a similar range, from Vp1, W11 and W12 to Ta8 and Gw9, but at the arid end of this range it is partially replaced by Eucalyptus marginata subsp. thalassica.

The vegetation systems, similar edaphically but differing in climate, can be considered to be components of a continuum on a regional scale (tens to hundreds of kilometres), with the contrasting vegetation formations described above representing the two extremes of that continuum. Taxa such as Corymbia calophylla and Eucalyptus marginata subsp. marginata provide the fabric of such a continuum, spanning the entire range and filling its centre.

It needs to be pointed out that the detailed climatic zonation adopted in this study is at variance with the broad climatic zoning of south western Australia used by Hopper (1992) in his study of plant diversity. Hopper used just three rainfall zones, namely high rainfall, transitional rainfall and arid. Of these, he considered the transitional rainfall zone to have the richest flora. He considered the high rainfall zone to have been less affected by past climatic fluctuations. Much of the area mapped and described in this thesis falls into Hopper's high rainfall zone, with extensions into the transitional rainfall zone. Brown (1989) recorded a continuum of floristic change
along a rainfall gradient in the kwongan (heath) vegetation of the wheatbelt of Western Australia, much of which falls into Hopper's (1992) transitional rainfall zone. Burgman (1988), who carried out spatial analysis of vegetation patterns in south western Australia, hypothesised that at the macro-scale (tens to hundreds of kilometres) geographic distance may be a factor independent of soils and climate.

Models of tree species richness constructed by Austin et al. (1996) for south eastern New South Wales indicated that maximum species richness of eucalypts occurred at high temperatures, and intermediate rainfall, radiation and nutrients. They considered that all of these environmental variables should be studied before concepts such as niche saturation are invoked.

In a comparable climatic region in Spain, Gavilán et al. (1998) analysed climatic attributes both by classification and ordination. They identified temperature, rainfall and summer aridity as the key trends and related them to vegetation patterns. The inclusion of thermal gradients is probably due to much stronger altitudinal differentiation in Spain than in south western Australia. The rainfall and summer aridity are interpreted in terms of water availability and water balance.

On a global scale, Box and Meentemeyer (1991) consider moisture availability rather than moisture input to be the key determinants of vegetation patterns, and to be reflected in vegetative cover. They also consider rooting depth of vegetation to be inversely proportional to moisture balance, being highest in dry climates. Similarly, the international classification and mapping of vegetation (UNESCO 1973) assumes that floristics cannot be used in vegetation mapping at a scale coarser than
1:1,000,000, and that at these scales supplementary terms inferring to climate and landform may need to be added to the description of vegetation in terms of structure.

Conclusion

The prediction that climate is the key determinant of vegetation patterns at regional (macro-scale) level of tens to hundreds of kilometres appears to be valid in the forested area under study. Similar observations have also been made outside the study area, both in Australia and overseas.

However, the hypothesis needs to be modified for finer patterns of vegetation on local scale. This is dealt with in subsidiary Hypothesis 4.

Subsidiary Hypothesis 4:

Statement

The effect of landform on vegetation is more likely to be discernible on a local scale rather than a regional scale. It will be expressed indirectly through the modification of the climatic control of the structure and composition of the overstorey and directly in the composition of the understorey.

Discussion

This hypothesis has been extensively covered in Chapter 4, in comparing the predictions of the map legend for three sets of vegetation systems against the FloraBase records. The differences between neighbouring vegetation systems were
found not to be as clear-cut as the differences between climatic zones, partly due to drift in geographic references. This is significant because the landforms are mapped at a finer scale (kilometres) than the climatic zones (tens of kilometres). The vegetation systems formed continua from seasonally waterlogged valley floors and depressions to well drained slopes and uplands, such as from Gw9 and Bw8 to Ta8 and Ja8, and from Cw0 and Ev2 to Vp1 and Vp2. Where the vegetation system is comprised of two or more vegetation complexes, the validity of the difference between these often cannot be established because of the paucity of the FloraBase records at that fine level of detail. The differences between vegetation systems that are adjacent to one another along a topographic or edaphic catena are less clear than differences between vegetation complexes located at the opposite end of the catena. The differences are best expressed in the composition of the understorey, particularly as the shrub and herb species are generally represented in FloraBase at a level two to three times higher than that of the trees.

The finer patterns of vegetation tend to be overlooked in vegetation studies of broader scale such as those of Hopper (1979). There is a tendency to view the Australian landscape as flat and uniform, yet the differences found within this landscape within an altitudinal belt of 300 m can be as great as those in an altitudinal belt of 1000 m in mountainous terrain of New Guinea (Havel 1972) or Chile (Armesto et al. 1997). Fine scale variation in south western Australia is recognised by Hopper et al. (1996). Strong influence of edaphic factors has also been described from eastern Australia. For instance, Enright et al. (1994) concluded that, in the Grampian Range of western Victoria, primary variation in the species composition and richness was associated with soil texture and moisture availability. They also observed an association between
low nutrients in the soil and high diversity of vegetation, and attributed this to inhibition of competitive exclusion. Similarly, Le Brocque and Buckney (1995) found that the vegetation patterns of the central coast of New South Wales were strongly correlated with measured environmental factors, in form of complex environmental gradients.

Conclusion

The hypothesis is amply supported by evidence from the south western forest region. Parallel observations have also been made elsewhere in Australia.

Subsidiary Hypotheses 5 and 6:

Statement

The geomorphic pattern is largely determined by the dissection of the lateritised plateaus that are the dominant landform in the south west of Western Australia, and by the re-deposition of the products of erosion, either on the plateaus or on the adjacent coastal plain.

The degree of erosion, and hence the prevalence of steep slopes with fertile but shallow soils lacking water storage capacity, tends to be controlled by the proximity to features with great height differential, such as escarpments. The re-deposition of the products of erosion, leading to deep but infertile soils, often with inadequate internal and external drainage, will be prevalent in landforms lacking vertical differentiation, such as coastal plains and depressions in the plateaus.
Discussion

Although these subsidiary hypotheses are essentially about geomorphology rather than ecology, they are relevant to vegetation patterns. In the dissection of a plateau, catenas are generated that have ecological significance. The highest component is normally one in which the erosion process has as yet not commenced and the original leached and impoverished, but deep, soils predominate, such as under vegetation systems Vp1, Vp2, Ip3, JP3, JP4, Jp5, JP6, Jp6, Mp8 and Jp9 in the case of the crystalline plateaus, and Ig0, Jg5 and Jg6 in the case of the sedimentary plateaus.

The next component is one in which erosional processes predominate, the degree of this dominance being determined by altitudinal drop below the plateau surface. At the margins of plateaus, such as the Darling Scarp, and deeply incised valleys near the escarpment, such as those of the Avon, Helena, Canning, Serpentine, Murray, Harvey, Collie and Blackwood Rivers, the dominance is complete and steep rocky slopes with shallow but fertile soils predominate. This is particularly well demonstrated on the Perth, Pinjarra and Collie sheets of the set of vegetation complex maps. The shallowness of soils is reflected in the associated vegetation systems such as Ds0, WS2, Rs4, MS5, Ms5 and Rs7, in which lichens, herbfields, shrublands and woodlands provide strong structural and floristic contrasts to the forests of the adjacent plateau uplands with deep soils. The vegetation systems of steep rocky slopes contain a number of tree species either centred in them (Eucalyptus laeliae) or extending on to them from the north east (Eucalyptus loxophleba subsp. loxophleba, Eucalyptus accedens, Eucalyptus wandoo subsp. wandoo) and the south west (Corymbia haematoxylon). Many shrub (Calothamnus graniticus, Daviesia horrida,
Darwinia citriodora) and herb species (Borya sphaerocephala, Stypandra glauca) reach their maximum development here.

Deeper into the plateaus, the altitudinal drop between the plateau surface and the stream channel becomes less, the erosional stripping is less complete and soils are therefore deeper, though still mainly fertile. In the corresponding vegetation systems (WM2, Wm2, Mm4, NM6, Km8), the absence of Eucalyptus marginata is less complete, though subsp. thalassica tends to be displaced in the semiarid to arid zone by Eucalyptus wandoo subsp. wandoo. Eucalyptus marginata subsp. marginata is displaced in the perhumid zone by Eucalyptus diversicolor. In most climatic zones, it is also partially displaced by Corymbia calophylla and Eucalyptus patens.

In the mildest dissection of the plateau, corresponding to the least drop from plateau surface to the streamline, and hence generally to valleys of minor tributaries, the stripping of the slopes is least and there is also accumulation of the products of erosion on the lower slopes and valley floor. These landforms are covered by such vegetation systems as W11 and W12 in the arid east and north, and H16 in the humid north and centre. Though displacement of Eucalyptus marginata subsp. thalassica by Eucalyptus wandoo subsp. wandoo takes place in the semiarid to arid zone and of Eucalyptus marginata subsp. marginata by Eucalyptus patens and Eucalyptus megacarpa in the subhumid to humid zone, it is less complete than on the steeper valley slopes.

On the sedimentary plateaus the differences between the plateau surface and the valleys etched into it are generally less prominent, in that the valley slopes tend to be milder, and the soils developed on them deeper and less fertile than on crystalline
plateaus. This pattern is best displayed on the Busselton – Augusta map sheet of the vegetation complexes. Within the Blackwood sedimentary plateau, the slopes of the major valleys (Mn6) differ from the uplands (Jg5) only in the high occurrence of *Eucalyptus haematoxyylon* on the Rosa (RO) landform. The strong association between the Fw5 vegetation system of the valley floors and *Eucalyptus rudis* – *Melaleuca rhaphiophylla* combination is not reflected in the limited FloraBase record for this system. There is a single record of *Banksia seminuda*. For the shallow valleys (Bk7), the main difference compared to adjacent uplands (Jg5) resides in the valley floor rather than the slopes. This is reflected in the recorded presence of such species as *Banksia littoralis* and *Eucalyptus patens*, and to a lesser degree *Banksia attenuata* and *Banksia ilicifolia*.

The strong effect of geomorphology on vegetation through edaphic gradients has also been described elsewhere in south western Australia. Hnatiuk and Hopkins (1981) described a gradient of soils and vegetation from heath (kwongan) vegetation north west of the mapped area. The gradient spanned the range from lateritic uplands through deep sands to winter wet clay depressions. Maximum floristic diversity occurred at the laterite – sand interface and least on the winter wet depression.

Similar observations have been made in other parts of Australia. For instance Elliott *et al.* (1983) described several gradients of soils and vegetation along transects from interfluve to valley floor in central New South Wales. They considered this to show that good correlation exists between landform, soil type and vegetation. Similarly, Hahs *et al.* (1999) concluded that variations in plant community composition and
structure of the dry mediterranean type vegetation studied by them in western Victoria were primarily due to variation in soil properties.

Conclusion

It is concluded that subsidiary hypotheses 5 and 6 reflect the situation in south western Australia, which is tectonically stable and has a predominance of plateau landscapes.

Subsidiary Hypothesis 7:

Statement

Landforms with steep slopes and shallow soils lack a capacity for water storage and therefore tend to support vegetation that is more xeric than the zonal average. Landforms lacking slopes, and hence prone to waterlogging because of inadequate lateral drainage, tend to be only weakly responsive to climate and have vegetation that is more hydric than the zonal average. Landforms combining mild slopes and great depth of soil with low fertility tend to be only moderately responsive to zonal climate, being buffered by good water storage capacity. If the annual rainfall is high and summer evaporation low, the vegetation of such landforms is limited by soil fertility and is structurally inferior to that on shallower but more fertile sites. If the summer evaporation is high and annual rainfall low, the beneficial effect of soil moisture storage overrides the low fertility and the height and density of vegetation exceeds that of shallower but more fertile soils. Landforms with moderate slopes generally combine moderate water storage capacity and moderate to good fertility and hence will best reflect the zonal climate.
Discussion

The discussions of subsidiary hypotheses 1-6 have set the stage for, and to a degree already partly covered this main subsidiary hypothesis, that is, that the landforms play a key role in determining the availability of water, and through it the vegetation patterns in south western Australia.

The discussion of climatic variables (Chapter 2) identified the seasonal mismatch between incoming rainfall and outgoing evaporation as the key factor. During the summer season, when the evaporation demand is at its peak, there is little or no incoming rainfall to balance that demand. During winter, when the bulk of the rainfall falls, the evaporation demand is at its minimum. The acuteness of that mismatch varies with distance from the oceans. The distance from the Indian Ocean, together with topographic configuration, determines the magnitude of the rainfall. The distance from the Southern Ocean influences both the magnitude and the seasonality of the rainfall. When the seasonality and the magnitude of rainfall are accounted for, as is the case with the map of the vegetation systems, there still remains its disposal, that is whether the water runs off or is stored in the soil. The key factors in this are the topographic position, the steepness of the slopes and the depth and porosity of the soil, all of which are attributes of the landform. Maximum run-off should be associated with steep slopes with shallow, heavy-textured soils, which in the plateau landscape tend to occur together. Minimum run-off should be associated with mild slopes and deep porous soils, which in a lateritized plateau landscape also tend to occur together.
The relative position of steep and mild slopes in relation to one another determines the subsequent destination of the run-off. Plateau surfaces occurring above steep slopes are relatively unaffected by them. Lateritised plateau surfaces with a deep (30 – 50 m) solum also do not greatly contribute to the slopes. However, the run-off from steep slopes augments the water supply of mildly sloping surfaces below them, such as the alluvium and colluvium of the valleys and the coastal plain. In winter rainfall regions, lateral accretion of water is beneficial up to a point, and beyond that may become harmful, particularly if there is no ready means of disposing of the surplus water, such as by incised streams with adequate gradient.

When the rainfall / evaporation gradient is overlaid on the topographic gradient, a more complex gradient is created. At one end of the gradient are those sites in which steep slopes and shallow soils combine with low rainfall and high evaporation. These correspond to the Bindoon (Bi), Michibin (Mi), Helena (He) and Darling Scarp (DS) vegetation complexes in an arid to perarid climate, that is, annual median rainfall <700 mm which is strongly seasonal and is linked with summer evaporation >800 mm. At the other end of the gradient are low-lying sites with inadequate drainage receiving lateral run-off from adjacent uplands, such as Blackwater (BW), Kordabup (KO), Owingup (OW), Quagering (Q) and Hazelvale (HA) in perhumid to hyperhumid climates, that is median rainfall >1300 m which is only moderately seasonal and is linked with summer evaporation of <450 mm.

In between are all the possible permutations, such as sites with mild topography and deep soils in arid climate, corresponding to vegetation complexes Y5 and Y6 (Yalanbee), and steep slopes in perhumid climate, corresponding to Kg (Keystone)
and Gg (Gardner). Less extreme combinations are those with moderate slopes with soils of intermediate depth with moderate rainfall (>1000 mm) and moderate summer evaporation (>500 mm) such as Murray (My1) and Yarragil (Yg1). The corresponding vegetation systems should reflect the divergence in environmental conditions, in particular water balance. The match between predictions regarding vegetation based on combinations of climate and landform, and the actual occurrence of plant species has been the subject of Chapter 4, in which a representative set of landforms from three climatic zones (arid – perarid, subhumid – humid and perhumid – hyperhumid) were examined in terms of the FloraBase records and the predictions of the map legend. These are summarised in Tables 4.3, 4.4 and 4.5. It will be seen that the corresponding vegetation systems do reflect major differences in composition of the vegetation. The vegetation systems corresponding to steep slopes in arid climate (Ds0, Wm1) do have a unique tree stratum of Eucalyptus loxophleba subsp. loxophleba, Acacia acuminata, Eucalyptus wandoo subsp. wandoo and Eucalyptus rudis in form of woodland, as well as some shrub and herb species associated with the treeless rocky complex such as Borya sphaerocephala, Cheilanthes austrotenuifolia, Gastrolobium spinosum and Hakea undulata.

Similarly, the vegetation systems corresponding to low lying, poorly drained sites in perhumid – hyperhumid climate (Gw9, Bw8) have a unique woodland tree stratum of Banksia ilicifolia, Banksia littoralis, Eucalyptus patens, Eucalyptus megacarpa, Eucalyptus brevistylis, Agonis flexuosa var. flexuosa, Agonis juniperina and Melaleuca preissiana. They also contain species that are components of treeless shrublands (Beaufortia sparsa, Homalospermum firmum, Agonis parviceps) and sedgelands (Anarthria prolifer, Anarthria scabra, Evandra aristata).
Neither of these extreme permutations bears much resemblance to less extreme permutations, such as the humid – subhumid sites with deep soils, corresponding to vegetation system JP4 and JP6. These are open forests dominated by *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla*, with a second storey of *Persoonia longifolia, Banksia grandis* and *Allocasuarina fraseriana*, and an understorey of *Hovea chorizemifolia, Leucopogon capitellatus, Leucopogon propinquus, Leucopogon verticillatus, Styphelia tenuiflora, Hakea ruscifolia, Hakea lissocarpha, Macrozamia riedlei* and *Clematis pubescens*.

Tables 4.3, 4.4 and 4.5 cover other intermediate permutations. One such permutation is the arid uplands with deep soils, whose vegetation systems Vp1 and Vp2 consist of woodland of *Eucalyptus accedens, Eucalyptus wandoow* subsp. *wandoo, Corymbia calophylla* and *Eucalyptus marginata* subsp. *thalassica*. Another permutation is the steeper slopes with shallow soils in perhumid climate whose vegetation system Ta8 consists of tall open forest of *Eucalyptus diversicolor, Eucalyptus guilfoylei, Eucalyptus brevistylis* and *Eucalyptus jacksonii*, with a second storey of *Allocasuarina decussata, Agonis flexuosa var. flexuosa* and *Persoonia longifolia*.

The maps, the map legends and the FloraBase records bear out the essence of this subsidiary hypothesis, namely that steep slopes support vegetation that is more xeric than the average. The vegetation systems of the steep slopes of the arid zone described above have more in common, structurally and floristically, with the woodlands of the wheatbelt to the east of the Jarrah bioregion than with the remainder of the bioregion. The steep slopes of the humid – subhumid north support vegetation systems (Rs4,
MS5) that have greater affinity with mild slopes and uplands of the arid north, than with the vegetation of surrounding uplands (JP4, JP6) and neighbouring milder slopes (NM6, HI6).

This is reflected in the westward and southward extension of the woodland of *Eucalyptus wandoo* subsp. *wandoo*, which contrast with the open forest of *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla* of the uplands and open forest of *Corymbia calophylla*, *Eucalyptus patens* and *Eucalyptus marginata* subsp. *marginata* of the milder slopes.

Similarly, the hypothesis that the landforms prone to waterlogging are weakly responsive to climatic influences is supported by Tables 4.3, 4.4 and 4.5. *Melaleuca preissiana*, *Eucalyptus patens* and *Banksia littoralis* are components of woodlands and emergents above shrublands both in vegetation system Sw3 in the humid north and Gw9 in the perhumid south. The stability of these swampy vegetation systems is such that Sw3 could be used to cover the climatic range from arid to humid. *Banksia littoralis* occurs even in the perarid Cw0, though its main associates are the shrubby *Melaleuca teretifolia* and to a lesser degree the taller *Melaleuca rhaphiophylla*, not *Melaleuca preissiana*.

The hypothesis about moderate responsiveness of lateritic uplands to climate is reflected in the FloraBase output even more than in the map legend prediction. Even though the vegetation of plateau uplands in the arid north (Vp1) is predicted to be woodland of *Eucalyptus accedens*, *Eucalyptus wandoo* subsp. *wandoo*, *Corymbia calophylla* and *Eucalyptus marginata* subsp. *thalassica*, the record also contains
Eucalyptus marginata subsp. marginata. The same subspecies is, as predicted, the main component of the plateau uplands in the humid zone (JP6), accompanied by Corymbia calophylla in the overstorey and Persoonia longifolia in the second storey. The same combination is also present in the lateritic uplands in the perhumid south (Ja8), though accompanied by Eucalyptus brevistyliis and Eucalyptus guilfoylei.

The vegetation of milder slopes that combine moderate depth with fertility, has been predicted to be the most responsive to climatic influences. The northern arid representative of this category, Wm1, has Eucalyptus wandoo subsp. wandoo, Eucalyptus accedens, Acacia acuminata and Corymbia calophylla predicted against it in the map legend and recorded against it in the FloraBase record. The humid equivalent of this category, the NM6 vegetation system, has predicted and recorded against it Corymbia calophylla, Eucalyptus marginata subsp. marginata and Eucalyptus patens. The perhumid equivalent, the Ta8 vegetation systems, has predicted and recorded against it Eucalyptus brevistyliis, Eucalyptus jacksonii, Eucalyptus diversicolor, Eucalyptus guilfoylei, Corymbia calophylla and Eucalyptus marginata subsp. marginata. Eucalyptus patens and Eucalyptus megacarpa have been recorded, though not predicted. The rate of change with respect to climate is maximum on this landform, both floristically and structurally (open woodland to tall open forest).

These observations can be summed up in a model of the dynamics of vegetation of south western Australia, which illustrates how the annual possibility of summer drought and winter water logging is influenced by the landforms:
1. The vegetation of the steep stony slopes is always at risk from drought, as the soils underlying it have a very poor capacity to buffer the annual and longer term fluctuation in climate. It is affected even by minor drought cycles.

2. The vegetation of the moderate slopes has the best capacity to respond to climate. It is not strongly limited by fertility of the soils and the depth of soil is sufficient to buffer it against short-term drought. However, some large trees, in particular *Eucalyptus marginata* subsp. *marginata*, died in the 1970’s prolonged drought cycle. The slope is generally sufficient to prevent acute waterlogging problems.

3. The vegetation of mildly undulating lateritised uplands is buffered against climatic fluctuations by the great depth of solum and infertility of the soil. The infertility of the soil prevents excessive build-up of foliage area and the great depth of solum ensures that not only the annual cycle of rainfall and drought, but even longer term cycles, can be absorbed without major perturbation. It remained largely unaffected by the 1970’s drought cycle.

4. The vegetation of near level, low lying deposits in broad depressions and valleys of the plateaus, and on coastal plains, is rarely at risk from drought, as it receives lateral supplies of water. It is not entirely drought proof, as soils often have hardpans (impeded horizons) that limit root penetration and generate perched water tables. It is at risk from wet cycles, such as that of the mid 1960’s, when many trees of *Eucalyptus rudis* died on the periphery of wetlands, and a new zone of regeneration became established upslope.
Melaleuca rhaphiophylla survived by generating adventitious roots up to 1 m up the stem. Agonis juniperina and Melaleuca cuticularis appear to have even better tolerance to prolonged waterlogging. Melaleuca preissiana and Banksia littoralis combine tolerance to waterlogging with some tolerance to drought.

A tabular statement of the model is contained in Appendix 5.1.

The limitations imposed on, and opportunities generated for species in Eucalyptus subgenus Monocalyptus, by the interaction of climate and landform in Western Australia, were explored by Ladiges et al. (1987). The ranges of distribution varied enormously from a very restricted localised distribution of Eucalyptus jacksonii to very broad distributions of Eucalyptus marginata and Eucalyptus patens. Several other species had intermediate ranges of distribution, such as Eucalyptus megacarpa, Eucalyptus todtiana, Eucalyptus calcicola and Eucalyptus staeri. Ladiges et al. (1987) also attempted to define the environmental factors governing the distribution patterns, such as deep loams and 1250 mm annual rainfall for Eucalyptus jacksonii, coastal impoverished sands for Eucalyptus todtiana and coastal calcareous sands over limestone for Eucalyptus calcicola. The distribution patterns of the rare eucalypts were also studied by Kelly et al. (1995). A common pattern is their confinement to the less favourable sites on which the competitiveness of the more common species, such as Eucalyptus marginata subsp. marginata, is reduced. This enables the rarer, less competitive species to persist, provided they can cope with the limitations of such sites.
The hydrology of the jarrah forest was described by Schofield et al. (1989). They observed that along a gradient from high (1400 mm) to low (700 mm) rainfall there is an increase in the proportion of the total rainfall that is utilised by the forest, resulting in a decreasing streamflow. In the low rainfall virtually the entire precipitation is used up by the forest, leading to accumulation of salt in the subsoil.

The focus of the above discussions was the relationship between tree species and landforms in the context of the water regime, in particular the response to drought and waterlogging as reflected in the distribution of the species. There are, however, other studies in which the physiological behaviour of individual tree species is the primary focus.

The pattern of water use by jarrah was studied by Doley (1967), who showed that the species maintains a high level of transpiration even during the hot and dry summer season. It is able to maintain a high level of hydrologic conductance by extracting water from deep in the subsoil, its fine roots being detected as deep as 40 m. The inability of jarrah to control transpiration by stomatal closure puts it at a disadvantage if the soil water storage is inadequate, either due to lower rainfall or shallower soils. Under these conditions, species with better capacity to constrain transpiration through stomatal closure, such as marri and wandoo, are able to displace jarrah. The difference between jarrah and marri is apparent only on hottest days, whereas between jarrah and wandoo it occurs throughout summer (Doley 1967). Lamont (1985) has shown that wandoo has an efficient root system. It is able to displace jarrah on shallow soils in subhumid zone and on deep soils in perarid zone. Pate et al. (1998) studied the growth of *Banksia prionotes* in relation to water and nutrient utilization,
and demonstrated its capacity to exploit deep infertile sands. Dodd and Bell (1993) concluded that *Banksia* species tended to function as phreatophytes in deep sands. On the Darling Plateau deep sandy soils are usually associated with depositional landforms, which are frequently water-gaining by virtue of their low position in the landscape.

The interaction of climate and landform in limiting the occurrence of tree species was also studied in other parts of Australia. Varying responses to drought by eucalypt species of south eastern Tasmania were observed by Davidson and Reid (1989). They attributed the variation in the severity of drought to variation in the water holding capacity of the soil and biomass of the stand.

Austin *et al.* (1996) identified mean annual temperature as the most important predictor of tree species richness. The response to rainfall depends on temperature. Their findings supported earlier observation of Austin *et al.* (1983) that patterns of co-occurrence of species from the *Eucalyptus* subgenera are governed by differences between the subgenera in environmental preferences.

*Conclusion*

This hypothesis reflects the situation in winter rain / summer drought (mediterranean) climate, such as south western Australia. In regions with uniform rainfall or summer rainfall / winter drought the effect of landform on vegetation is less conclusive.
Subsidiary Hypothesis 8:

Statement

The vegetation patterns of landforms conducive to extremes of water economy, that is either excessive drainage and inadequate storage, or inadequate drainage and waterlogging, will have a finer scale than those with a more balanced water economy, because even minor variations in depth of soil have a major effect on the vegetation structure and composition. The vegetation patterns of landforms with a deep solum and hence good water storage capacity will be very broad scale.

Discussion

The linkage between landforms and vegetation was covered in Chapter 3. It operates not only at the coarser level of vegetation systems (1:500,000) and finer level of vegetation complexes (1:250,000), but even at the still finer level of vegetation types (1:10,000 – 1:50,000). It is only at this detail that the map polygons approach homogeneity, though for edaphically extreme sites, such as steep slopes with rock outcrops and seasonally flooded sites, even finer detail is needed (Havel 1975b).

The maps developed as part of this project cannot add much to the observations made by Havel (1975b) regarding the extreme site-vegetation types A and G, corresponding to vegetation complexes S (Swamp) and Ce (Cooke), and vegetation systems Sw3 and Rs3 respectively. The reason for this is the coarseness of scale (1:250,000 to 1:500,000) of the maps, at which even the categories defined by Havel (site-vegetation types) are not mappable.
However, many toposequences utilized in the compilation of these maps do record fine-scale changes in vegetation. They fall into four main classes:

1. Seasonally waterlogged or flooded sites with coarse textured soils (Gw9, Bw8, Gw5, Sw5, Sw6, Sw7, Sw4, Sw3, Gw3, Gw4, Cw0).

2. Seasonally waterlogged sites with fine-textured soils (Zv9, Sv8, Sv6, Fv5, Ev5, Yv4, Zv4, Fv3, Cv1, Ev2, Cv2).

3. Mosaic of uplands and depressions (Sv9, Kv7, Jw7, Jw5, Jv4, Jv3).

4. Steep rocky slopes (Ra8, Rs5, MS5, Ms4, Rs4, Rs3, Ds2, WS2, Ds0).

At the other end of the gradient are the vegetation types of lateritised plateau uplands, which are homogeneous at the scale of kilometres, such as JP6, Jp5, Jg5, JP4, JP3, Ip3, Vp2 and Vp1.

The reason for these contrasts is largely related to critical depth of soil. When groundwater is close to the surface, such as in categories 1, 2 & 3 above, even a difference of several centimetres has significant biological consequences. Similarly on sites with shallow depth of soil over crystalline country rock, such as category 4 above, even a few centimetres make a difference between lichens, herbfield and shrubland. In lateritic soils of plateau uplands, which are measurable in tens of metres, a change in depth of solum of the order of metres is not very significant.
The significance of granite outcrops to plant distribution was highlighted by Hopper et al. (1997), who considered the plant communities on these sites to be "complex, ever changing and rare in their own right". Both Hopper et al. (1997) and Piggott and Sage (1997) considered the plant communities of granitic rocks to be particularly susceptible to invasion by exotics. The strong edaphic variation of granitic outcrops and its effect on ecological diversity was recognised by Main (1997). The concentration of endemic taxa of the Warren bioregion in swamps and on granite rocks and fringes was recorded by Lyons et al. (2000). Very fine patterns of vegetation were described from upland swamps of central New South Wales by Keith and Myerscough (1993).

The question of map scales and appropriate criteria was examined locally by Beard (1979d), who concluded that "for a vegetation mapper there can be no absolute concept of the plant community". Rather, the concept is dictated by the scale. If the principle is reversed, that is, that concept must be matched by scale, then on edaphically extreme sites structurally and floristically uniform plant communities would need to be mapped at very fine scales of 1:1,000 to 1:10,000. They are not mappable at the coarse scales of 1:250,000 or 1:500,000, except as mosaics.

**Conclusion**

The hypothesis is broadly supported by evidence for the local combination of climate and landform. It may be less valid for regions with rainfall regimes better atuned to transpirational needs of plants.
Subsidiary Hypothesis 9:

Statement

Climatic changes will have the most immediate impact on the vegetation of those landforms in which water balance is not buffered by good soil water storage capacity, and more delayed impact on those in which water balance is well buffered by good soil water storage capacity. On the landforms with inadequate lateral drainage the effect of climatic change will be opposite to that on well drained sites, that is adverse for a rise in rainfall and positive for a decrease in rainfall, except when complicated by salinity of the groundwater.

Discussion

This hypothesis has been discussed to a considerable degree in subsidiary hypothesis 7. The chief difference is in time perspective. Whereas subsidiary hypothesis 7 dealt with the present and the recent past, this hypothesis deals with likely impact of long-term climatic changes, both in the past and in the future. As such it cannot be falsified, but it has a bearing on the predictions that have been made about the past and are being made about the future. Those predictions made on the basis of changes in rainfall alone, without consideration of evaporation and soil moisture storage, are too coarse. In the case of decreasing rainfall, the impact on jarrah forest or woodland of the lateritised uplands will be dampened by the great depth of the solum. If the change in climate should exceed the buffering capacity of medium depth soils on mild valley slopes (NM6), the invasion by species of greater tolerance to drought does not have to come from distant edaphic equivalents such as WM2, but can take place from shallow soil and rock outcrops in the neighbouring vegetation system MS5.
Similarly, should rainfall increase, it does not mean that the NM6 vegetation system would automatically be replaced by the edaphically equivalent system such as Km8, because the massive barrier of Ms5 of the Blackwood Valley, combining lower rainfall with shallower soils, may prove too strong. It appears to have done so in the past. The three tingle species (*Eucalyptus jacksonii*, *Eucalyptus guilfoylei* and *Eucalyptus brevistylis*) appear to have been prevented from fully exploiting the climatic and edaphic potential of the hyperhumid – perhumid zone west of Walpole, by the intervening swamps of vegetation systems Sv9, Bw8 and Gw9.

There has been a greater recognition that adverse changes in climate do not totally wipe out a species from a particular climatic zone, provided that there are available within it edaphically favourable sites that can serve as refugia. The jarrah residuals described by Abbott and Loneragan (1986) and Gentilli (1989) from the perarid zone, and the outliers of karri in the humid zone of the south coast hinterland and of the northern Margaret River Plateau described by Gentilli (1989) and Bradshaw *et al.* (1997) owe their survival to favourable edaphic conditions that augment the inadequate rainfall. Two common cases are the moist periphery of swamps, and the colluvium below granitic outcrops whose water supply is augmented by run-off from the outcrops.

The majority of the minor tree species covered in Appendix 4.4, such as *Eucalyptus decurva*, *Eucalyptus drummondii*, *Eucalyptus exilis*, *Eucalyptus falcata*, *Eucalyptus graniticola*, *Eucalyptus latens*, *Eucalyptus occidentalis* and *Eucalyptus loxophleba* subsp. *loxophleba* occur in the RFA region for opposite reasons. Edaphically adverse
sites enable them to escape competition from larger and more aggressive species such as *Eucalyptus marginata* (subsp. *thalassica* and *marginata*), *Corymbia calophylla* and *Eucalyptus wandoo* subsp. *wandoo*.

The bioclimatic analysis of southern beech (*Nothofagus cunninghamii*) in south eastern Australia by Busby (1986) indicated that its geographic limits are closely correlated with climate, but that it is absent from some areas with suitable climates in north eastern Victoria and southern New South Wales. It was suggested that the species may be migrating north east along a corridor of suitable climate to reoccupy its former range, but that the rate of migration is extremely slow because of its poor dispersal ability and because of the adverse impact on it of recurrent fires. There may be a parallel with this in the case of several species with south western centre of occurrence in Western Australia, such as *Eucalyptus diversicolor*, *Eucalyptus jacksonii*, *Eucalyptus guilfoylei* and *Eucalyptus brevistylos*, except that there are strong edaphic barriers against the migration of these species into climatically favourable areas.

**Conclusion**

The hypothesis cannot be falsified, as statements about long term trends in the past can only be inferred from circumstantial evidence, and statements about long term trends in future are only projections. It does, however, explain the current distribution patterns of many tree taxa, and thus may have some predictive capacity for the future. For future predictions, it is only applicable to species that have a broad current range. Species whose current range is already narrow probably will have very limited capacity to adjust to adverse changes.
Subsidiary Hypotheses 10 and 11:

Statements

Tree species respond to climatic limitations along a continuum, one end of which is a direct response to adverse water balance or infertility of the soil. They adjust to unfavourable conditions by reduced structure (lower height and density of stand and reduction from tree form to mallee form), but do so at the loss of their competitiveness with hardier species. The other end of the continuum is an inability to compete with species capable of forming taller and denser stands under a more favourable water balance or higher fertility. Each species reaches its structural optimum (height, diameter) at the point where its competitive capacity begins to fail.

Tree species with a poor competitive capacity will have a disjunct distribution at the interface of disparate landforms or at the margin of climatic zones, that is at the point where the competitors that normally exclude them lose their dominance but before their own capacity to cope with adverse sites fails. Capacity to cope with adverse site conditions (droughtiness, waterlogging, low fertility and salinity) provides a means of escaping competition.

Discussion

Earlier discussions have established that the vegetation of south western Australia forms a continuum from the hyperhumid south coast to the perarid north east. They have also established that the effect of climate is strongly modified by landform. It is
now proposed to examine this with respect to individual species, in particular those tree species that dominate the upper storey.

The topic of particular interest in this subsidiary hypothesis is the mechanism that enables individual species to dominate a particular segment of this continuum.

At the southern end, on the shores of the oceans, the rainfall / evaporation ratio is optimal, but other environmental factors are extreme. The dunes closest to the ocean carry shrubby vegetation that reflects the excessive calcium content and porosity of the soil, and the heavy exposure to wind abrasion and salt spray. As these adverse factors are reduced with progress inland, such as by protection from wind and salt spray exposure and by leaching out of calcium, the climatic potential is able to be expressed in vegetation systems such as Ko8 situated on the lee side of the Gracetown dunes between Augusta and Margaret River. The optimal development, in terms of structure and composition of the overstorey, is reached on the crystalline hillslopes of the Ta8 vegetation system. It can be speculated that if the land extended further south, or if the climatic belts extended further north, a temperate rainforest such as that found in western Tasmania, western South Island of New Zealand and southern Chile, would be found.

It could be argued that on optimum sites *Eucalyptus jacksonii*, by virtue of its size and density of crown, outcompetes the other tinges (*Eucalyptus guilfoylei, Eucalyptus brevistylis*), karri and marri. It can also be argued that it rapidly reaches its climatic limit, not extending as a forest formation much beyond the hyperhumid zone. Even within this zone it is severely constrained by edaphic conditions. The swampiness and
infertility of the Gw9 and Bw8 vegetation systems have limited its expansion within the hyperhumid zone. The same is true, to a lesser degree, of _Eucalyptus guilfoylei_. _Eucalyptus brevistylis_ is likewise limited by edaphic conditions to the perhumid zone near Walpole. Only _Eucalyptus diversicolor_ fully occupies most edaphically suitable sites within the perhumid–hyperhumid zone, and weakly extends beyond it. Within the hyperhumid zone it occupies a wide range of edaphic sites, including relatively infertile ones (Inions _et al._ 1990b), whereas at the margins of its range it is confined to edaphically favourable sites (fertile, water gaining slopes of valleys). However, it does not extend to a minor enclave of the perhumid zone north of the Blackwood River.

_Corymbia calophylla_ enters the picture as an associate of the above species in tall open forest, but also extends on to less favourable sites in association with _Eucalyptus marginata_ subsp. _marginata_. It extends from the south coast to the arid north east and enters into an association with a number of other tree species:

- with _Eucalyptus marginata_ subsp. _marginata_ in open forest on lateritised plateau uplands and mild slopes in the humid to perhumid zone,
- with _Eucalyptus accedens_ and _Eucalyptus wandoo_ subsp. _wandoo_ in woodlands of both uplands and slopes in the arid zone,
- on the coastal plain it associates with and even displaces _Eucalyptus marginata_ subsp. _marginata_ on the better drained and more fertile sites, and
- its strongest development is on crystalline slopes with _Eucalyptus patens_ on deeper soils, and with _Eucalyptus laeliae_ on shallower soils.
Although *Eucalyptus marginata* subsp. *marginata* is more limited climatically and edaphically, it tends to be more dominant within its range of occurrence than *Corymbia calophylla*. It also tends to extend beyond the edaphic range of *Corymbia calophylla* on to less fertile and more porous soils, forming woodlands with *Banksia attenuata* and *Banksia ilicifolia*. In the semi-arid to arid zone north of Perth its range on coastal sands decreases to a narrow band between sites too wet and too dry, its place being ultimately taken by *Banksia ilicifolia*, *Banksia attenuata* and *Eucalyptus todtiana*. On the more fertile valley slopes it is partially displaced, and on the shallow rocky sites it is fully displaced, by other species. In the north eastern woodlands it is largely displaced by *Eucalyptus marginata* subsp. *thalassica*, *Eucalyptus accedens* and *Eucalyptus wandoo* subsp. *wandoo* even on the lateritised uplands. Nevertheless, its climatic and edaphic range is extensive.

*Eucalyptus wandoo* subsp. *wandoo*, *Eucalyptus accedens*, *Eucalyptus loxophleba*, *Eucalyptus astringens* and *Eucalyptus occidentalis* only enter into the drier margin of the forested region, their centre of distribution being to the east and north of it. They exploit the edaphically adverse sites in more mesic zones.

The final and perhaps the most interesting group of tree species is that comprised of *Eucalyptus patens*, *Eucalyptus cornuta* and *Eucalyptus megacarpa*. To a considerable degree, they share the overall climatic range of *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla*, but rarely directly compete with them. More commonly they occur at the edaphic limit of the major tree species, such as swamp margins in the humid – subhumid zone, the seaward edge of woodland and forest on coastal dunes and the periphery of rock outcrops in the perhumid zone. There is no
readily discernible edaphic link between these occurrences, but there is a strong environmental link, namely the marginality of site that gives a limited freedom from competition without total physiological exclusion. The question to be answered is - what gives the open forest of *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla* such a strong capacity to exclude other species? This is dealt with in Subsidiary Hypothesis 12 on page 328.

The possibility that species confined to adverse sites (obligates) may owe their survival there to freedom from competition was raised by Coates and Kirkpatrick (1992).

At this stage it may be appropriate to introduce a second model of the vegetation of south western Australia. It is in the nature of a static snapshot, with the dynamics temporarily frozen. It can be visualised as a greenback turtle basking in the mid-morning (NE) sun. The bulk of the turtle consists of its tough green shell mildly indented between the plates. In the front, facing the sun, the shell has a yellowish hue, at the back, away from the sun, it has a bluish hue. The head and front legs have stronger reddish hue, the hind legs a dark blue hue.

The green part of the turtle's shell is the jarrah-marri open forest on lateritised uplands and mild slopes, tough and almost impervious to impact. The undulation in the shell are valleys incised into the plateaus, carrying mixed forest in which jarrah is replaced by other large tree species, such as *Eucalyptus accedens* and *Eucalyptus wandoor* subsp. *wandoor* in the north, *Eucalyptus megacarpa* and *Eucalyptus patens* in the centre, and *Eucalyptus diversicolor*, *Eucalyptus guilfoylei* and *Eucalyptus jacksonii*
in the south. The hues extend from the indentation onto the plates at the extremes of
the shell – *Eucalyptus wandoo* subsp. *wandoo* and *Eucalyptus accedens* in the
insolation of the northern end, *Eucalyptus guilfoylei* and *Eucalyptus brevistyliis* in the
shade of the southern end.

The head and neck of the turtle represents the woodlands of fertile but shallow valley
slopes in the arid zone, with *Eucalyptus loxophleba* subsp. *loxophleba*, *Acacia
acuminata* and *Allocasuarina huegeliana*. Its right front foot corresponds to
depressions and valley floors in the drier zones, with *Casuarina obesa*, *Melaleuca
spp.*, *Eucalyptus rudis* and *Actinostrobus pyramidalis*. Its left front foot are woodlands
of the north western sedimentary plateau and sandy deposits with *Eucalyptus todtiana,*
*Banksia prionotes* and *Banksia menziesii*. The left hind foot are the perhumid wetlands
of the southern coastal plains and southern coastal dunes with *Agonis flexuosa* var.*
*flexuosa*, *Agonis juniperina*, *Corymbia ficifolia*, *Banksia ilicifolia* and *Banksia
quercifolia*. The right hind foot are the species of the south eastern sedimentary
plateaus, such as *Eucalyptus staeri*, and depressions, such as *Eucalyptus occidentalis*.

It is possible to bring some dynamics into the picture by considering what would
happen if the sun should be higher or lower in the sky. In the former case,
corresponding to a drier epoch, the shaded portion of the shell would retreat to the tail
deck, and the bulk of the shell would take on a yellow hue of drought adjustment
through expansion of the woodlands of *Eucalyptus accedens* and *Eucalyptus wandoo
subsp. wandoo*. In the latter case corresponding to a moister, cooler epoch, the yellow
hue of drought and woodland would retreat to the northern end, and the blue hue of
better moisture balance and tall open forest of *Eucalyptus diversicolor, Eucalyptus*
guilfoylei and Eucalyptus brevistyli would expand from the southern end. It is even possible that with longer periods between wildfires, tall shrub species with denser foliage, such as Trymalium floribundum, Podocarpus drouynianus and Chorilaena quercifolia might develop into a low closed temperate rainforest that would interfere with the regeneration of the eucalypts.

It would require a major change in climate to cause a shift in the vegetation of lateritised uplands represented by the turtle’s shell. By contrast, the vegetation represented by the turtle’s extremities (neck, head and feet), would be much more vulnerable to the impact of climatic change.

In their study of beech (Fagus sylvatica) in Scandinavia, Diekmann et al. (1999) described a pattern reminiscent of the jarrah forests, that is a species dominant over an extensive area, only replaced by other species under extreme conditions, such as wet or droughty sites, or outcompeted on mesic fertile sites.

Conclusion

The hypothesis on the displacement through competition by taller and denser stands is too simplistic, as under local conditions competition for light is probably not the most significant form of competition. The remaining hypotheses are supported by observations, including the map and the FloraBase records, to some degree. However, additional factors appear to be involved in generating patterns of vegetation in south western Australia. These will now be explored.
Subsidiary Hypothesis 12:

Statement

Tree species with a good capacity to cope with fire, either by strong vegetative recovery after fire damage or by reproductive strategies that utilise the destructive effect of fire on competitors, will occupy many landforms in many climatic zones. Tree species with a poor capacity to respond to fire will be confined to landforms that reduce either the frequency or the intensity of fires, such as low fuel accumulation and fire shadows on rocky sites, or shorter fire season due to persistence of water into the summer on swampy sites. Alternatively, they will be confined to climatic zones with either a low fuel accumulation but long fire season (perarid), or high fuel accumulation but short fire season (hyperhumid).

Discussion

One of the outstanding limitations of the genus *Eucalyptus*, and related genera such as *Corymbia*, is the inability to form a closed canopy. Jacobs (1955) attributed this to the vulnerability of terminal naked buds to abrasion, such as when branchlets at the interface of two neighbouring tree crowns rub one against the other. The exclusion of one species by another is therefore unlikely to be due to overshadowing. This is demonstrated by the success of such tree genera as *Persoonia*, *Allocasuarina* and *Banksia* under the *Eucalyptus* overstorey. The mechanism of exclusion or domination must therefore lie elsewhere. On the lateritised uplands the infertility of the soil, and hence the need to exploit vast volumes of soil, may be a contributing factor. It could account for exclusion of such species as *Eucalyptus patens*, except that this species copes with low fertility in such vegetation systems as Bw8, in which moisture is more
readily available. It does not account for the capacity of *Eucalyptus marginata* subsp. *marginata* and especially *Corymbia calophylla*, to descend on to the more fertile valley slopes (particularly in the humid – subhumid zone) and successfully compete there.

Much has been written about the effect of fire on the competition of eucalypt forest with denser plant formations, such as the temperate and subtropical rainforest, (Jackson 1968; Ashton 1981; Gill *et al.* 1981; Singh *et al.* 1981). Although water balance sets the stage, and soil fertility reinforces it or compensates for its effect, the balance is most frequently tipped by fire, which is the dynamic factor in the equation. In south western Australia fire is so frequent and so universal a phenomenon, that the natural occurrence of temperate rainforest is only considered to have been a feature of past humid epochs (Christensen 1992).

Less attention appears to have been paid to finer details of this equation, that is, what role fire plays in shaping competition between eucalypt dominants in forests and between eucalypts and other species in woodlands. Even less attention has been given to the role of fire in the domination of the second storey and understorey by eucalypts, though Bell *et al.* (1989) did refer to floristic changes related to interval of time since fire.

An indication of how this may operate is given by studies of fuel accumulation in forest and in woodlands of south western Australia. McCaw (in press) studied fuel accumulation in perhumid tall open forest of karri, and recorded high accumulation of fuels. High fuel accumulation in the karri forest was also recorded by O'Connell and
Menage (1982), who also identified the contribution made to the nutrition of the forest by leguminous species of the understorey, which, like karri, regenerate after intense fires. The pattern in the perhumid tall open forest dominated by *Eucalyptus diversicolor* is one of less frequent fires and higher fuel accumulation, resulting in more intense fires. *Eucalyptus diversicolor* mainly relies on ashbed regeneration and rapid progression to the reproductive stage (Christensen 1992). It is more susceptible to fire damage because of its smooth, thin bark than *Corymbia calophylla* and *Eucalyptus marginata*. Among the understorey shrubs of the karri forest there is a higher proportion of tall shrubs reliant on post-fire germination and rapid initial growth, rather than persistence through lignotubers, than in the jarrah forest (Christensen *et al.* 1981).

Hobbs and Atkins (1988) recorded soil temperatures under fires in the arid woodlands at, and outside the northern periphery of the Jarrah bioregion. They recorded strong variability in soil temperatures, which they attributed to variation in fuel distribution and type. They did, however, also record a very intense fire in heavy fuel accumulation, under which fuel temperatures were uniformly high. They concluded that fire variability would be reflected in post-fire regeneration response, especially in temperature-dependent germination and cone opening. Atkins and Hobbs (1995) studied the variation in fire temperatures and in the fuel accumulation. *Borya* herbfield, characteristic of very shallow soils, had a dampening effect on fire spread. They followed this up by studying the vegetation responses. The results suggested that the differences in responses are mainly attributable to differential responses of seeds to fire treatment.
The fuel accumulation in the jarrah – marri forest is intermediate, in that it is more uniform than that of the wandoo woodland, but not as high as that of the karri forest. It has been described by Bell et al. (1989). The pattern in the arid woodlands dominated by *Eucalyptus wandoo* subsp. *wandoo*, *Eucalyptus accedens* or *Eucalyptus loxophleba* subsp. *loxophleba* is markedly lower and uneven accumulation of fuels, and hence less intense and less uniform fires. All of these species have thinner bark and are more susceptible to fire damage than *Eucalyptus marginata* and *Corymbia calophylla*.

Lamont (1985) has provided an explanation for the greater patchiness of shrub fuels in wandoo woodlands, namely the exclusion of shrubs through competition for water between the extensive lateral root system of the wandoo and the roots of the shrubs.

The strong feature of all components of the jarrah – marri forest, from the overstorey of *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla* through to the second storey of *Banksia grandis*, *Persoonia longifolia* and *Allocasuarina fraseriana*, to the varied but not floristically rich understorey, is the possession of several features for coping with frequent fires, such as:

a. serotinous fruits releasing seeds after scorch,

b. utilization of ashbeds for germination and initial growth,

c. a lignotuberous juvenile stage for trees, and permanent lignotuberous stage for shrubs, as a means of coping with fires of moderate intensity, and

d. thick bark and epicormic buds on stem and branches as means of coping with wildfires of high intensity (Bell et al. 1989).
Lamont and Markey (1995) suggest that the high proportion of re-sprouters (fire-tolerant) among Banksia species in the extreme south west of Western Australia may be explained by the elimination of seeders (fire-killed) through frequent burning by Aborigines in late Quaternary.

It is therefore likely that in addition to the more readily identifiable effect on water balance, climate and landform also influence the frequency, intensity and uniformity of fires. The fire pattern prevailing at the centre of the climatic continuum, namely frequent fires of moderate intensity and high uniformity, favour Eucalyptus marginata and Corymbia calophylla. The less frequent but more intense fires of the perhumid zone favour Eucalyptus diversicolor. The more heterogenous fires of the arid zone increase the survival chance of Eucalyptus wandoo subsp. wandoo, Eucalyptus accedens and Eucalyptus loxophleba subsp. loxophleba. The uneven fuel accumulation on rocky slopes favours the survival of the less common species such as Eucalyptus laeliae. Delayed drying and lower frequency of fires on seasonally wet sites favour the survival of Eucalyptus megacarpa, which is particularly thin-barked and prone to fire damage. Some of these differential responses were identified by Bell et al. (1989).

The study of ecological effects of fire by Burrows (1995) is focused on the jarrah forest, which is the most extensive vegetation formation in the south west. Burrows discussed acute impacts of fire and acute impact zones, which he considered to give rise to ecological effects. He considered the most meaningful description to be those that reflect the amount and rate of heat energy released and its distribution. He observed that most understorey species in the jarrah forest have thin barks, are killed to the ground level by fire and most of them resprout from subterranean organs. Trees
are more resistant by virtue of their thick protective bark. Burrows considered rough-barked trees such as jarrah to be significant contributors to the fuel load. The burning of the bark in hot fires, reaching up to 30% of total thickness, contributes to the cambial damage on the lee side of the jarrah boles.

Responses to fire by vegetation were also studied by Tolhurst (1995), who examined different methodologies for defining the ecological effect of fire. He found that the amount of fuel burnt was the primary factor affecting tree death, and that the threshold diameter for tree mortality was easier to predict than threshold bark thickness. Tree scorch height reflected the amount of sensible heat transferred above the flaming zone of the surface fire, and was directly related to the ecological impacts of fire on tree growth.

The influence of fire on vegetation has also been recorded outside south western Australia. The frequency of fires was considered to be an important factor in the maintenance of heathland mosaics in New South Wales by Keith (1995). Excessive frequency of fires, and excessive length between fires are both considered to have the potential to cause elimination of species. Keith and Myerscough (1993) postulated that fire response of vegetation varied along a soil moisture gradient. Species persisting after infrequent fires in swamps tended to have clonal forms and long life spans, enabling them to take advantage of rare events favourable to seedling establishment. Similarly, Morrison et al. (1995) concluded that fire frequency exercised a strong influence on the structure and composition of vegetation of the central coast of New South Wales. Fire-tolerant species were favoured by increased fire frequency, at the expense fire-sensitive species.
Patchiness of vegetation was considered by Braithwaite (1995) to be influenced by intensity of fires. Under the conditions of the study area (savannah in summer rainfall climate of the Northern Territory) low intensity fires favoured patchiness of the ground layer, and high intensity fires favoured patchiness of the tree layer. Although Kirkpatrick et al. (1987) attributed the bulk of the differences in eucalypt forests and woodlands on a plateau in the Northern Territory to topography and soils, they also considered the flammability of understorey to be an important factor. The continuity of fuel was seen as being edaphically controlled.

Whelan and Tait (1995) view both fire intensity and fire frequency as capable of altering population dynamics of plant communities through their effect on post fire recruitment.

In comparing the vegetation of the Mediterranean Basin with that of other regions with comparable climate, Pausas (1999) commented on the relative paucity in the basin of trees with strong fire adaptations, such as epicormic buds, serotiny and with dependence on fire for regeneration and hypothesised how this might be utilised in modelling vegetation dynamics.

Conclusion

Although this hypothesis is in considerable agreement with observed facts and with published reports, it cannot be taken as anything more significant than a suggestion about future research.
5.2 Main Hypothesis

The discussion of subsidiary hypotheses open the way for consideration of the main hypothesis, namely that the vegetation patterns in south western Australia are determined by the interaction of climate and landform.

If this is interpreted in the narrow sense, namely that all vegetation patterns can be explained in terms of the direct effects of temperature, rainfall, steepness of slope, soil texture and soil fertility, then the hypothesis has been falsified. The distribution patterns of the main tree species, in particular *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla* are too broad, and the distribution patterns of the minor tree species are too narrow and too irregular, to be accounted for by the direct physical effect of climate and landform.

If, however, the hypothesis is interpreted more broadly, namely that the combination of climate and landform sets the stage on which the vegetation patterns are determined by the interplay of species, it becomes more difficult to falsify. This broader interpretation of the role of current climate and landforms, as expressed in the vegetation system map, goes a considerable distance toward explaining the current vegetation patterns. It reduces the need to rely on historical factors operating on a broad scale. It identifies the high heterogeneity hidden under the apparent structural uniformity and floristic homogeneity of the overstorey, and provides theoretical backing for the vegetation maps, which are the primary product of this study.
6.1 Introduction

The primary product of this study is a set of maps. These maps are unique in many respects. They cover an extensive region (4.5 million hectares), yet do so in considerable detail (1:250,000 and 1:500,000). They represent the integration of past studies of climate, landform, soils and vegetation in the region. It is the first time that this combination of extent and detail has been attempted in the region, though a vegetation map based on structure of the vegetation has been in existence for some time (Beard 1981a). The forested region of south western Australia can now be seen as a whole, yet at the same time in considerable detail.

The polygons of the map are backed by information in both verbal (legends and descriptions) and pictorial and tabular (toposequences) format. The vegetation, which is floristically very rich (3000 species), is described in terms of both structure and composition. The maps are constructed on the premise that the vegetation and the underlying environmental factors form interacting continua. Within the broad pattern of climate is nested a finer pattern of landforms. The landforms do not represent uniform categories, but contain still more detailed continua of soils and vegetation, which are mappable only at the finer scales of 1:10,000 to 1:50,000. The concept of vegetation as a continuum is not new, but the broad scale mapping of vegetational continua is unique.
The questions that might be asked at this stage are:

- Could the mapping be improved, now that the reasoning behind the process has been made explicit in the thesis?

- How can the maximum benefit be derived from this very considerable expenditure of time and money?

### 6.2 Scope for Improvement

The compilation of the maps was a constant struggle between getting bogged down in too much detail and giving insufficient detail. Now that the maps have been tested against FloraBase, it has become obvious that there is a significant difference in information content between the two sources of information.

By combining FloraBase with vegetation maps, it is possible to see what taxa have been collected within a given map polygon, within the limits of the precision of geographic referencing available at the time of collection. FloraBase makes no judgement about the ecological significance of the taxa, such as whether they are significant components of the vegetation type that the polygon represents, whether they are rare taxa confined to that type or whether they are common species present over a whole set of vegetation types. At this stage it cannot even guarantee that a
particular collection took place in that exact polygon, and that it is not a drift from adjacent polygons due to imprecise geographic referencing in the past.

The map legend, on the other hand, is an attempt to represent the information resident in the map polygons in as concise a form as possible. Given that there are 3000 taxa of vascular plants in the region, it is a necessity, not an option. However, the concise description needs to be sufficiently accurate to separate one map category from another.

The most obvious opportunity to improve both the FloraBase and the map is to check the records against the map legend. This may entail checking the precision of the geographic references, particularly if there is an apparent discrepancy between the description of the polygon and the presence of a particular taxon within it. A number of such records have been identified in appendices to Chapter 4, such as coastal species recorded against inland localities, species of the semiarid zone recorded against the perhumid zone and swamp species recorded against polygons representing upland vegetation.

The obverse side of the coin is to examine species used in the map legend to describe a particular map polygon, but not recorded against that polygon, with a view of determining whether the omission is due to lack of collections in that climate/landform combination, or whether it is an error in definition of the characteristic taxa for that combination. Similarly, multiple records of a taxon against a map polygon for which it is not mentioned in the map legend need to be examined. Is this due to the fact that it
is a common species omitted because it lacks discriminatory power, or is it a significant omission of a taxon that could have improved the definition of the polygon?

Ideally, a program of objective stratified sampling based on the map, backed by sound geographic referencing, should be instituted to deal with these issues. There are numerous map polygons that have inadequate representation in the FloraBase records. The coverage of the forested region by botanical collection is very patchy and is biased toward more accessible locations or locations with special significance to land use issues. The reality is that finance for that level of effort only becomes available every two decades or so.

There is not much that can be done about the brief legend printed on the map, which is very general anyway, but the separate and more detailed mid-length legend (Appendix 3.6) can still be modified in light of the FloraBase questioning, before being published as an appendix to the report on the mapping process.

In the longer term, there is scope for modification of the map polygons in future editions of the map. Some desirable changes have already become obvious, such as improvement in the definition of some edaphically extreme vegetation complexes, such as Ce, by using treeless categories on the maps of Bradshaw et al. (1977) which are based on detailed photo-interpretation of vegetation structure. The definition of Ce in the northern third is too broad compared to corresponding vegetation complexes, such as Kg, Lg, BAg and Gg, in the southern two thirds of the map. This is due to differences in the precision of the landform maps on which the vegetation complexes are based. In fact, there is scope for improvement in landform mapping for the
Darling Plateau north of the Blackwood River catchment, up to the level of the peripheral surveys of King and Wells (1990) in the north west and of Lantzke and Fulton (1992) in the north east. The mapping of that detail may prove difficult at the scales of 1:250,000 and 1:500,000. The Ww1 vegetation complex of the Margaret River Plateau, which covers several landform units (Wv, Ww and Wvw) of Tille and Lantzke (1990), is ecologically too broad, yet is barely mappable at the scale of 1:500,000 even in its present form.

### 6.3 Extension of the Mapped Area

In view of the considerable effort that has gone into the mapping of the forested portion of the south west, the obvious question is: Could the approach used in this study be applied to the surrounding regions and beyond?

There is no simple single answer. The Swan Coastal Plain to the west has been already mapped by Heddle *et al.* (1980), though at the time the available quantitative information was limited to the sand dune systems of the State forest north of Perth (Havel 1968). Since then, the vegetation patterns of the southern Swan Coastal Plain have been analysed by Gibson *et al.* (1994) and the landforms of the most complex portion of this, centred on the lower Murray River, have been remapped in greater detail by Wells (1989). The area is now covered by the climate map and climatological analysis of Gentilli (1989). It should be feasible therefore to remap the vegetation of the Swan Coastal Plain in greater detail, and with more confidence, than
was possible in 1980. Unfortunately, upgrading of landform maps is difficult to extend laterally. It cannot be done as just a desktop exercise, but requires considerable field survey and photo-interpretation. A further handicap is the high proportion of the Swan Coastal Plain that has been already cleared for agriculture and urban development. The vegetation studies referred to above were, by necessity, based on remnant vegetation, and thus unavoidably have a bias toward the landforms with less fertile soils. All these factors would make the remapping of the Swan Coastal Plain up to a higher standard difficult, but not impossible.

The eastward extension of the maps into the wheatbelt region is also a possibility. In addition to the original studies of Muir (1976, 1977a,b) there have been more recent studies, such as those of Gibson and Keighery (in press) for the Lake Muir district, and other vegetation studies are in progress along the eastern periphery of the forested region (Gibson\(^1\) personal communications). The landform mapping for the Northam-York district (Lantzke and Fulton 1992) is of a high standard, but it is not matched by maps of comparable detail further to the south. The handicap of high level of agricultural clearing is even more acute in the wheatbelt than on the coastal plain. Much of the vegetation would have been cleared even before the pioneer work of Diels (1906). It might be difficult to improve upon Beard's (1981a) vegetation map of the Swan Region.

The most straightforward extension would be eastwards along the southern coast, for

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which landform maps of Churchward et al. (1988), with some ecological annotations, already exist. Although quantitative analysis of the vegetation of this district in advance of the mapping would be desirable, the procedures used for the mapping of the southern forested areas not covered by Strelein (1988) and Wardell-Johnson et al. (1995), in particular the use of toposequences, would provide a reasonable first approximation.

The advantage of this extension, from the scientific point of view, would be the inclusion of the Porongorup Range, which is the largest outlier of karri forest. It would also give a fuller coverage of jarrah forest and woodland.

It is difficult to be optimistic about any of these extensions taking place. Vegetation mapping is a costly exercise, the finance for which generally only becomes available through political process. In most of the potential extensions the battle for conservation of remnant vegetation, which fuels such process, is considered to have been already largely lost (Swan Coastal Plain and wheatbelt) or won (South Coast).

It is also difficult to be optimistic about adoption of the approach described here in other regions of the state. Outside the south western region (coastal plain, forest and wheatbelt) lie the pastoral regions and the deserts, in which the level of economic activity does not appear to warrant mapping beyond the level of detail already achieved by Beard (1981b). The only exceptions are the mining leases, where vegetation mapping is normally funded by the proponents of mining as part of the environmental impact assessment process and is carried out in considerable detail by their environmental consultants. For the broadscale assessment of conservation needs
in these regions, a different methodology, which is more appropriate to the situation where no prior studies exist, has already been developed by McKenzie and Robinson (1987).

Although considerable interest has been expressed in the maps described here from other Australian states, it is unlikely that this methodology will be transferred there. The differences in vegetation patterns, in particular the greater floristic diversity of the tree stratum in eastern Australia, have already been discussed in Chapter 3. Reference has been also made to other significant differences, such as a higher level of forest classification and a lower level of landform mapping compared with Western Australia. A further point of difference is that in most other states the climatic patterns are less constraining, more diffuse and more complex, resulting in a more dispersed forest estate consisting of islands surrounded by anthropogenic vegetation. The continuity of vegetation is therefore less obvious and it would be more difficult to utilise it in the mapping process. In common with Western Australia, the other states have recently gone through the Regional Forest Agreement process, so that the political will to fund vegetation mapping has probably been exhausted for the next one or two decades.

6.4 Use of the Maps

There is no need to speculate how the vegetation maps generated by this project might be used. A precedent has already been established by the maps of the Jarrah bioregion, developed on similar principles 20 years ago by Heddle et al. (1980).
These maps were developed to assist in planning of the conservation estate (Department of Conservation and Environment 1983) and until now remained the only means of assessing the adequacy of conservation in that bioregion (Havel 1989b, McKenzie et al. 1996). The improvement in conservation estate in the jarrah bioregion between the evaluations of Havel (1989b) and McKenzie et al. (1996) has been uneven and many of the vegetation complexes considered to be inadequately represented by Havel, such as Williams (Wi), Darling Scarp (DS), Muja (MJ) and Cardiff (CF), remain in that category. They should be the focus of future efforts. Others, like Helena (He2), Wilga (WG) and Michibin (Mi), are now adequately protected through additions to the conservation estate by the Department of Conservation and Land Management.

A simplified version of this current set of maps has been generated for, and has been recently used in a major decision making process, namely to assess the adequacy of conservation of old growth forest (RFA 1998b). They are currently also being used to relate vertebrate fauna records to forest types (Christensen2 personal communications) and an interest has been expressed in using them for studies of the distribution of invertebrate fauna and of fungi. The feasibility of using the maps to get a better coverage of the forest region by botanical collections has already been mentioned in section 6.2.

The maps of Heddle et al. (1980) have also been used to assess the broad impact on vegetation of human activities such as mining (E. M. Mattiske and Associates, 1979-1994) and dam building (Havel Land Consultants 1987) and to evaluate the potential
impact of forest diseases (Shearer and Tippett 1989). The detailed assessment of impact requires mapping at finer scales, like that of Havel (1975b).

The use of the vegetation maps in land use planning and forest management described above is somewhat unusual, in that world-wide there is a marked decline in published information along the continuum from theoretical studies through broadscale mapping to the use of maps in the management of forests (Havel 1980a, b).

There are other, as yet untried, possible uses for the current set of maps. They could be used to predict the likely impact of climatic changes on the vegetation of the region from a sounder basis than has been done so far from distribution maps of individual taxa and from rainfall maps. However, the predictions would be limited by the fact that the maps only cover what is considered to be a region of relatively high rainfall on a continental scale (Hopper 1992). It would be feasible to predict the effect of decreasing rainfall, resulting in contraction of a taxon’s range to the coast, but not the expansion of a taxon into the inland as a result of increased rainfall, except for the taxa currently confined to hyperhumid – perhumid zones. This may not be a serious limitation as much of the inland region has been largely converted into pasture and crops, and re-invasion by forest and woodland species would be hindered and distorted by competition from exotic species aided by prolonged application of fertilisers. The predicted greenhouse effect for the forested region is, in any case, reduction of rainfall and increase in temperature (Main 1993).

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2 Formerly Department of Conservation and Land Management WA, Como. Now a private consultant.
The maps could also be used to identify ecological systems that are at risk from fragmentation by current and future activities. The bulk of the two bioregions dealt with in this thesis falls into two compact, contiguous areas of State-owned land. Lyons et al. (2000) observed that 83 per cent of recorded taxa of the Warren bioregion occurred within conservation reserves and further a 6 percent within State forest. However, there are many vegetation systems that exist in the context of fragmentation that is of concern to Hobbs (1996). The Rs4 vegetation system of the western periphery and the Ds0 and Ev2 systems of the eastern periphery can be looked on as frontier ecosystems, inadequately protected in existing reserves yet subject to maximum attrition. The threat of fragmentation is also acute in the Blackwood River catchment east of the Darling Scarp (vegetation systems Nm5, Ms5, Mm4, Ms4, Fv3, Jv3, Gw3, Ds2 and Cv1) and on the Margaret River Plateau (Km9, Jp8, Mm6 and Jp6). In the context of strategic ecological surveys of Bunce et al. (1966) the ecological systems of the contiguous forest areas can be looked upon as an upland landscape, characterised by low human population and high proportion of natural and semi-natural vegetation. The areas subject to fragmentations, such as the Blackwood Valley and Margaret River Plateau, as well as the adjacent Swan Coastal Plain and wheatbelt, can be looked upon as an arable landscape with a higher population and lower proportion of natural vegetation.

Finally, the thesis and the associated maps, could be used as a starting point for further research. The thesis raises a number of hypotheses about the factors that control the distribution of tree species in south western Australia. These could be tested by experimental planting of species, like that carried out in Western Australia by Witkowski and Lamont (1997) and in Tasmania by Kirkpatrick and Gibson (1999).
Karri has already been transplanted from the perhumid zone south of Manjimup to the arid zone west of Northam. The resulting stand exhibited early precocious flowering. Such experimentation may merely test the capacity to cope with limiting physical factors. More complex experiments, involving inter-specific competition under periodic fire, may be needed to test the subsidiary hypothesis numbers 11 and 12.
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and


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APPENDIX 2.1: SUMMARY OF GEOMORPHOLOGICAL CLASSIFICATIONS AND MAPS

This appendix enumerates and links the various geomorphological classifications and maps on which the vegetation mapping was based. In subsequent text the landforms presented in bold format are those used in constructing the maps of vegetation complexes (Appendix 3.4).

Churchward and McArthur (1980)

Churchward and McArthur's (1980) subdivided the Darling Plateau into the following major categories:

- Lateritic Uplands
- Minor Valleys
- Major Valleys including Slopes and Floors
- Major Valley Floors and
- Major Valley Slopes and Scarp.

These subdivisions were not actually mapped, nor given any generic name.

The lateritic uplands were subdivided into six mapping units. Churchward and McArthur's (1980) considered their mapping units, based on aerial photographs and contour base maps of between 1:25 000 and 1:50 000, to be approximately equivalent to soil associations. The units were given names of the locality in which the particular landform was best expressed.

- Dwellingup – extensive uplands with coarse gravels in the west and northwest
- Yalanbee – extensive uplands with fine gravels in the east and northeast
- Hester – residual narrow crests in the south

Three additional units were included in the uplands

- Cooke – hills (monadnocks) raised above the plateau surface
- Goonaping – sandy deposits in heads of drainage lines in the north
- Wilga – sandy deposits on flat or gently undulating divides in the south

The minor valleys, most of which have NW-SE lineation determined by the basement rock, include both the floors and slopes and are divided into the following set of mapping units.

- Yarragil – valleys with smooth slopes and narrow swampy floors in the west
- Pindalup – broader floors and greater stripping of the laterite on slopes, in centre and east
- Catterick – more irregular and rockier slopes, in the south
- Coolakin – extensively stripped slopes with much rock outcrop, in the east.

The major valleys, occurring in the deep dissection of the plateau, were subdivided on the magnitude of the relief, the steepness and rockiness of the slopes and on the nature of the floor. The component units were

- Helena – deep (200 m) valleys with steep (30°) slopes and rocky bed
- Bridgetown – deep (200 m) valleys with steep (30°) slopes and terraced floor, mainly in the south
APPENDIX 2.1 (Continued)

**Murray** – moderately deep (90-120 m) valleys with intermediate (15°) slopes and narrow floors, mainly in the centre and north  
**Balingup** - moderately deep (90-120 m) valleys with intermediate (15°) slopes and narrow floors, mainly in the south.

Where the valley floors were broad enough to be mapped separately, they were defined as follows  
**Williams** – gentle gradient, loamy deposits and duplex soils  
**Avon** – steep gradient, sandy deposit  
**Brockman and Noonig** – terraces with red earth soils  
**Mumbullup** – complex terraces.

Major valley slopes and scarps are steep slopes with laterite largely stripped away and include minor valleys too small to be mapped separately. They are separated on relief, steepness, rockiness and soil cover  
**Michibin** – least relief, in the east  
**Bindoon** – moderate relief, in the northwest  
**Lowdon** - greatest relief, in the southwest  
**Darling Scarp** – straight linear occurrence in west.

Similar subdivisions also exists for the Swan Coastal Plain and the Dandaragan Plateau, which are only peripheral to the RFA area. Those mapping units falling marginally into the northwestern periphery of the RFA region are:

On the Dandaragan Plateau  
**Wannamal** - sandplain with a high proportion of swamps and lakes situated at the interface between the Darling and Dandaragan Plateau  
**Cullala** - more extensive sandplain without lakes  
**Mogumber** - remnant of the lateritised uplands with grey sand detritus  
**Karamal** - remnant of the lateritised uplands with yellow sand detritus  
**Moondah** – broad shallow minor valleys with brown, earthy sands  
**Reagan** – gently sloping scarp with laterite spurs and sandy slopes.

On the northern Swan Coastal Plain  
**Beermullah** – alluvial deposits with solonetzic soils  
**Yanga** - alluvial deposits with solonetzic soils in depressions and sandy soils on intervening flat benches  
**Coonambidgee** – mildly sloping sandy deposits flanking the Reagan scarp  
**Forrestfield** – sandy and gravelly spurs at the foot of the Darling Scarp  
**Guildford** – mildly sloping alluvial plain with duplex soils.

The Blackwood Plateau and the southern Swan Coastal Plain, which were only peripheral to the System 6 project, have been more fully described in the subsequent land resources surveys carried out by the Department of Agriculture (Tille and Lantzke 1990, Tille 1996). This is also true of some of the southern landforms of the Darling Plateau described above, such as Wilga, Catterick, Balingup, Bridgetown, Mumbullup and Lowdon, some of which were redefined in the process (Tille 1996).
APPENDIX 2.1  (Continued)

King and Wells (1990)

The valley forms of Churchward and McArthur (1980) were subsequently subdivided and mapped for a limited area of alienated (privately-owned) portion of the Darling Plateau near Perth by King and Wells (1990), who referred to Churchward and McArthur’s (1980) mapping units as geomorphologic elements and to their subdivisions of them as landforms.

The Murray valley form (My) was subdivided into the following landforms:

- My1 - Moderately steep to steep valleys slopes with yellow and mottled duplex soils and with common rock outcrops
- My2 - Moderately inclined to moderately steep valley sideslopes with yellow and mottled yellow duplex soils
- My3 - gentle to moderately inclined lower valley sideslopes, with complex duplex and gradational soils
- My4 - very gently inclined valley floors, with yellow, red and brown gradational earths which are commonly saline

From the above description it seems that the uppermost valley slopes, with their strong lateritic influence, were described as part of the adjacent uplands, namely as landform D3 of moderately inclined undulating slopes.

King and Wells (1990) described each of their landforms in the terms of topsoil and subsoils texture, topsoil and subsoils field pH, profile permeability, profile gravel and stone, nutrient availability and nutrient retention ability in topsoil and profile, moisture availability, rooting conditions, salinity risk, as well as such applied criteria as foundation soundness, soils instability risk, soils absorption ability and subsoil retention ability, damsite construction suitability, soil workability, groundwater supply, surface supply, water erosion, wind erosion, microbial purification ability, water pollution risk and flood risk.

Many of these criteria can be related to vegetation, though King and Wells (1990), who were mainly surveying a strongly anthropogenic landscape, did not make references to the original vegetation.

It would, however, not be difficult to make the connection with Havel’s (1975a,b) site-vegetation types. Southeast of Perth the linkage would be:

<table>
<thead>
<tr>
<th>King and Wells (1990) landforms</th>
<th>Havel (1975a,b) site-vegetation types</th>
</tr>
</thead>
<tbody>
<tr>
<td>My1</td>
<td>R, G</td>
</tr>
<tr>
<td>My2</td>
<td>U, R</td>
</tr>
<tr>
<td>My3</td>
<td>Q</td>
</tr>
<tr>
<td>My4</td>
<td>C, CQ</td>
</tr>
</tbody>
</table>

At the level of Churchward and McArthur’s (1980) landform mapping units and Heddle et al.’s (1980) vegetation complexes the equivalence is:

<table>
<thead>
<tr>
<th>Churchward and McArthur’s units</th>
<th>Heddle et al.’s vegetation complexes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Murray</td>
<td>Murray Complex in Medium to High Rainfall</td>
</tr>
<tr>
<td>Bindoon</td>
<td>Muray and Bindoon Complex in Low to Medium Rainfall</td>
</tr>
</tbody>
</table>
APPENDIX 2.1  (Continued)

Tille's (1996)

Tille's (1996) map of the Wellington-Blackwood district provides not only an example of his hierarchical approach, but also covers landforms not covered, or less adequately described by Churchward and McArthur (1980) where the two maps overlap. Tille (1996) divides the district into the Donnybrook Sunkland Zone of the sedimentary low plateau in the west, the high-rainfall Western Darling Range Zone and the low rainfall Eastern Darling Range Zone of the crystalline plateau. His survey stops short of the Zone of Rejuvenated Drainage, which marginally enters the study area, and just touches on the Warren-Denmark Southland Zone, the bulk of which is covered by Churchward's (1992) and Churchward et al.'s (1988) surveys.

Within the Western Darling Range Zone Tille(1996) identifies three systems:

- Darling Plateau System of the undulating surface of the crystalline plateau
- Lowden Valleys System of valleys cut into the crystalline plateau
- Coalfields System of sedimentary basins within the crystalline plateau

The Darling Plateau System is essentially equivalent to Churchward and McArthur's (1980) lateritic uplands and the shallow minor valleys within them, which have been already described. The same basic nomenclature is used (Dwellingup, Hester, Wilga, Yarragil, Pindalup), but some categories common in the north of the Darling Plateau are omitted (Yalanbee, Goonaping, Coolakin, Cooke, Swamp) and the following additional categories are defined in the south:

- **Boonarie** Subsystem of shallow swampy valleys in Kirup Conglomerate
- **Harris** Subsystem of shallow swampy floors of major rivers
- **Mornington Hills** Subsystem of low hills rising above the plateau surface

The Louden Valleys System consists of the following components:

- **Donnybrook** Subsystem of gravelly slopes over Donnybrook sandstone
- **Dickson** Subsystem of steep loamy slopes on the Darling Scarp
- **Wishart** Subsystem of low gravelly slopes on the Darling Scarp
- **Gale** Subsystem of low apron below the Darling Scarp
- **Grimwade** Subsystem of moderately incised valleys with loams and gravels
- **Kirup** Subsystem of slopes with gravels and sands on Kirup Conglomerate
- **Queenwood** Subsystem of lateritic slopes on Kirup Conglomerate
- **Southampton** Subsystem of alluvial brown deep sands on river flats

The Coalfields System of Permian and subsequent sedimentary basins also retains the nomenclature of Churchward and McArthur's (1980) for Collie Basin (Collie, Cardiff, Muja), but extends to the southeast into the Wilga and Boyup Brook Basins. A new subsystem (Stockton) is introduced. The full set thus is:

- **Collie** Subsystem of broad lateritic divides with gravels and sands
- **Cardiff** Subsystem of broad tracts of swampy terrain
- **Muja** Subsystem of shallow major valleys with well drained flats
- **Stockton** Subsystem of shallow minor valleys with swampy floors.
APPENDIX 2.1 (Continued)

Within the Eastern Darling Range Zone, which is a dissected terrain with large remnants of the lateritic plateau, Tille (1996) identifies two systems:

Eulin Uplands System of the uplands of the laterised crystalline plateau and its remnants, together with the intervening poorly drained flats over sedimentary deposits

Boyp Brook Valleys System of valleys incised into the Eulin uplands by the Blackwood River.

The Eulin Uplands System is a rather heterogeneous collection of subsystems:
- **Dalmore** Subsystem of broad ridges and divides with gravels, loams and sands
- **Sandalwood** Subsystem of low hills rising above the plateau
- **Kulikup** Subsystem of extensive flats with poor drainage, over sedimentary deposits, surrounded by dissected terrain of valleys
- **Qualeup** Subsystem of extensive flats with poor drainage, over sedimentary deposits, surrounded by low hills
- **Lukin** Subsystem of shallow minor valleys with swampy floors

The Boyp Brook Valleys System is also a rather heterogeneous collection of subsystems, associated with the Blackwood River and its tributaries:
- **Newgalalup** Subsystem of moderately to deeply incised major valleys in crystalline terrain, with moderate to steep slopes
- **Boree** Subsystem of shallow major valleys in sedimentary terrain, with gentle slopes
- **Gnowofergerup** Subsystem of narrow flats on minor valley floors, often waterlogged and affected by salinity
- **Condinup** Subsystem of narrow well drained flats on floors of major valleys.

The Eastern Darling Zone entered marginally into the System 6 region mapped by Churchward and McArthur (1980), who placed the uplands into their Dwellingup, Yalanbee, Hester and Wilga landforms, and the valleys into the Michibin and Coolakin landforms. The use of this nomenclature is now confined to Darling Range north of the Blackwood River dissection.

Within the Donnybrook Sinkland Zone Tille (1996) recognises three systems:
- **Blackwood Plateau** System of broadly undulating uplands of the plateau
- **Goodwood Valley** System of valleys formed by the dissection of the plateau
- **Whicher Scarp** System forming the northern margin of the plateau.

The Blackwood Plateau System is subdivided into:
- **Kingia** Subsystem of broad lateritic divides with gravels
- **Telerah** Subsystem of broad, more sandy divides
- **Coate** Subsystem of swampy upland depressions
- **Bidella** Subsystem of shallow minor valleys with swampy floors
- **Jalbaragup** Subsystem of deeper valleys with narrower, better drained floors
- **Milyenup** Subsystem developed on Bunbury basalts
APPENDIX 2.1 (Continued)

The Goodwood Valley System is subdivided into:
- **Rosa** Subsystem of valley side slopes in the north and west of the Blackwood Plateau
- **Blackwood** Subsystem of valley side slopes in the centre of the Blackwood Plateau, on the Blackwood River and its tributaries
- **Preston** Subsystem of alluvial terraces in the north and west of the Blackwood Plateau
- **Darradup** Subsystem of alluvial terraces in the centre of the Blackwood Plateau, on the Blackwood River and its tributaries
- **Layman** Subsystem of swampy depressions within the major valleys
- **Bentley** Subsystem of raised flats within the major valleys.

The **Whicher Scarp System**, which consists of a low scarp separating the Blackwood Plateau from the southern Swan Coastal Plain, is subdivided into:
- **Whicher** Subsystem of gentle lateritic slopes of the scarp
- **Yelverton** Subsystem of a low shelf below the scarp.

The Donnybrook Sunkland Zone of Tille (1996) is closely related to the western half of the area Manjimup region mapped by Churchward (1992), who refers to it as the Blackwood Plateau. He subdivides it into:
- Units associated with drainage lines
- Uplands units (other than those of the drainage lines)

He subdivides the latter into
- Units developed on Mesozoic sediments
- Units developed on crystalline rocks – Bunbury Basalt

The upland units developed on Mesozoic sediments are further subdivided into:
- Undulating local divides
- Swampy tracts

Within the undulating local divide group he recognises three units:
- **Kingia** unit of gently undulating ridge crests forming local drainage divides
- **Telerah** unit of slightly undulating ridge crests forming local drainage divides
- **Jangardup** unit of slightly undulating terrain at the interface of the Blackwood plateau and Scott Coastal Plain.

Kingia and Telerah have also been mapped by Tille (1996), who adopted Churchward’s (1992) nomenclature but distinguished the more gravelly Kingia from sandier Telerah. He did not describe Jangardup as it does not extend so far north.

Churchward recognised only one unit within the swampy tracts
- **Coate** unit of the broad swampy upper tracts of the drainage systems. It was also described by Tille (1996), who adopted Churchward’s (1992) nomenclature.
APPENDIX 2.1 (Continued)

Within the units developed on Bunbury Basalt Churchward (1992) distinguished between

Scott unit associated with scarps and valley slopes and loamy soils and
Milyennup unit associated with uplands and gravelly-sandy soils.

Only Milyennup extended marginally into the area mapped by Tille(1996), who adopted Churchward’s (1992) nomenclature and description.

Churchward’s (1992) units associated with drainage lines are divided into

Major Valleys
Blackwood unit of valleys 40-60 m deep, with relatively steep slopes
Jalbaragup unit of valleys 20-40 m deep, with moderate slopes
Barlee unit of valleys 20 m deep, with mild slopes

Minor Valleys
Bidella unit of minor valleys less than 20 m deep, with mild slopes
Layman unit of broad concave valleys with flat floor, considered to be former valley of the Blackwood River.

Churchward’s (1992) units associated with drainage lines only partly match the Goodwood Valleys System of Tille (1996), who separated the valley floors of the Blackwood unit from the slopes as the Darradup Subsystem of river terraces. In addition he described the Rosa and Preston Subsystems which occur only in north. He did not describe an equivalent of the Barlee unit, which does not occur so far north.

He also treated the Jalbaragup and Bidella units as part of his Blackwood Plateau System, presumably because they are only shallowly incised into the plateau.

The landforms of the Blackwood Plateau have also been described near its western interface with the crystalline Margaret River Plateau by Tille and Lantzke (1990), but the nomenclature is so radically different that it will be dealt with separately.

In addition to the Blackwood Plateau Churchward (1992) also mapped the southwestern portion of the Darling Plateau centred on Manjimup, extending from Yornup in the north to Pemberton and Quininup in the south. He subdivided this region into:

Units associated with drainage lines
Upland units (other than those of the drainage lines)

Within the upland group he distinguished between:

Units developed mainly on crystalline igneous rocks –granites and gneisses
Units developed on quartzite and/or unconsolidated quartzose sediments.

The upland units on crystalline igneous rocks were further subdivided into:

Units of the western fringe of the plateau
Units of the plateau surface.
APPENDIX 2.1  (Continued)

Within the western fringe group Churchward (1992) distinguished between:

**Dickson** unit of stripped, moderately steep slopes, in the northern portion of the Darling Scarp

**Wishart** unit of weathered, milder slopes of the southern portion of the Darling Scarp

**Gale** unit of depositional apron of the Wishart unit, with very gentle slopes.

Within the plateau surface group Churchward (1992) distinguished between:

**Hills**

Undulating plateau elements and broad crests

Swampy tracts.

The hills group contained the following units:

* **Mattaband** unit of single higher hills rising 20-40 m above the plateau surface

* **Collis** unit of single low hills rising less than 20 m above the plateau surface.

The undulating plateau elements and broad crests group was subdivided into:

* **Bevan** unit of gently undulating tracts comprising broadly convex crests and shallow minor valleys

**Corbalup** unit of very gently undulating terrain with very broad crests and broad, sandy, poorly drained concavities

* **Crowea** unit of broadly convex ridge crests and the gentle flanking upper slopes

**Cattaminup** unit of very gently undulating terrain of low rises and shallow flat drainage floors

**Hawk** unit of very gently undulating terrain with minor swampy drainage floors at the interface between the southern tip of the Darling Plateau and the Southern Coastal Plain.

The swampy tracts group contains:

* **Yornup** unit of swampy plains with some included low rises

**Kapalarup** unit of semi-permanent swamps and swampy plains.

The units developed on quartzite and/or unconsolidated quartzose sediments is subdivided on the base of topography into:

**Quartzite** unit of ridge crests and low hills

**Quininup** unit of low smoothly convex hills and vales

**Toponup** unit of broad ridge crests capped by lateritic duricrust

**Forrard** unit of crests and upper slopes formed on Kirup Conglomerate

**Cormint** unit of swampy tracts and low rises

* **Quagering** unit of very gently sloping, poorly drained sandy terrain

* **Angove** unit of very gentle slopes and broad drainage divides.

The broad group of drainage line units on the crystalline plateau is subdivided into major and minor valleys.
The major valley units are:

- **Donnelly** unit of very deeply incised (100-140 m) valleys with moderate to steep slopes in gneissic or migmatic terrain
- **Warren** unit of deeply incised (60-100 m) valleys with moderate to steep slopes in gneissic terrain
- **Wilgarup** unit of moderately incised (50-70 m) valleys with irregular slopes, in granitic terrain
- **Lefroy** unit with moderately incised (40-60 m) valleys with moderate to steep slopes and clearly defined stream channel, in gneissic terrain
- **Wheatley** unit of moderately (20-40 m) incised valleys with moderate slopes and swampy floor, in gneissic or migmatic terrain
- **Yerraminnup** unit of moderately incised (20-40 m) valleys with moderate slopes in granitic terrain
- **Strachan** unit of shallowly incised (less than 20 m) valleys with smooth gentle slopes slopes in granitic terrain

The minor valley units are:

- **Pemberton** unit of moderately incised (20-40 m) valleys with mild to moderate slopes and gently sloping floors with little or no channel development, in deeply weathered terrain
- **Catterick** unit of shallowly incised valleys (20 m) with mild to moderate slopes and flat swampy floors in granitic terrain
- **Carnarvon** unit of shallowly incised valleys (less than 20 m) with mild to moderate slopes and broad swampy floors in deeply weathered terrain
- **Yannah** unit of shallowly incised valleys (less than 20 m) with mild slopes and broadly concave swampy floors, in deeply weathered terrain.

Those of Churchward’s (1992) mapping units marked with asterisk (*) are widely spread landforms that occur throughout the southern forests. They were first defined in Churchward et al.’s (1988) survey of the south coast and hinterland. However the 1988 survey also defined a number of landform units that only occur south and east of the area surveyed by Churchward (1992). Similar classification was used for these:

The three major categories described by Churchward et al.’s (1988) were:

I. Units developed on granitic rocks and associated unconsolidated sediments
II. Units developed on siltstones and sandstones
III. Units developed in coastal Aeolian and fluviatile sediments.

Within the broad group of landforms developed on granitic rocks and associated unconsolidated sediments, the next level of subdivision was:

- Plateau Elements
- Hills and Hilly Terrain
- Swampy terrain

The units of the south coast hinterland described by Churchward et al. (1988) differ from those described from the Manjimup region by Churchward (1992) by being divided on the basis of soils into subunits.
APPENDIX 2.1  (Continued)

The main component of the Plateau Element group, the Bevan unit, is extensively distributed through the south coast hinterland. It has two subunits:
- BEy with yellow duplex soils (Dy3.62)
- BEb with yellow duplex soils (Dy2.62) and red earths.

The other component of the group, the Crowea unit, is subdivided into three subunits:
- CRy with yellow duplex soils (Dy3.62)
- CRb with yellow duplex soils (Dy2.62) and red earths.
- CRd yellow duplex soils with grey sandy topsoil (Dy5.81).

The only new Plateau Element unit is Perillup unit of gently sloping or slightly undulating plains with some included swampy depressions and few shallow valleys.

The Hills and Hilly Terrain group is much more strongly developed in the south coast and hinterland than in the Manjimup region surveyed by Churchward (1996). This is due to the fact that the bulk of it falls into the Albany-Fraser Orogen rather than the Yilgarn Craton. Churchward et al. (1988) included the Mattaband and Collis units in this category rather than the Plateau Elements.

In the case of Mattaband, the complex of low (20-60 m) hills with smooth slopes, the subunits are:
- MTy of yellow duplex soils with grey brown topsoil and some lateritic duricrust on mild upland slopes
- MTb of brown duplex soils, red duplex soils and red earths, with some granitic outcrops on steeper slopes
- MTP of shallow duplex soils with gritty topsoil and some granitic outcrops
- MTd of duplex soils with grey sandy topsoil and some quartz gravel.

Similarly, the Collis unit of low hills (less than 20 m) with smooth flanking slopes includes the following subunits:
- COy of grey-brown sandy topsoil with some boulders of lateritic duricrust on mild upland slopes
- COb of brown duplex soils, red duplex soils and red earths, with some granitic outcrops on steeper slopes
- COP of shallow duplex soils with gritty topsoil and some granitic outcrops
- COd of duplex soils with grey sandy topsoil and some quartz gravel.

Additional members of the Hills and Hilly Terrain group described from the south coast and hinterland are:
Keystone unit of hills and ridges rising up 60 - 300 m above the swampy corridors, with granite outcrops (domes) on upper slopes and smooth midslopes on weathered granite and gneiss. It is subdivided on the basis of rock outcropping, surface texture and hue of the subsoil into
- Kg dominated by granitic outcrops, with shallow, brown gritty soils
- Kb on broad crests and flanking slopes with yellow and red duplex soils and yellow and red earths
APPENDIX 2.1 (Continued)

*Ky* on moderate to gentle slopes with gravely yellow duplex soils and lateritic duricrust
*Kp* on mid to lower slopes with yellow duplex soils with shallow gritty topsoil
*Ks* pockets sandy podzols in saddles and concavities, often poorly drained.

**Lindesay** unit of hills and ridges rising up 60 - 300 m above the adjacent terrain, with frequent granitic and gneissic outcrops (pavements, domes). Hill slopes are of irregular form, with outcrops interspersed with varying depth of weathered mantle and sands. The unit is subdivided on the degree of rock outcropping and on soils into

*Lg* extensive granitic outcrops flanked by shallow brown gritty loams
*Ly* smooth slopes with much less frequent rock outcrops and gravely yellow duplex soil
*Lp* smooth mid slopes with yellow duplex soils with shallow gritty topsoil
*Ls* pockets of sandy podzols in saddles and concavities, often poorly drained.

**Gardner** unit of coastal hills and ridges with relief of more than 60 m, whose upper slopes and crests consist of granitic and gneissic outcrops but lower slopes are smooth and covered by deep weathered mantle and sometimes by calcareous sands. The unit is only weakly represented in the project area as

*Gg* granite pavements and domes
*Gm* most of it occurring further to the east.

**Barrow** unit of hills and ridges with relief of 60 - 300 m. There are granite outcrops (domes, pavements and tors) on upper slopes and smooth lower slopes of weathered granite and sand mantle, sometimes surrounded by Plantagenet sediments. It is subdivided on the basis of rock outcropping into

*Bag* upper slopes and crests dominated by granitic outcrops, with shallow gritty loamy soils
*Baf* moderate to gentle slopes with yellow duplex soils with sandy topsoil and boulders of lateritic duricrust.

Another hill unit, described only from the extreme east of the project area, and then only as one small occurrence, is

**Pillenorup (PN)**, consisting of isolated hills rising less than 60 m above the general level of the plateau north of Mt Barker, developed on granite partially covered by Pallinup siltstone. Usually there are no granitic outcrops and the soils are yellow duplex soils with deep sandy topsoil.

The Swampy Terrain group is particularly strongly developed on the Southern Coastal Plain and as belts between the hills in the hinterland. The units described by Churchward *et al.* (1988) include:

**Angove (A)** already described above

**Camballup (CM)** swampy plains with broad drainage floors, permanent and ephemeral swamps, lunettes and low rises of weathered rock, in granitic terrain. The dominant soils are yellow solonetzic soils.
APPENDIX 2.1 (Continued)

Caldyanup (CA) poorly drained plains and broad drainage floors between hill ridges, mainly in granitic terrain but with some siltstone. The dominant soils are yellow solonetzic soils.

Sidcup (SD) Narrow and shallow drainage depressions in granitic terrain, filled with colluvial sands occurring as extensions of Camballup. The dominant soils are humus podzols.

Quindabellaup (QN) slightly concave valley divides or elongate saddles. The dominant soils are humus podzols.

Pingerup (PI) poorly drained plains and interridge corridors, including broad drainage floors, ephemeral and permanent swamps and few low granite domes. The dominant soils are humus podzols.

Burnett (BU) gently sloping plains with drainage floors and numerous granite outcrops. The dominant soils are humus podzols on plains and shallow gritty soils around the outcrops.

Morande (MO) complex of lunettes, dunes and hummocks with intervening swampy terrain, mostly in weathered Pallinup siltstone. The dominant soils are heavy clays or yellow solonetzic soils in swamps and podzols on the dunes and lunettes.

Quagering (Q) broadly convex or flat valley divides with some swamps, with unconsolidated sandy sediments over granite or quartzite. The dominant soils are humus podzols and peaty podzols.

Hazelvale (HA) swampy corridors partially incised by minor streams, developed on shallow unconsolidated sandy sediments over weathered granite. The dominant soils are humus podzols, peaty podzols and sandy yellow duplex soils.

Within the second major group of units, namely those developed on siltstones and sandstones, the main division is between Plateau Elements and Swampy Terrain.

The Plateau Elements group contains the following mapping units:

Redmond (R) flat or gently undulating upland plain on Pallinup siltstone, with ephemeral swamps and lakes and ill-defined drainage lines. The dominant soils are yellow duplex soils, often with lateritic gravel in topsoil.

Dempster(D) spurs and ridges in the dissected southern margin of the Pallinup siltstone plateau, with both lateritic duricrust and deep sands. The unit is subdivided into:

Dc broad convex crests of spurs and ridges with yellow duplex soils containing lateritic gravel.

Ds gentle slopes adjacent to Dc, with humus podzols developed on deep sands.

Mitchell (MI) gently undulating uplands with broadly convex crests and gentle flanking slopes and some included swampy, sandy depressions, developed on sandstones. The dominant soils are gravely duplex soils on crests, deep sands on slopes and humus podzols in depressions.
APPENDIX 2.1 (Continued)

Trent (TR) low hills with less than 40 m relief, with broad convex crests and gentle flanking slopes, on siltstones and sandstones. The unit is subdivided into:
TRc ridge crests with gravely sandy yellow duplex soils and some lateritic duricrust
TRs gentle slopes with deep grey sands and podzols

The Swampy Terrain group contains the following mapping units:
Boulongup (BO) broad, shallow, circular, poorly drained depressions in the siltstone plateau, with some included lunettes and hammocks. The dominant soils are yellow solonetzic soils, but there are also cracking clay soils.
Fernley (F) gently undulating terrain of broad low rises and broad swampy depressions on siltstones, sandstones and sandy detritus. The dominant soils are yellow duplex soils on the rises and humus podzols in depressions.

The broad group of landforms (mapping units) developed on coastal Aeolian and fluviatile sediments (III) is subdivided into:
Dune systems and
Coastal Swampy Terrain

The units comprising the dune systems are:
d’Entrecasteaux (E) broad coastal ridges often more than 100 m high, adjacent to curved bays between granite headlands, with steep seaward scarps and mild landward slopes, formed on Tamala limestone, which is cemented calcareous aeolian sand. The dominant soils are deep calcareous sands, with outcrops of limestone (travertine), but there are also some shallow brown sands and podzols.
Meerup (M) complex of parabolic dunes extending inland from the southern coast, considered to be the product of four successive phases of deposition. The dunes often overlie granitic headlands, d’Entrecasteaux ridges and coastal alluvium. The dunes are subdivided into:
Ms oldest dunes furthest inland, with smooth rounded crests and gentle slopes. The dominant soils are podzols over slightly calcareous sand at depth.
Mp second oldest dunes with sharper crest and steeper slopes. The dominant soils are podzols over slightly calcareous sand at depth.
Mc third phase of sand dunes with sharp irregular crests and steep slopes. The dominant soils are pale calcareous sands with organic enrichment in the surface 10 cm.
My youngest phase of sand dunes adjacent to the beach, with very sharp irregular crests and very steep slopes. The dominant soils are loose pale calcareous sands with very slight organic enrichment at the surface.
Mu unstabilised dunes, usually but not always close to the shoreline. The dominant soils are loose pale brown calcareous sands.
APPENDIX 2.1 (Continued)

Mf flats and gently undulating depressions enclosed by parabolic dunes with swampy elements. The dominant soils are podzols over calcareous sand.
Mr beach ridges, generally less than 5 m high, and intervening swales. The dominant soils are pale brown calcareous sands, with organic enrichment in the swales.

The coastal swampy terrain consists of the following units:
Blackwater (BW) poorly drained coastal plain with very diffuse drainage patterns, some linear dunes and granitic tors and pavements, developed on unconsolidated sands and clays over mainly granitic substrate. The unit is divided on the basis of soils into:
BWp broad swampy plains with humus and peaty podzols
BW (Bwo) narrow swampy coastal plain on fluviatil sediments, with solonetzic soils.
Owingup (O) poorly drained estuarine plains with swamps and lakes, with some included dunes and lunettes. The dominant soils are solonetzic soils.
Kordabup (KO) broad swampy tracts in lower reaches of stream, often composed of low broad rises and intervening drainage floors on unconsolidated sandy sediments. The dominant soils are humus podzols.
Walpole (Wp) flat to gently undulating benches of unconsolidated sandy sediments and Aeolian sands. The dominant soils are humus podzols.

The broad group of landforms (mapping units) associated with drainage lines (IV) is subdivided into:
Major valleys (V) and
Minor Valleys (S)

The valleys of the south coast and hinterland do no reach the depth of dissection of the valleys in the western margin of the Darling Plateau. The major valleys:
V1 valleys are only incised 40-60 m into the granitic plateau, and have mainly smooth steep slopes with only occasional rock outcrops. The dominant soils are red earths, but there are also red and yellow duplex soils on slopes and brown sandy loams on terraces.
V2 valleys are generally upstream of V1 and are 20-40 m deep, with moderate smooth slopes largely without rock outcrops. The dominant soils are gravely yellow duplex soils, but there are also red earths on slopes and earthy sands and peaty podzols on valley floors.
V3 valleys traverse belts of hills and are 20-40 m deep, with rocky granitic slopes. The dominant soils are yellow duplex soils.
V4 valleys are courses of major streams traverse traversing swampy terrain, are less than 10 m deep and include terraces. The dominant soils are loamy and silty sands.
V5 valleys occur in the north and are set 40 m into a granitic plateau, with mild smooth slopes. The dominant soils are yellow duplex soils on slopes and yellow solonetzic soils on the floor.
V6 valleys only occur east of this project area.
APPENDIX 2.1 (Continued)

V7 valleys are incised 20-40 m into sedimentary rocks, have steep and irregular slopes with outcrops and terraced floors. The dominant soils are gravelly yellow duplex soils on slopes and deep loamy sands on terraces. V8 valleys are broad but shallow, incised 20 m into sedimentary rock. The soils range from gravelly yellow duplex soils on upper slopes through deep leached sands on lower slopes and yellow solonetzic soils on terraces.

The Minor Valleys (S) group consist of the following set of units:
S1 valleys set in granitic plateau upstream of V2, less than 20 m deep with mild smooth slopes and swampy floor. The dominant soils are yellow duplex soils on slopes and peaty and humus podzols on the floor.
S2 valleys resemble S1 valleys except that their floors are gently concave and prone to salinity problems.
S3 valleys are shallow valleys with concave floors in swampy terrain, less than 5 m deep, with mild slopes. The dominant soils are peaty podzols and humus podzols.
S4 valleys are broad swampy drainage zones only 5 m deep. The dominant soils are humus podzols.
S5 valleys are narrow incisions in granitic terrain, less than 10 m deep. The dominant soils are sandy yellow duplex soils.
S6 valleys are narrow, often V-shaped valleys incised into sedimentary terrain, less than 10 m deep. The dominant soils are sandy yellow duplex soils on slopes and deep sands on floors.
S7 valleys are open U-shaped valleys with broadly concave or flat floors incised less than 30 m into sedimentary terrain. The dominant soils are deep leached sands on slopes and humus podzols on floors.
S8 valleys are broad shallow valleys and alcoves in undulating sandstone terrain. The dominant soils are deep leached sands or gravelly sands on slopes and humus podzols on floors.

In his survey of the Manjimup region Churchward (1992) covered the remainder of the Southern Coastal Plain westward up to Black Point. In this study the western edge of the Darling Plateau is used as a dividing point. East of this the nomenclature of Churchward et al. (1988) has been retained. West of it the nomenclature of Tille and Lantzke (1990), developed for the remainder of the coastal plain westward to Cape Leeuwin, where the Southern Ocean meets the Indian Ocean, has been used. The primary reason for that is that west of the Darling Scarp the nature of the coast changes, in that granitic and gneissic headlands are absent until the west bank of the Blackwood River at Augusta is reached. The only crystalline headland in that portion of the coast is the Black Point, composed of Bunbury Basalt. The coastal plain behind the dunes is also markedly different, being much swampier and lacking crystalline outcrops. Churchward’s (1992) maps, which straddle the Darling Scarp, provided a link between Churchward et al. (1988) and Tille and Lantzke (1990).
APPENDIX 2.1  (Continued)

There is one landform (mapping unit) described exclusively by Churchward (1992), namely

Cleave (CV) swampy terrain which represents the shallow (less than 10 m) dissection of the Blackwater swampy plain by minor streams, which are flanked by very gentle slopes. The dominant soils are humus podzols or peaty podzols.

Tille and Lantzke (1990) describe the coastal dunes east of Augusta as the D’Entrecastaux Dune System (D) and the coastal plain north of it as the Scott Coastal Plain (S). At its northern margin The Scott Coastal Plain merges almost imperceptibly into the Blackwood Plateau.

Tille and Lantzke (1990) define the D’Entrecasteaux Dune System as beach backed by steeply sloping parabolic calcareous dunes 20-80 m high, which in turn are backed on the landward side by a series of lower siliceous dunes 20-40 m high. They divide the system into the following units:

- Db beaches with deep calcareous sand
- DE5 south facing calcareous dunes exposed to strong winds from the Southern Ocean
- DEm5 blow-outs in Dem5.
In this study Db and Dem5 are combined with the more extensive DE5.
- D5 sheltered northern slopes of the calcareous dunes
- D interdune flats with deep calcareous sands
- Dd5 moderately sloping siliceous dunes
- Dd2 gently sloping siliceous dunes
In this study Dd2 with Dd5 has been combined.
- Dd flats between the dunes with deep bleached siliceous sands
- Dr rocky dunes with calcerinite rubble
- Drd rocky flats underlain by calcerinite.

Tille and Lantzke (1990) describe Scott Coastal Plain (S) as a broad, poorly drained, level to gently undulating plain, formed on Quaternary sediments, rising from sea level to 40 m at its junction with the Blackwood Plateau. They subdivide it into the following units:

- Sd poorly drained flats with deep bleached sands
- Swd extremely poorly drained flats with organic stained sands
- Swi extremely poorly drained with shallow sands over ironstone
- Sd2 low sandy rises.
  In this study Sd and Sd2 has been combined.

To the west of the Scott Coastal Plain Tille and Lantzke (1990) define the Blackwood Alluvial Plain (B), described as a level to gently undulating plain formed on Quaternary alluvial floodplains and terraces of the Blackwood river. Most, though not all, of the soils are sandy, and on the whole the Blackwood Alluvial Plain is better drained than the Scott Coastal Plain, though there are some extensive poorly drained patches. It is subdivided into the following units:

- B well drained flats or rises
- Bw poorly drained depressions
APPENDIX 2.1 (Continued)

Bf well drained loamy soils  
Bd low rises with deep bleached sands.

The key area surveyed by Tille and Lantzke (1990) was the Leeuwin-Naturaliste region, in particular the Margaret River Plateau composed of granitic-gneissic rocks. The plateau extends from Cape Leeuwin in the south to Cape Naturaliste in the north. In the west its Indian Ocean coast is partially overlain by aeolian sediments (Leeuwin-Naturaliste Coast), on the eastern, inland side it abuts on to the sedimentary Blackwood Plateau and in the northeast on to the Swan Coastal Plain.

The Leeuwin-Naturaliste Coast is subdivided into
Kilcarnup Dunes (K) and
Gracetown Ridge (G).

Kilcarnup Dunes (K) are a discontinuous band of steeply inclined high (up to 200 m) parabolic dunes of calcareous sand overlaying the western slopes of the Gracetown Ridge. The following units are recognised within it:

KE recently formed dunes of pale calcareous sand exposed to strong winds.  
Kb beaches and foredunes  
KEf older dunes of calcareous sand in which organic matter has accumulated in the topsoil, exposed to winds but vegetated  
KEm blowouts in the dune systems, which because of their limited size have been included in KEf  
KrE oldest exposed dunes in which aeolinite has began to form and the organic matter in the topsoil has built up to a dark topsoil

There are limited occurrences of Kilcarnup Dunes on the sheltered lee side of the dune system

Kf steep dunes not exposed to seawinds, with organic matter in the topsoil and  
Kr dark calcareous sands containing limestone rubble.

The Gracetown Ridge consists of older dunes, rising up to 210 m, which have been lithified to form Tamala Limestone. It has the following component units:

Ge gently undulating crest  
GE moderately inclined western sideslopes subject to strong winds from the Indian Ocean  
G2 moderately inclined eastern sideslopes sheltered from strong winds, with deep brownish yellow siliceous sands  
G3 gently inclined eastern footslopes sheltered from strong winds, with red-brown siliceous sands  
Gk karstic topography with caves and sinkholes  
Gv deep narrow minor valleys cut into the Gracetown Ridge.

The crystalline Margaret River Plateau is divided into the
Cowaramup Uplands (C)  
Wilyabrup Valleys (W) and  
Metricup Scarp (M).
APPENDIX 2.1 (Continued)

The Cowaramup Uplands consist of a gently undulating to undulating plain, rising from 20-80 m in the south to 80-140 m in the north, formed on lateritised granitic-gneissic basement rocks. It is subdivided into the following units:

C flats and gentle slopes with yellow-brown duplex soils and pale grey mottled soils
Ci laterite cap at or near surface (included in C)
Cvw shallow drainage depression with broad poorly drained floors
Cv shallow drainage depressions with narrow, v-shaped floors
Cw poorly drained slight depressions (Cv, Cvw and Cw have been mapped as Cw because of scale problem)
Cd2 flats and low rises of deep bleached sand (mapped as Cd)
Cr shallow rocky soils.

The Wilyabrup Valleys are a valley system moderately deeply incised into the Margaret River Plateau, forming undulating to rolling hills below the upland surface of the plateau. Tille and Lantzke (1990) recognise many subdivisions within it on the base of slopes and soils, many of which are difficult to map at the scale used in this study. They have been reduced to:

W sideslopes of the valleys with yellow-brown, gravelly duplex soils and red-brown gravelly gradational soils (earths)
Ww broad drainage depressions with swampy floors
Wr steep rocky slopes with shallow soils and rock outcrops
Wd milder slopes with deep bleached sands

In addition there are localised occurrences of the Wilyabrup system on the southwestern coast, exposed to strong winds.

Three subsystems have been mapped:

WE granitic headlands with maximum exposure
We coastal well drained low slopes
Wew coastal poorly drained depressions

The Metricup Scarp is the eastern edge of the northern Margaret River Plateau. It has a relatively uniform slope, but has been dissected by small deep valleys. Tille and Lantzke (1990) recognise several subdivisions within it, but just two are mapped:

M even moderate main slope of the scarp with deeper yellow brown gravelly soils with some lateritic outcrops
Mv steeper slopes of minor valleys with shallower soils and rock outcrops.

At the southeastern margin of the Margaret River Plateau Tille and Lantzke (1990) delineated a transitional system of

**Glenarty Hills (H)** which overlaps on to the Blackwood sedimentary plateau. The system consists of undulating rises and rolling low hills formed by dissection of the two plateaux by the McLeod and Glenarty Creeks. Tille and Lantzke (1990) recognised a number of subdivisions which have been combined into just three:

H gently inclined valley sideslopes and ridge crests with yellow brown gravelly duplex and pale grey mottled soils, with some lateritic outcrops
Hw broad swampy valley floors and poorly drained depressions
Hd low rises of yellow and bleached sands.
APPENDIX 2.1 (Continued)

Blackwood sedimentary plateau, which occupies the bulk of the land between the Margaret River Plateau in the west and the Darling Plateau in the east, is considered by Tille and Lantzke (1990) to be somewhat more dissected at its western margin. They describe three systems:

- **Treeton Hills (T)** the central higher portion of the plateau
- **Yelverton Shelf (Y)** flanking T in the north
- **Nullup Plain (N)** flanking T in the south.

The Treeton Hills are undulating rises and rolling hills developed on lateritised sedimentary rocks of the Perth Basin through the dissection by Margaret and Carbanup Rivers and Chapman Brook. The hills range in height from 20 to 120 m. Tille and Lantzke (1990) recognise a number of subdivisions which in this study are reduced to just three:

- **T** gently inclined ridges and hill crests with moderately inclined hill slopes with yellow-brown duplex soils and pale grey mottled soils with some lateritic outcrops
- **Td** areas of deep leached sands
- **Tw** valley floors and depressions, often poorly drained.

The Yelverton Shelf is considered by Tille and Lantzke (1990) to be the remnant of an ancient plain or plateau, forming gently inclined slopes rising from the Swan Coastal Plain to the Treeton Hills. Tille and Lantzke (1990) recognise a number of subdivisions which here are reduced to just three:

- **Y** gently inclined slopes with yellow-brown duplex soils and pale grey mottled soils with some lateritic outcrops
- **Yd** areas of deep leached sands
- **Yw** valley floors and depressions, often poorly drained.

The Nullup Plain is considered by Tille and Lantzke (1990) to be the transition, in the form of a level or gently undulating plain, between the Scott Coastal Plain and the Treeton Hills. Tille and Lantzke (1990) recognise a number of subdivisions which are here reduced to just three:

- **N** flats with pale grey mottled soils
- **Nd** areas of deep leached sands
- **Nw** shallow open drainage lines and depressions, often poorly drained.

The Swan Coastal Plain within the region mapped by Tille and Lantzke (1990) is only its southernmost extremity. It is subdivided by them into:

- **Abba Plain (A)**
- **Ludlow Plain (L)**
- **Quindalup Coast (Q)**.

The Abba Plain is a gently undulating plain formed on Quaternary alluvium. It lies between 10-40 m a.s.l. and contains extensive areas of poor drainage. It is essentially a patchwork of shallow depressions and low rises. Tille and Lantzke (1990) recognise a number of subdivisions which in this study are reduced to just five:

- **A** low rises with sandy grey-brown gradational and duplex soils
APPENDIX 2.1 (Continued)

Ad low rises and dunes of deep bleached sand
Adw depressions with sandy soils
Af well drained flats sandy grey gradational soils and red-brown sandy loams
Aw deeper depression with clay soils.

The Ludlow Plain is a narrow strip of land between the Abba Plain and the Quindalup Coast. It is level to gently undulating and is formed on the aeolianite and calceranite of the Tamala limestone. Only one of the several units described by Tille and Lantzke (1990) falls into the project area, namely
Lw shallow depressions with seasonal waterlogging.

Similarly, only one of the subdivisions of the Quindalup Coast system is mapped, namely
Qw defined by Tille and Lantzke (1990) as wet flats, with poor subsoil drainage in winter.

In addition to the land systems, subsystems and mapping described above there is a significant area in the east and southeast of the project area for which published information is either limited or lacking. However even in these areas information is available in the form of maps and informal descriptions.

In the Blackwood catchment east of the area surveyed by Tille (1996) published information is available down to the level of zones and systems (Grein 1995), and unpublished information to the level of subsystems. In the Eastern Darling Zone there are two land systems not covered by Tille (1996), namely Boscabel and Darkan, which are considered by Grein (1995) to be dissected lateritic terrain.

Boscabel (Bo) gently undulating rises and small alluvial plains with sandy and gravelly soils, subdivided into
Bo1 crests and slopes with duricrust and shallow sandy gravels
Bo1s mid and lower slopes with deep sandy duplex soils or deep loose sands

Darkan (Dk) gently undulating to undulating rises with sandy gravels on divide crests, and sandy or loamy duplex soils on weathered granite or dolerite on slopes, subdivided into
Dk1 divide crests with duricrust and loamy gravels
Dk2 moderate valley slopes with gravelly yellow duplex soils
Dk3 steep valley slopes with loamy duplex soils, shallow skeletal soils and rock outcrops
Dk4 footslopes and drainage lines with deep grey duplex soils
Dk5 near level broad depressions and valley floors with lunettes, with solonetzic soils on floors and deep sands on lunettes
Dk5f footslopes with sandy gravels

Immediately east of the Eastern Darling Zone is the Zone of Rejuvenated Drainage, described by Grein (1995) as rolling terrain between 240 and 380 m a.s.l., in which the dissection of the lateritic profile generates moderately to gently inclined rises and
APPENDIX 2.1 (Continued)

hills which are either rounded or with breakaways below lateritic remnants. Locally there are steeper slopes with exposed basement rock. The drainage lines may be sluggish but the streams flow in clearly incised courses.

The only system of this zone that occurs within the project area is **Farrar (Fa)**, described as undulating hills and rises drained by the Balgarup River, developed over granitic or doleritic country rock. Only a small proportion of the system remains covered in laterite, in the form of small plateaus with sandy gravels separated from the slopes by breakaways. It is subdivided into:
- **Fa1** upper slopes, ridges and minor plateaus with sandy gravels
- **Fa2** moderate slopes with red or yellow duplex soils
- **Fa3** steep valley slopes with loamy duplex soils, shallow skeletal soils and rock outcrops
- **Fa4** footslopes and lower slopes with grey sandy duplex soils
- **Fa5** near level broad depressions and valley floors with solonetzic soils.

The systems for which no published information is so far available occur at the eastern margin of the project area, east of the Manjimup survey of Churchward (1992), south of the Wellington-Blackwood survey of Tille (1996) and north of the south coast hinterland survey of Churchward *et al.* (1988).

The unpublished survey of Stewart-Street and Smolinski\(^1\) defines the following systems:
- **Frankland Hills (FH)**
- **Gordon Flats (GD)**
- **Unicup Flats (UC)**
- **Wingewelup (Wg)**
- **Jingalup (Jp)**
- **Nuniup Nu**
- **Mallawillup (Mm).**
- **Pumpareena (Pu).**
- **Yarraleena (Ya)**

Frankland Hills system is described as low hills east of the Perup Plateau with lateritic gravels, yellow brown gravelly sands and gravelly yellow duplex soils. Only five of the subsystems defined have been utilised, namely:
- **FH1** lateritic crests and upper slopes including isolated low gravelly rises, with yellow brown gravelly duplex soils and gravelly sands, with lateritic boulders
- **FH2** upper to lower slopes, with gravelly yellow mottled duplex soils and pale yellow and bleached sands
- **FH3** minor valleys with moderately deep to deep sandy duplex soils and deep pale yellow sands
- **FH4** lower slopes and flats including swampy depressions, with moderately deep grey sandy duplex soils

\(^1\) Agriculture WA, South Perth
APPENDIX 2.1 (Continued)

FH5 saline valley floors with shallow to moderately deep yellow and gleyed mottled duplex soils, usually with grey or bleached topsoil

Gordon Flats system consists mainly of poorly drained alluvial flats and benches with some gravely and sandy rises. The system is characterised by strong development of sodic soils. Within the project area it is surrounded by Frankland Hills and merges into Unicup Flats in the south. Of the six subsystems described only three have been utilised:

GD1 broad swampy flats and drainage lines, with shallow gravelly duplex soils and sodic clays
GD2 low sandy rises with moderately deep to deep grey sandy duplex soils. Included within this study is GD2
GD3 low gravelly rises with loamy and gravelly duplex soils have been included in GD2
GD4 swampy terrain with shallow to moderately deep yellow sodic duplex soils with conspicuously leached A2 horizon over clay. We have included in it GD5 saline drainage lines and flats have been included in GD4.

The Unicup Flats consists mainly of poorly drained flats with lakes, swamps and low gravelly and sandy rises.

The system is subdivided as follows:

UC1 generally flat terrain with intermittent lakes and swamps. The dominant soils are pale sands overlying bog iron hardpans or gravels with mottled clay within 2 m.
UC2 low sandy rises with deep pale sands which may overlie gravel layers
UC3 gravelly rises yellow brown gravelly duplex soils on crests and gravelly sands over laterite or bog iron ore
UC4 swamps with pale sands over bog iron ore, seasonally waterlogged

The Jingalup system was represented only very marginally in the project area, the bulk of the system being to the north and east. It consists of gently undulating rises drained by the Tone River. The only subsystem mapped was:

JP2 simple to convex lower slopes with moderately deep gravelly duplex soils and grey sandy duplex soils.

The Nuniup system is only marginally represented in the project area by

Nu gently undulating plains developed on bog iron ore, with sandy gravelly duplex soils

The Wingewelup system consists of

Wg swampy valley floors with minor rises and lunettes, with solonetizc soils and sands

The Yarraleena system is only marginally represented in the project area by

Ya raised alluvial terrace with fine sands over blocky clay
APPENDIX 2.1  (Continued)

The Pumpareena system consists of
   Pu gently undulating plain with low rises, with sandy gravels over clay or deep sands

The Mallawillup system consists of
   Mm low rises developed on bog iron ore, with gravely duplex soils.

In order to balance the size of the mapping units, some of the smaller subsystems have been combined, as discussed above, e.g. GD2 and GD3 and GD4 and GD5. The underlying assumption was that although such subsystems might be sufficiently different in terms of their arability, cropping potential or erosion risk, they were not sufficiently distinct in terms of their potential to support natural vegetation.
APPENDIX 2.2: LINKAGE BETWEEN VEGETATION CLASSIFICATIONS OF STREILEIN (1988) AND HAVEL (1975a)

The linkage between the classifications of Strelein (1988) and Havel (1975a) is described below with emphasis on floristic similarities.

Strelein’s type S is represented lateritic uplands, defined by indicator groups very similar to Havel’s groups GRAMED (Banksia grandis, Hovea chorizemifolia), FREGRA (Leucopogon propinquus, Macrozamia riedlei) and HIGRA (Pteridium esculentum, Leucopogon verticillatus), which define Havel’s site-vegetation type S, but with some modifications. For instance, the third member of Havel’s GRAMED group, Persoonia longifolia, is so widespread in the southern jarrah forests, that it has only a negative indicator value. It is only absent from extremely wet (F, A) or dry (M, Y) site types. The FREGRA and HIGRA indicator groups, which are relatively precise indicators of moist and moderately fertile lateritic uplands in the north, are only absent from the more extreme site types (B, F and A), largely due to the higher rainfall and greater degree of dissection in the southern jarrah forest. By contrast, another component of Havel’s GRAMED group, Adenantheros barbigera, is so rare in the south that it does not figure as an indicator in Strelein’s study.

A new indicator group of lateritic gravels, consisting of Acacia browniana, Acacia myrtifolia, Bossiaea aquifolium subsp. laidlawiana, Crowea angustifolia, Hakea lasianthoides, Petrophile diversifolia, Sphaerolobium medium and Xanthorrhoea gracilis, has been defined by Strelein. It is labelled here SOGRA (southern lateritic gravels), as many, though not all, of its constituents have a strong southern bias in their overall distribution. There are several other indicators utilised by Strelein, which are absent from Havel’s classification. Three of them, Hovea elliptica, Hakea amplexicaulis and Patersonia umbrosa occur on lateritic gravels with loamier and hence more fertile matrix. They are placed in the SOGRAF group, which is also characteristic of type S.

Strelein’s site type T is closely related to Havel’s T, sharing with it the indicator groups GRAMED, FREGRA and HIGRA. It differs from S in having weaker development of SOGRA. This trend away from indicators of laterite is accentuated in site type Q, in which both SOGRA and GRAMED are replaced by a group of indicators of higher fertility such as Eucalyptus patens (Havel’s FEHIRA), Acacia urophylla (Havel’s GRAHIR), Tremandra stelligera, Clematis pubescens and Acacia alata. They have been brought together under the label SOFER (southern fertile sites), though they are not exclusively southern species.

A very similar set of indicators, but without Eucalyptus patens, defines Strelein’s type U. Strelein’s U and Q differ from Havel’s types U and Q in containing Eucalyptus marginata. In addition, Strelein’s Q lacks Trymalium floribundum. The edaphic equivalent of Havel’s types U and Q in the cooler, moister south is tall forest of karri (Eucalyptus diversicolor) described by Inions (1990a,b).
APPENDIX 2.2 (Continued)

Strelein’s type X differs from his types U and Q in lacking SOFER and containing another set of southern indicators such as Agonis flexuosa, Anarthria scabra and Anigozanthus flavus, which are indicative of sandier sites than S, T, Q and U. They are labelled SOBROSAN (southern broadly sandy sites).

A type weakly endowed with clear-cut indicators is Strelein’s type V, which has a weak to moderate representation of FREGRA, SOBROSAN and SOFER. It also has a strong representation of Acacia extensa. Strelein’s types X and V appear to be southern equivalents of Havel’s W and E, both of which occur on water gaining lower slopes in lateritic landscape.

Strelein’s types K and N are significant natural lineages with Inions (1990) classification, in that they contain karri (Eucalyptus diversicolor) as well as jarrah (Eucalyptus marginata subsp. marginata). The principal indicator group defining them consists of Acacia pentadenia, Eucalyptus diversicolor, Chorizema ilicifolium and Allocasuarina decussata and is labelled SOFERMO (southern fertile moist). The second major indicator group consists of Boronia gracilipes, Agonis parviceps and Podocarpus drouynianus (labelled SOSALOM - southern sandy loams, moist). The labels were chosen because of the edaphic preference of the species and the southern bias in their distribution. An exception is Chorizema ilicifolium, which extends north where it is part of Havel’s FEHIRA (fertile, high rainfall) indicator group with Trymalium floribundum. Though Trymalium floribundum is a prominent associate of karri on optimum sites, it does not feature in Strelein’s classification. Yet another indicator is Xanthorrhoea preissii, which is a very widespread species, reaching its strongest dominance on moist sandy flats on the northern Swan Coastal Plain, where it is an indicator of optimum sites for exotic tree plantations (Havel 1968). It has been placed here in the indicator group BROMO (broadly moist). In addition to SOFERMO and SOSALOM, types K and N are also associated weakly with indicator groups SOGRA, SOFER, and FREGRA. K differs from N in not containing any SOBROSAN, which indicates it is less sandy. Within Strelein’s classification K and N are the optimum sites, combining favourable moisture regime with good fertility of the soil.

Site P is a transitional site in that it lacks clear association with any indicator group. It contains some representation of indicator groups SOGRA, SOGRAF, GRAMED, SOSALOM and FREGRA. It also contains Desmoclados fasciculatus and Desmoclados flexuosus (formerly belonging to the genus Loxocarya) and Xanthorrhoea preissii. These species, together with Kingia australis, Lepidosperma squamata (formerly L. angustata) and Acacia extensa have been placed into indicator group BROMO (broadly moist), which is similar to Havel’s (1975a) group of that name in the north. It terms of site, this group is associated with colluvium below lateritic uplands. Strelein’s site type P has weak floristic association with Havel’s P, which also comes from lateritic colluvium, but in a drier climate.

The trend toward lowland position and water gaining site is accentuated in type R, whose key indicator groups are SOBROSAN, BROMO, SAMORG and SOSAM. The SAMORG (sandy, moist organic soils) group consists of Adenanthis obovatus,
Dasypogon broomiiifolius and Leucopogon concinnus. It is very similar to Havel’s SAMORG. The extension of BROMO and SAMORG into, and strong development in the moister south, is readily explainable by the fact that in the north these groups are dependent on the proximity of ground water to the surface. The SOSAM (southern sands, moist) group, consists of Pultenaea reticulata, Thomasia grandiflora, Hakea ruscifolia and Melaleuca thymoides. In type R the last two groups, indicative of sandy colluvium below lateritic uplands, reach their optimum development. Type R is the southern equivalent of Havel’s type B. Site type I has a moderate development of the indicator groups SOGRA, SOGRAF, GRAMED, SOSALOM, BROMO, SAMORG and FREGRA, but lacks any outstanding indicator groups. It is equivalent to Havel’s type O, and like it is indicative of slightly heavier textured colluvium within lateritic uplands.

Strelein’s type B is defined by the absence of the widespread species of the southern lateritic uplands in indicator groups SOGRA, SOGRAF, GRAMED, HIGRA and FREGRA. It also lacks the widespread tree species marri (Corymbia calophylla). It thus represents a significant departure from the norm. It has moderate representation of the groups SOSALOM and SAMORG, indicative of water-gaining sites with sands and sandy loams. This is reinforced by the presence of such other species as Kingia australis (BROMO) and Eucalyptus patens (SOFER). It is similar to Havel’s type D. The trend toward seasonal water logging peaks in Strelein’s type F, strongly defined by the absence of the key species of the southern jarrah forest, jarrah (Eucalyptus marginata subsp. marginata), marri (Corymbia calophylla) and Persoonia longifolia, as well as of the common indicator groups SOGRA, SOGRAF, GRAMED, SOSALOM, HIGRA and FREGRA. It thus represents maximum departure from the norm. Its key indicator group is SOWET (southern wetlands) with Anarthria prolifer, Beaufortia sparsa and Homalospermum firmum. Other species present are Leucopogon australis, Agonis parviceps and Dasypogon broomiiifolius, all of which also have a bias toward water gaining sites. The site type is representative of largely treeless swamps, and is the endpoint of the continuum from uplands to swamp in the high rainfall zone. It has no clear equivalent in Havel’s classification, being essentially confined to the perhumid southern region, though in topographic position it resembles Havel’s type A.

However, the true equivalent of Havel’s type A is Strelein’s type A, which is primarily developed in the drier eastern inland of the southern jarrah region. It contains Melaleuca preissiana, Banksia littoralis, Eucalyptus rudis and Melaleuca viminea (indicator group VERWET - very wet sites). The presence of other species such as Hakea lissocarpa, Astroloma ciliatum, Xanthorhoea preissii, Allocasuarina humilis and Eucalyptus marginata subsp. marginata suggests that some lower slopes with better drainage are also included in addition to the flat waterlogged valley floors.

Another inland type is Strelein’s type Y, whose primary indicator groups are FREGRA with Leucopogon propinquus, Macrozamia riedlei and Bossiaeae linophylla, and BROMO with Desmoclados fasciculatus and Acacia extensa. Additional species such as Trymalium ledifolium, Hypocalymma angustifolium and Astroloma ciliatum, have been lumped into indicator group DRYGRA (dry gravels). Other species present
are *Hakea lissocarpa* (BROFER), *Bossiaea ornata* (GRAMED) and *Leucopogon australis* (SOBROSAN). The nearest equivalent type in Havel’s classification is W, though some of its indicators, such as *Eucalyptus patens* and *Lepidosperma squamatum* (formerly *L. angustatum*) are absent. It is representative of moderately incised eastern valleys with loamy soils.

It has close affinities with Strelein’s type M, which shares with it most of the indicators except the Bossiaea species and *Acacia extensa*, and has such additional species such as *Eucalyptus wando*, *Dryandra bipinnatifida*, *Dryandra lindleyana* (formerly *D. nivea*) and *Astroloma pallidum*. These additional species have also been placed in indicator group DRYGRA, which is broader than Havel’s group of that name. Strelein’s vegetation type M is a near equivalent of Havel’s type M from the dry inland slopes.

The final of Strelein’s types, Z, shares many indicators with Y and M. It differs chiefly in the absence of *Eucalyptus wando*, *Dryandra lindleyana* and *Hypocalymma angustifolium*. It is a near equivalent of Havel’s type Z of eastern dry slopes, but differs from it in having *Leucopogon verticillatus*, confined in the north is to higher rainfall zone.
APPENDIX 2.2: LINKAGE BETWEEN VEGETATION CLASSIFICATIONS OF STRELEIN (1988) AND HAVEL (1975a)  
This table represents Strelein's description of site types of southern jarrah forest with the species re-arranged to highlight ecological relationships.

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The primary subdivision of Mattiske Consulting Pty Ltd (1996) survey of the Scott Coastal Plain was based structure of the vegetation:
1. woodland to open forest
2. low open woodland
3. open heath
4. sedgeland.

The secondary subdivision was based on edaphic differences within the structure classes. Within the woodland-open forest class the edaphic subdivisions were:
1.1. drier open woodland
1.2. open forest - woodland
1.3. seasonally moist open forest-woodland
1.4. to 1.6 moist to wet open forest
1.7. woodland on sandy loams
1.8. open forest on southern sandy dunes
1.9. open forest on deep sandy loams.

Similarly, the low open woodlands were subdivided as follows:
2.1. low open woodland, sedgeland and heath on dunes
2.2. low woodland-open forest on dunes
2.3. to 2.5 seasonally swampy low open woodland
2.6. to 2.7 seasonally wet swamps.

A similar approach was followed for heath and sedgelands.

In analysing the data set, it became obvious that the floristic patterns did not coincide with the primary subdivision based on structure of the vegetation. Rather, they approximated more closely the secondary subdivisions based on edaphic criteria. By applying the Braun-Blanquet methodology, as modified for Australian conditions by Bridgewater (1981), and utilising the species/site relationships described by Havel (1975a,b), McCutcheon (1980) and Strelein (1988), a continuum from well drained sites, mainly carrying woodlands and open forest, to seasonally inundated swamps, was developed.

The continuum is shown in the tabular form after the text section of this Appendix.

Within this overall continuum, there are several well-defined floristic groupings. At the dry end of the continuum there were several group of species largely confined to uplands. The smallest group is that defining community 1.7, that is the SOGRAF group of Eucalyptus diversicolor, Hovea elliptica and Podocarpus droymianum. The next group, present on 1.1,1.2, 1.6, 1.8, 1.9 and 2.2, consists of upland species with preference for well drained sands and sandy gravels. The linkage to McCutcheon’s
APPENDIX 2.3 (Continued)

study is through his indicator groups LOSAN (*Hakea lissocarpa* and *Xanthorrhoea gracilis*) and GRAMED (*Bossiaea ornata*, *Persoonia longifolia* and *Hovea chorizemifolia*). The GRAMED label has been retained.

A closely related group, extending on to communities 1.3, 1.4, 1.5 and 4.2 of moister and slightly more fertile sites, has links to both Strelein and Havel (1975a,b) through *Leucopogon verticillatus* (Strelein’s HIGRA), *Banksia grandis* (McCUTCHEON’s and Strelein’s GRAMED) and *Macrozamia riedlei* and *Leucopogon capitellatus* (McCUTCHEON’s and Strelein’s FREGRA). The presence of these groups indicates laterisation of the soils and higher proportion of colloidal iron in the soils than in the previous group. The FREGRA label has been retained.

Another group with a narrow range, restricted to communities 1.2, 2.1 and 2.2, consists of *Gompholobium scabrum*, *Adenanthis meisnerii*, *Banksia attenuata*, *Calytrix flavescenta* and *Gompholobium confertum*, all species with known links to sandy soils of low fertility. The clearest link with McCUTCHEON’s study was *Banksia attenuata* of SANLEA, followed by *Adenanthis meisneri* of MOSAN. The SANLEA label has been retained.

The progress toward moister sites commences in the next group, whose range extends into communities 3.2, 4.5, 4.6, 2.5, 2.3 and 2.4, all of which are described as seasonally moist or seasonally swampy.

The linkage to McCUTCHEON is through *Dasypogon bromeliifolius* of SAMORG and *Daviesia decurrens* of SANGRA. The linkage to Strelein is through *Agonis flexuosa* of SOBROSAN, *Hakea ruscifolia* of SOSAM, *Lepidosperma squamatum* and *Kingia australis* of BROMO and *Dasypogon bromeliifolius* of SAMORG, most of which are associated with moderately moist sites. The group has been labelled SCOBROMO (Scott broadly moist).

The next group has a similar range of communities, but is absent from communities 1.7, 1.8, 1.9 and 1.6. Its linkage is through *Banksia illicifolia* (McCUTCHEON’s MOSAN), *Petrophile linearis* (McCUTCHEON’s SANLEA), *Acacia browniana* and *Allocasuarina fraseriana* (McCUTCHEON’s SANGRA). These species and species groups are indicative of moist sands and sandy gravels. It has been labelled SCOMOSAN (Scott moist sands).

The species group occurring in a still narrower range of communities, that is mainly 4.3, 3.2 and 2.5, consists of species mostly discovered and named relatively recently, such as *Restio serialis* (ms), *Darwinia ferricola* (ms), *Grevillea manglesioides* and *Dryandra nivea* subsp. *uliginosa*, which are associated with shallow soils over ferruginous B horizon (hardpan). It has been labelled it IRONPAN. Other as yet unnamed species (*Pimelea* sp. and *Calothamnus* sp.) also fall into this group.

The next species group has a much broader range, occurring in most communities except on those that tend to be frequently flooded, namely 2.6, 2.7 and 2.8. This
APPENDIX 2.3 (Continued)

group, containing such species as Eucalyptus marginata subsp. marginata, Anarthria prolifer, Xanthorrhoea preissii and Acacia pulchella subsp. pulchella, therefore has only negative indicator value. In Strelein’s classification Eucalyptus marginata subsp. marginata is also a negative indicator, being only absent from extreme swamps, Xanthorrhoea preissii is included in the broad indicator group BROMO, Acacia pulchella is included in the broad indicator group BROFER, but Anarthria prolifer belongs to indicator group SOWET of wet sites. This group has been labelled BROGRA.

The broadness of range is also true of a similar group, which is also absent from 1.7, 3.3 and 4.4. This group is linked to Strelein’s group SOBROSAN through Anarthria scabra, Anigozanthus flavidus and Leucopogon australis, to SOSAM and to McCutcheon’s group MOSAN through Melaleuca thymoides. The SOBROSAN label has been retained.

Yet another group of broad range species has linkage to McCutcheon’s group BROWET through Lyginia barbata, and Agonis parviceps. It has further linkage to McCutcheon through Adenanthis obovatus of SAMORG, Mesopelana tetragona of BROMO and Pultenaea reticulata of VERWET. It also has a linkage to Strelein through Agonis parviceps of SOSALOM, Adenanthis obovatus of SAMORG, Pultenaea reticulata of SOSAM and Bossiaea linophylla of FREGRA. With the exception of the last one, these species are associated with moist sandy sites. The group is only absent from the extremes of Mattiske’s communities, namely 1.7, 1.8 and 1.9 at the dry and 2.6, 2.7 and 2.8 at the wet end of the continuum. The BROWET label has been retained.

The species group with the broadest occurrence across Mattiske’s communities is that containing Melaleuca preissiana, Astartea fascicularis and Banksia littoralis (McCutcheon’s and Strelein’s VERWET) and Meeboldina scariosa (McCutcheon’s BROWET). It is only consistently absent from community 1.7, yet the species containing it are considered to be indicators of wet sites by both Havel and McCutcheon, as indicated by the mnemonic labels VERWET and BROWET. It is indicative of the low-lying, poorly drained topography and high rainfall of the Scott Coastal Plain, where adequately drained sites are an exception rather than the rule. The VERWET label has been retained.

There are two species groups with an even stronger bias toward poorly drained sites, expressed in the absence from adequately drained sites, that is communities 1.1, 1.2, 1.7, 1.8 and 1.9.

One of these groups is also absent from communities 2.6, 2.7 and 2.8, which tend to be seasonally flooded. Its chief affinity is with Strelein’s group SOWET, through Beaufortia sparsa, Evandra aristata and Homalospermum firmum. It also contains Calothamnus lateralis subsp. lateralis, identified by Havel (1968) to be the indicator of extremely wet sites on the Northern Swan Coastal Plain, and Lepidosperma tetroquetrum of the riparian zone of the northern jarrah forest (Havel 1975a). The SOWET label has been retained.
APPENDIX 2.3 (Continued)

However the group with the greatest tolerance to waterlogging and flooding is that containing *Hakea ceratophylla* (McCutcheon's VERWET), *Melaleuca rhaphiophylla*, *Melaleuca cicutularis*, *Baumea juncea*, *Baumea vaginalis* and *Meeboldina* (formerly *Leptocarpus*) *coangustatus*. It's primary occurrence is in seasonally flooded communities 2.6, 2.7 and 2.8, with which few other species can cope. The group has no common species with Strelein's classification, being wetter than his SOWET and VERWET groups, but has a counterpart in Wardell-Johnson et al (1995) of the south coast, which is yet to be discussed. It has been labelled FREQWET (frequently wet).
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| **FREGRA (Continued)** |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Grevillea brachystylis subsp. australis | +   | +   |     |     |     |     |     |     | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Leucopogon capitellatus | +   | +   | +   |     | +   |     |     |     | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Persoonia ?elliptica | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| **SCOBROMO** |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Agonis flexuosa | +   | +   | +   | +   | +   | +   | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Lindseaea linearis | +   | +   | +   | +   | +   | +   | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Scaevola calliptera | +   | +   | +   | +   | +   | +   | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Hakea ruscifolia | +   | +   |     | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Xylomelum occidentale |     | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Dasypogon bromeliifolius | +   | +   | +   | +   | +   | +   | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Andersonia caerulea | +   | +   | +   | +   | +   | +   | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Acacia browniana var. obscura | +   | +   |     |     | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Eutaxia epacridoides | +   | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Burchardia congesta | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Daviesia decurrens |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Desmocladas flexuosus (ns) | +   | +   | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Lepidopsperma squamatum | +   | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Gompholobium capitatum |     | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Jacksonia horrida | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Kingia australis |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| **SCOMOSAN** |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Hypocalymma strictum | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Anarthria gracilis |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Chorisema ilicifolium | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Daviesia flexuosa | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Banksia ilicifolia | +   | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Eucalyptus linearis |     | +   | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Petrophile linearis | +   | +   |     |     | +   | +   | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Bossiaea rufa |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Leucopogon gilbertii | +   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

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| Agonis juniperina           |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Baumea articulata           |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Triglochin procerum         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Leptocarpus tenax           |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Melaleuca rhapsophylla      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Melaleuca caticularis       |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Baumea juncea               |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Hakea ceratophylla          |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Baumea vaginalis            |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Leptocarpus coaugustatus    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
APPENDIX 2.4: LINKAGE BETWEEN VEGETATION CLASSIFICATIONS OF INIONS ET AL. (1990a,b) AND STRELEIN (1988)

Inions has described 13 community types within the karri forest.

One such community type is Ednie-Brown (No 1), characterised by sandy soils with low phosphate levels. The species of high fidelity, equivalent to Strelein's (1988) indicator species, are *Persoonia longifolia* and *Banksia grandis* in the second storey, *Macrozamia riedlei*, *Boronia gracilipes*, *Hibbertia cunninghamii*, *Podocarpus drouynianus*, *Conospermum caeruleum*, *Lomandra nigricans*, *Lomandra integra* and *Ricinocarpus glaucus* in the shrub and herb storey and *Eucalyptus patens* in the overstorey. Some of these feature in Strelein's indicator groups such as SOSALOM (*Boronia gracilipes*, *Eucalyptus patens* and *Podocarpus drouynianus*), GRAMED (*Banksia grandis* and *Persoonia longifolia*) and FREGRA (*Macrozamia riedlei*). On basis of these indicator groups the affinity of this type is with Strelein's types K and N, which do contain some karri. The remaining species have not been picked up as indicators by either Strelein or Havel, possibly because some of them (*Ricinocarpus* and *Lomandra* spp.) have wide edaphic and climatic tolerances. *Hibbertia cunninghamii*, *Conospermum caeruleum*, *Lomandra nigricans*, *Lomandra integra* and *Ricinocarpus glaucus* have been put in a new species group labelled INFEKA (infertile karri sites).

The second community type, Lane-Poole (No 2), is weakly defined in terms of indicator species, the only ones identified being *Boronia gracilipes* (Strelein's SOSALOM) and *Acacia pentadena* (Strelein's SOFERMO), *Crowea angustifolia* (Strelein's SOGRA) and *Ricinocarpus glaucus*. On basis of these, it is also similar to Strelein's types K and N. Lane-Poole is more favourable than Ednie-Brown in terms more summer rainfall and higher phosphate, which is reflected in the presence of *Acacia pentadena* and in the absence of the GRAMED indicators. The combination of *Acacia pentadena* and *Crowea angustifolia* has been named the SOFERMO species group.

The Kessel community group (No 3), which is described as occurring on gravely yellow or brown duplex soils in the south, is defined by *Chorizema ilicifolium* of SOFERMO group, *Pteridium esculentum* of HIGRA and *Hibbertia commutata*, *Macrozamia riedlei*, *Lasiopetalum floribundum* and *Leucopogon propinquus* of the FREGRA group. This places it between Strelein's jarrah types K and T. It is richer in phosphate than Lane-Poole and markedly richer than Ednie-Brown. The last species, *Paraserianthes lophantha*, has not been recognised as indicator in other studies. It has a considerable edaphic range and is a pioneer species, but is included here in FREGRA.

The Stoate community group (No 4) occurs on brown duplex soils. In the moister south it extends on to the slopes of hills, but in the drier centre it is concentrated on lower slopes and valley floors. It is relatively low in phosphate. Of its main indicators only one, *Acacia pentadena*, is used by Strelein and has been placed in the SOFERMO group. *Chorilaena quercifolia*, *Eucalyptus guilfoylei* and *Lepidosperma effusum* are largely confined to karri sites. They are included in the SOLOAM
APPENDIX 2.4 (Continued)

(southern loams) group. *Lomandra nigricans* is a widespread species with wide edaphic tolerance. This community type also has weak links with Strelein’s types K and N.

The Harris community group (No 5) is described as forest-heathland ecotone. It has the highest summer rainfall and lowest phosphate. It shares some indicators (*Acacia pentadentia, Lepidosperma effusum*) with Stoate, but has a set of unique indicators such as *Acacia divergens, Dampiera hederacea, Hibbertia cuneiformis, Hibbertia furfuracea, Scaevola microphylla* and *Pimelea clavata*. These have not been used by Strelein, but are known to be associated with sandier and more acidic soils of the older dunes. This indicator group has been labelled HEATHEO (heath ecotone). Three species shared with Strelein, *Agonis parviceps, Patersonia umbrosa* and *Leptomeria cunninghamii*, which are here confined to Harris community group, have been also included in HEATECO. Others also shared with Strelein are *Agonis flexuosa* (SOBROSAN) and *Allocasuarina decussata* (SOFERMO). This community group is difficult to relate to Strelein’s types, other than that it is somewhere near Strelein’s K, N and B, and that it is an ecotone rather than a well-defined community or a type.

The Wallace community type (No 6) is described as occurring on moist but well-drained sites with low phosphate and moderate acidity. The indicators shared with Strelein include *Crowea angustifolia var. dentata and Chorizema illicifolium* (SOFERMO), *Lepidosperma effusum* (SOLOAM) and *Anigozanthus flavidus* (SOBROSAN). *Eucalyptus jacksonii*, which does not feature in Strelein’s classification is included in SOFERMO. The community has an affinity with Strelein’s types K and N.

The Stewart community type (No 7) is distinguished from those already described by coming from the drier northeast subject to summer drought, compensated for by higher phosphate. It has jarrah (*Eucalyptus marginata* subsp. *marginata*) as a canopy component. Its indicators include *Bossiaea linophylla* of Strelein’s FREGRA, *Hakea amplexicaulis, Acacia browniana* and *Acacia myrtifolia* of SOGRA, *Clematis pubescens* of SOFER and *Leucopogon australis* of Strelein’s SOBROSAN. In addition it has a number of specific indicators such as *Logania serpillofolia, Tremandra diffusa, Hybanthus debilissimus* and *Billardiera variifolia*, labelled DRYKA (dry karri). This community type has affinity with Strelein’s types Q and U. *Leucopogon australis* is included in Inions’ SOGRA, *Kennedia coccinea* in SOFER and *Eucalyptus marginata* and *Bossiaea linophylla* in DRYKA.

The Beggs community type (No 8) occurs on well drained, fertile upland sites in the drier north and has as its faithful species *Bossiaea aquifolium* subsp. *laevidawiana* of Strelein’s SOGRA, *Hovea elliptica* of SOGRAF, *Leucopogon verticillatus* and *Pteridium esculentum* of HIGRA, *Tremandra stelligera* of SOFER, *Acacia pulchella* of BROFER, *Banksia grandis* of GRAMED and *Leucopogon australis* of SOSAM. Three additional species, namely *Corymbia* (formerly *Eucalyptus*) *calophylla*, which is a component of the canopy, and *Lomandra drummondii* and *Opeleuraria hispidula*, which are perennial herbs have been placed in the HIGRA group. On basis of Inions’
APPENDIX 2.4 (Continued)

data, *Hovea elliptica* and *Leucopogon australis* are included in SOGRA and *Acacia pulchella* in HIGRA. The indicators place this community type close to Strelein's type T.

The McNamara community type (No 9) occurs in the dry northeast and has high average phosphate levels. Its faithful species (indicators) are *Acacia urophylla* of Strelein’s SOFER, *Leucopogon verticillatus* of HIGRA, *Hibbertia amplexicaulis* of SOGRA, *Banksia grandis* of GRAMED. Together they match the site description of moderately fertile upland sites with admixture of lateritic gravel. There is also a group of species not utilised by Strelein, consisting of *Helichrysum ramosum*, *Hibbertia commutata*, *Logania vaginalis*, *Hardenbergia comptoniana*, *Orthrosanthus laxus* and *Orthrosanthus multiflorus*, which has been labelled NOREKA (northeastern karri). Many of these are common species of the jarrah forest. This community is close to Strelein’s types T or U.

The Shea community type (No 10) occurs in northern areas with high but seasonal rainfall, on fertile but gravelly upland sites. The faithful species are *Bossiaea aquifolium* subsp. *laidlawiana* of Strelein’s SOGRA, *Tremandra stelligera* and *Acacia urophylla* of SOFER and *Chorilaena quercifolia*, which was not used by Strelein but is common in high rainfall karri forest. The community is close to Strelein’s types Q and U.

The Havel community type (No 11) occurs on moist sandy loams on streamlines in northern range of karri with high but seasonal rainfall. The soils are low in phosphate but have high cation exchange capacity. The indicator species are *Hovea elliptica* of SOGRA, *Chorilaena quercifolium* and *Lepidosperma effusum* of SOLOAM, and a specific group of *Chorizema diversifolium*, *Logania vaginalis*, *Opercularia volubilis* and *Veronica plebeia*, which has been labelled SOVAL (southern valleys). This community type has no close connection with any of Strelein’s types, which generally do not descend into the deeply dissected valleys of the high rainfall zone.

The White community type (No12) occurs on moist but freely drained sites in the north, with relatively fertile soils. Its faithful species are mostly unique to Inions’ classification and include *Callistachys* (formerly Oxylobium) *lanceolata* of DRYKA, *Amperea ericoides* of NOREKA, *Hibbertia grossulariifolia* of SOFER and *Hibbertia commutata* of FREGRA. *Hibbertia commutata* is a widespread species of the jarrah forest, whereas *Hibbertia grossulariifolia* has a largely a southern distribution. Only *Pteridium esculentum* of HIGRA is shared with Strelein. The White community type has no close connection with any of Strelein’s types.

Inions *et al.* (1990a,b) also describes Annels community type (No 13), which differs from White in higher phosphate values. However, as the characteristic species given by him are the same as for White, Annels will be only considered as a subset of White.
### APPENDIX 2.4: VEGETATION CLASSIFICATION OF KARRI FOREST BY INIONS ET AL. (1990a,b)

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APPENDIX 2.5: LINKAGE BETWEEN VEGETATION CLASSIFICATION OF WARDELL-JOHNSON ET AL. (1989) AND OTHER CLASSIFICATIONS

Wardell-Johnson et al. (1989) define twelve community types, and list characteristic species for them. The first of these, defined as *Pimelea longiflora* heathland community, occurs on damp sites with shallow sandy soils and has the following characteristic species, given here with corresponding Strelein (1988) groups in brackets: *Adenanthos obovatus* (SAMORG), *Agonis hypericifolia* (BROMO), *Allocasuarina fraseriana*, *Lyginia barbata*, *Xanthosia rotundifolia* and *Pimelea longiflora*. The last three species have been labelled the PIMLONG group. This community type has affinity with Strelein’s site groups R and I.

Community type 2, defined a *Agonis parviceps* shrubland community, occurs within granitic terrain on shallow pale sand over yellow brown mottled clay, and has as characteristic species *Agonis parviceps* and *Desmoclados* (formerly *Loxocarya*) *flexuosa* (BROMO), *Anarthria prolifera* and *Beaufortia sparsa* (SOWET) and *Anarthria scabra* (SOBROSAN), *Stylium scandens*, *Thysanotus pauciflorus* and *Burchardia umbellata*. The last three species have been labelled the AGOSH (Agonis shrubland) group. *Eucalyptus marginata* subsp. *marginata*, also listed by Wardell-Johnson et al. (1989), is not useful in Strelein’s classification because its commonness in the jarrah forest. On structure and composition this community type is close to Strelein’s type F.

Community type 3, described as *Beaufortia sparsa* plain on humus and peaty podzols, approaches Strelein’s F even more closely. It is defined by *Acacia myrtifolia* (SOGRA), *Adenanthos obovatus* and *Dasyypogon bromeliifolius* (SAMORG), *Anarthria scabra* and *Melaleuca thymoides* (SOBROSAN), *Anarthria prolifera*, *Beaufortia sparsa* and *Homalospermum firmum* (SOWET). *Leucopogon capitellatus*, *Corymbia* (formerly *Eucalyptus*) *ficifolia* and *Mesomelaena tetragona* have not been used by Strelein as indicators. The presence of *Leucopogon capitellatus* and *Eucalyptus marginata* subsp. *marginata* suggests that even this community type is not as extreme as Strelein’s type F, which lacks *Eucalyptus marginata*.

Community type 4, described as an ecotone between *Agonis parviceps* shrubland and *Bossiaea webbii* forest, occurs on gravelly yellow duplex soils. Its characteristic species are *Agonis hypericifolia* (Strelein’s GRAMED) and *Agonis parviceps* (SOSALOM), *Persoonia longifolia* (NEGIN), *Kunzea recurva* and *Bossiaea webbii*. The last two species have no counterpart in Strelein, and have been labelled AGBOS (*Agonis-Bossiaea* ecotone). This community type has some links with Strelein’s type P, but is sufficiently distinct to be considered a separate type.

Community type 5 is also described as an ecotone between *Agonis parviceps* shrubland and forest, but a forest with a different understorey, dominated by *Acacia browniana*. It is described as varying in both underlying edaphic conditions (podzols or sands or gravels over clay) and in structure (heathland to open forest). The characteristic species defined by Wardell-Johnson et al. (1989) are *Agonis parviceps* (Strelein’s SOSALOM), *Acacia browniana* (Strelein’s SOGRA), *Leucopogon australis*
APPENDIX 2.5 (Continued)

(Strelein’s SOBROSAN), Bossiaea webbii (AGBOS), Burchardia umbellata and Stylidium scandens (AGOSH), Pimelea longiflora and Xanthosia rotundifolia (PIMLONG). On the basis of these, the affinity of this community type is with Strelein’s types P, R and I.

Community type 6 is described as Dasypogon bromeliifolius heath and shrubland on deep leached sands and podzols. Its characteristic species shared with other classifications are Acacia myrtifolia (Strelein’s SOGRA), Acacia pentadenia (Strelein’s SOFERO), Dasypogon bromeliifolius (Strelein’s SAMORG), Amperea ercoides (Inions’ NOREKA), Anarthria scabra (Strelein’s SOBROSAN), Melaleuca thymoides (Strelein’s SOSAM), Desmocladius (formerly Loxocarya) flexuosa (Strelein’s BROMO). There is also a new group of three species not referred to previously, namely Jacksonia furcellata, Lysinema ciliatum and Vellea trinervis, labelled DASBROM. On the basis of the indicators it has affinities with Strelein’s type R, though it is quite distinct. One species (Amperea ercoides) is shared with the NOREKA group of Inions et al. (1990)

Community type 7 is described as Allocasuarina fraseriana forest community, occurring on humus podzols developed on deep sands. Its characteristic species are Allocasuarina fraseriana, Acacia myrtifolia (Strelein’s SOGRA), Agonis hypericifolia (Strelein’s GRAMED, Leucopogon australis (Strelein’s SOBROSAN), Leucopogon verticillatus (Strelein’s HIGRA), Pimelea longiflora, Lyginia barbata and Xanthosia rotundifolia (PIMLONG), Burchardia umbellata (AGOSH), and Mesomelaena pseudostygia (formerly M. stygia). This community type is similar but not identical to Strelein’s type R.

The next community type (No 8) differs sharply from all preceding ones by being tall open forest of Eucalyptus diversicolor on light brown gravelly duplex soils or red or yellow earths in hilly terrain. It is superior to all preceding types in terms of edaphic conditions, being relatively fertile and well drained. Its characteristic species are Acacia browniana (Strelein’s SOGRA), Leucopogon verticillatus (Strelein’s HIGRA), Acacia pentadenia, Eucalyptus jacksonii and Allocasuarina decussata (Inions’ and Strelein’s SOFERO), Chorizaena quercifolia and Lepidoperma effusum (Inions’ SOLOAM) and Hibbertia furfuracea (Inions’ HEATHECO). The type is thus closest to Inions’ community types Stoate, Harris and Wallace. It has also affinities with Strelein’s types K, N, Q and U.

Community type 9, described as Acacia littorea dune community is associated with relatively recent, weakly leached calcareous sands in form of steeply sloping dunes. It characteristic species are Agonis flexuosa (Strelein’s and Inions’ SOBROSAN), Desmocladius (formerly Loxocarya) flexuosa (Strelein’s BROMO), Acacia littorea, Isotropis cuneifolia and Senecio laetus. The last three species have been put in a new indicator group ALIT. This community type has no affinities with Strelein’s or Inions’ classifications, occurring only on coastal dunes.
APPENDIX 2.5 (Continued)

Community type 10, described as Banksia littoralis interdune community, is associated with podzols on siliceous sands in interdune plains and swamps of older dunes. Its structure ranges from heath to open forest. The characteristic species are: *Amperea ericoides* (Inions’ NOREKA), *Anarthria scabra* (Strelein’s SOBROSAN), *Melaleuca thymoides* and *Pultenaea reticulata* (Strelein’s SOSAM), *Desmocladius* (formerly *Loxocarya*) *flexuosa* (Strelein’s BROMO), *Agonis flexuosa* (Strelein’s and Inions’ SOBROSAN), *Allocasuarina fraseriana*, *Acacia littorea* (ALIT), *Banksia littoralis* (Strelein’s VERWET) and *Patersonia occidentalis*. The last species has been placed into BROMO. This community type has affinities with Strelein’s type R.

Community type 11 is described as *Jacksonia furcellata* dune community, associated with podzols overlying calcareous sands in older dune systems. Its characteristic species are *Agonis flexuosa* (Strelein’s and Inions’ SOBROSAN), *Pultenaea reticulata* and *Patersonia occidentalis* (Strelein’s SOSAM), *Senecio laetus* (ALIT), *Agonis parviceps* (Strelein’s SOSALOM), *Jacksonia furcellata* and *Velleia trinervis* (DASBROM). There is a small group of new species, which includes *Lindsaea linearis* and *Eutaxia obovata*, labelled JACFUR. Being a coastal type, this community type has no clear equivalents in Inions’ or Strelein’s classifications.

Community type 12 is described as *Allocasuarina humilis* dune community, associated with podzols overlying siliceous sands in older dune systems with smooth outlines. Its characteristic species are *Agonis flexuosa* (Strelein’s and Inions’ SOBROSAN), *Allocasuarina fraseriana*, *Amperea ericoides* (Inions’ NOREKA), *Isotropis cuneifolia* (ALIT), *Eutaxia obovata* (JACFUR), *Lepidosperma effusum* (Inions’ and Strelein’s SOSALOM), *Desmocladius* (formerly *Loxocarya*) *flexuosa* and *Patersonia occidentalis* (Strelein’s BROMO), *Logania serpyllifolia* and *Leucopogon capitellatus* (Inions’ DRYKA). There are two new characteristic species, *Allocasuarina humilis* and *Hakea prostrata*, labelled ALHUM. Being a coastal type, this community type has no clear equivalents in Inions’ and Strelein’s classifications. There are, however, linkages between Wardell-Johnson et al.’s types 9-12, all of which occur on coastal dunes. The differences between them mainly arise out of the degree of leaching, which is to a degree influenced by topographic position, but is primarily determined by the age of the dunes.

*Allocasuarina fraseriana*, which is identified as a characteristic species for several of Wardell-Johnson et al.’s community types, is absent from the classifications of Strelein and Inions, but has been used as an indicator of sandy gravels (SANGRA) by Havel (1975a). Similarly, *Mesomelaena tetragona* has been used as an indicator of broadly moist sites (BROMO).
### APPENDIX 2.5: WARDELL-JOHNSON ET AL. (1989) VEGETATION CLASSIFICATION OF WALPOLE NATIONAL PARK

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APPENDIX 2.6 SPECIES / SITE MATRIX FOR THE CLASSIFICATION OF WARDELL-JOHNSON ET AL. (1995)

The matrix represents the re-working of the unpublished community types / species matrix, which has been made available by the Director of Research in the Department of Conservation and Land Management WA, Dr Neil Burrows. It is restricted to those occurrences of species within the data set which exceed constancy of 50% within at least one of the 44 community types defined by cluster analysis (Czekanowski matrix, UPGMA) and ordination (SSH program of PATN).

The species have been re-arranged to maximise ecological relationships, using Zurich-Montpellier type analysis of Bridgewater (1981). The names of the species groups are mnemonic labels reflecting known or assumed links to underlying environmental factors, such as:

- EXSAN - extreme sandy sites
- DRYSAN - dry sandy sites
- BROGRA - broadly gravelly sites
- SAMORG - sands, moist, enriched by organic matter/

The matrix represents a multi-dimensional continuum whose extremes are infertile sands carrying woodland or shrubland and loamy valley slopes carrying tall open forest of karri.

| Group number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|--------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| No. in group | 48| 15| 11| 3 | 22| 11| 10| 5 | 5 | 2  | 4  | 3  | 1  | 13 | 10 | 4  | 2  | 7  | 1  | 3  | 5  | 2  | 2  | 1  |

**EXSAN**
- *Petrophile longifolia* 608 51
- *Pimelea longiflora subsp. longiflora* 622 88 82
- *Leucopogon glabellus* 489 57
- *Hyptis calycoma strictum* 409 59
- *Daviestia decurrens* 227 57
- *Bossiaea rufa* 129 57 80

**DRYSAN**
- *Lyginia barbata* 529 59 60 50
- *Gompholobium confertum* 138 55 53 82 50
- *Macleayция thymoides* 549 90 60
- *Allocasuarina fraseriana* 44 82 100

**BROGRA**
- *Lindsaea linearis* 502 51 80 77 55 100 100
- *Agonis hypericifolia* 34 63 87 68 100
- *Platysace compressa* 628 53 50 80 50 75
- *Xanthorrhoea preissii* 854 55 67 86 55 100 60 50 50 77 80
- *Eucalyptus marginata* 284 71 93 73 100 100 64 100 80 80
- *Persoonia longifolia* 603 61 53 82 50 80 57 60
- *Anarthria scabra* 60 96 93 100 100 91 73 70 60 80
- *Andersonia caerulea* 63 57 55 50 60 50

**SAMORG**
- *Adenantheros obovatus* 28 84 80 55 67 77 100 50 75 71 100 50
- *Dasyopogon bromeliifolius* 223 100 100 100 86 91 60 50 57 60
- *Anarthria prolifera* 59 98 93 100 100 95 82 80 80 100 57 60
- *Pulicaria reticulata* 668 78 73 100 100 100 71 100 100
- *Haemodorus spicatus* 349 53 73 100 100
- *Agonis parviceps* 38 90 80 82 100 100 100 100 100 100 100 100 50 100
- *Cassia racemosa* 172 61 60 50 75 50 71 60 50 100
- *Dampiera linearis* 217 90 100 100 67 91 91 80 80 100 67 71 67 100 100 50
- *Johnsonia lapulina* 425 71 82 91 50
- *Sciervola striata* 695 80 100 68 82 60 80 50

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**NAPODS**
- Lechenaultia expansa: 448
- Lysinema conspicuum: 532
- Nootia floribunda: 570
- Pericalymma crassipes: 600
- Eriocephalus scaber: 268
- Eutaxia obovata: 293
- Stylidiurn scardens: 769
- Bossiaea webbi: 130
- Monotoca tamariscina: 564
- Stylidiurn caespitosurn: 748
- **Stylidiurn piliferum**: 765

**DUSAN**
- Desmocladius flexuosus: 528
- Lepidosperma effusurn: 461
- Acacia pulchella: 15
- Sollya heterophylla: 715
- Isolepis nodosa: 417

**FLADUN**
- Acacia hastulata: 9
- Adenanthos cuneatus: 27
- Agrostosclinurn scabrum: 40
- Banksia quercifolia: 98

**BRODUN**
- Acacia littorea: 10
- Bossiaea linophylla: 127
- Conostylis aculeata subsp. aculeata: 195
- Hakea linearis: 358
- Lepidosperma gladiatum: 463
- Lysinema ciliatum: 531
- Oleastra axillaris: 575
- Phyllanthus calycinus: 615
- Pimelea rosea: 623

| Group number | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|--------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| No. in group | 48 | 15 | 11 | 3  | 22 | 11 | 10 | 5  | 5  | 2  | 4  | 3  | 1  | 13 | 10 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| **BRODUN (Continued)** |     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| *Sphaerolobium macranthum* | 723 | 50 | 71 | 100| 50 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| *Stylium emarginatum* | 752 | 50 | 54 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| *Stylium junceum* | 761 | 50 | 100|    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| *Velleia trinervis* | 833 | 50 | 75 | 54 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| **DUNON** |     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| *Lobelia alata* | 503 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Spyridium globulosum* | 729 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Rhodanthe citrina* | 846 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Hakea oleifolia* | 360 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Phebalium anceps* | 611 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Banksia littoralis* | 96  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Senecio laetus* subsp. maritimus | 710 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Asteridea pulvulenta* | 83  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Lobelia tenax* | 508 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| **WEDUN** |     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Villarsia pannassifolia* | 840 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Hibbertia grossularifolia* | 385 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Hardenbergia comptoniana* | 369 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Muehlenbeckia adpressa* | 565 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Rhugodia baccata* | 679 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Myoporum oppositifolium* | 566 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Haloragis brownii* | 367 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Senecio ramosissimus* | 712 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Hydrocotyle plebeya* | 401 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| **SUMP** |     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Juncus pauciflorus* | 429 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Melobolus cana* | 457 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Melobolus coaugustata* | 458 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Stylium adnatum* | 741 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|
| *Villarsia lastosperma* | 839 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 100|

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| Group number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
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**BROROC (Continued)**

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**YATEFLAT**

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**ROCVAL**

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#### ROCVAL (Continued)

- *Patersonia pygmaea*: 592
- *Aphelia cyperoides*: 72
- *Burchardia multiflora*: 141
- *Caladenia flavia*: 153
- *Hydrocotyle callicarpa*: 400
- *Austrostipa semibarbata*: 737

#### BRODRY

- *Philydrella pygmaea*: 612
- *Dryandra lindleyana*: 259
- *Levenhookia pusilla*: 501
- *Acacia browniana*: 4
- *Gompholobium ovatum*: 316
- *Conostylis setigera*: 201

#### MEDROC

- *Actinotus glemeratus*: 25
- *Trachymene pilosa*: 812
- *Laxmannia minor*: 447
- *Neurachne alopecuroidea*: 569
- *Caladenia marginata*: 162
- *Ozothamnus ramosus*: 372
- *Hemigenia microphylla*: 375
- *Stylium glaucum subsp. glaucum*: 757
- *Asplenium aethiopicum*: 75
- *Dillwynia sp. A*: 237
- *Stylium brevissimum*: 746
- *Trymallum ledifolium var. ledifolium*: 825
- *Darwinia oederoides*: 221
- *Phyllangium paradoxum*: 562
- *Acacia stenoptera*: 17
- *Thysanotus multiflorus*: 804

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**LOWROC**

- Callectasia grandiflora
- Comesperma volubile
- Thelymitra cristata
- Allocasuarina humilis
- Darwinia vestita
- Daviesia torrida
- Lagenniera hugetii
- Hakea undulata
- Amphipogon amphipogonoides
- Astroloma pallidum

**DRYVAL**

- Lepidosperma tenuis
- Hibbertia microphylla
- Levenhookia daphia
- Schoenus brevisetis
- Thysanotus thyrsoides
- Caesia micrantha/occidentalis
- Dampiera alata
- Tricoryne elaia
- Hibbertia aff. pulchella
- Stylium diversifolium
- Gonopholium polymorphum
- Hibbertia amplexicaulis
- Hypocalymma angustifolium
- Stylium spathulatum subsp. spathulatum
- Bacckoa camphorosmae
- Lepidosperma sp. GWJ 5257
- Eucalyptus wandoow
- Scaevola thesioides
- Thomasia foliosa

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**DRYLOG**

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**EXKAR**

- Poa drummondiana 634
- Hibbertia furfuracea 383 80
- Gahnia filum 302
- Acacia alata 2

*Acana echinata var. retorsumpilosa 24
*Alra caryophylla 41
*Anagallis arvensis var. arvensis 55
*Anagallis arvensis var. caerulea 56
*Bellardia trisago 109
*Brits maxima 135
*Brits minor 136
*Centaurea erytraea 175
*Centella asiatica 174
*Grahiola pubescens 330 100
*Holcus lanatus 393 100
*Hypochoeris glabra 407 50
*Lotus uliginosus 526
*Monadenia bracteata 563
*Oxalis corniculata 584
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*Parentucellia latifolia 586
*Polypogon monopellensis 641
*Romulea rosea 682 50
*Rhumus pulcher subsp. pulcher 685
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**EXSAN**
- Petrophile longifolia
- Pimelea longiflora subsp. longiflora
- Leucopogon glabellus
- Hypocalymma strictum
- Daviesia decurrens
- Bosistea ruffa

**DRYSAN**
- Lyginia barbara
- Gymnocalicium confertum
- Melaleuca thymoides
- Allocasuarina fraseriana

**BROGRA**
- Lindaea linearis
- Agonis hypericifolia
- Platysce compressa
- Xanthorrhoea preissii
- Eucalyptus marginata
- Persoonia longifolia
- Anarthria scabra
- Androsteria caerulea

**SAMORG**
- Adenanthera obovata
- Dasyypgon bromeliifolius
- Anarthia prolifera
- Pulenua reticulata
- Haemodorum spicatum
- Agonis parviceps
- Casispha racemosa
- Dampiera linearis
- Johnsonia lupulina
- Scaevola striata

|          | 50 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 50 | 100 | 100 | 50 | 100 | 50 | 100 | 50 | 100 | 50 | 100 | 50 | 100 |
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#### NAPODS
- Lechenaultia expansa
- Lysinema conspicuum
- *Nycteria floribunda* 100
- *Periclymenum crassipes* 50
- *Eriochilus scaber* 100
- *Eutaxia obovata* 50
- *Stylium scardens* 50
- *Bassiaea webbii* 50
- *Monotoca tamariscina* 50
- *Stylium caespitosum* 50
- *Stylium piliferum* 50

#### DUSAN
- *Desmocaldas flexuosa* 50 100
- *Lepidobberum effusum* 100 100 50 100 100 68 95
- *Acacia burchellii* 50 100 100 100 100 67
- *Solutea heterophylla* 100
- *Isolepis nodosa* 100

#### FLADUN
- *Acacia hastulata* 50
- *Adenanthos cuneatus* 50
- *Agrostoscirum scabrum* 100
- *Banksia quercifolia* 100

#### BRODUN
- *Acacia litorea* 50
- *Bassaera lepidophylla* 100
- *Conostylis aculeata subsp. aculeata* 50
- *Hakea linearis* 50
- *Lepidobberum gladiatum* 50
- *Lysinema ciliatum* 50
- *Olearia arillaris* 50
- *Phyllanthus calycinus* 100
- *Pimelea rosea* 50

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**BRODUN (Continued)**
- Sphaerolobium macranthum: 50, 100
- Styliolum emarginatum
- Styliolum junceum
- Velleia trinervis: 100

**DUNON**
- Lobelia alata: 100
- Styliolum globulosum
- Rhodanthe citrina
- Hakea oleifolia: 100
- Phebalium aniceps
- Banksia littoralis
- Senecio laetus subsp. mariimus
- Asteridea pulvinata
- Lobelia teraior

**WEDUN**
- Villarsia parnassifolia: 50
- Hibbertia grossulariifolia
- Hardenbergia comptoniana: 100
- Muehlenbeckia adpressa
- Rhododendron baccata
- Myoporum oppositifolium
- Huloragis brownii
- Senecio ramossissimus
- Hydrocotyle plebeya

**SUMP**
- Juncus pauciflorus
- Meuboldina cana: 50
- Meuboldina coagulata
- Styliolum adnatum
- Villarsia lasiosperma
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**WETPEAT**
- Actinotus annuifertilis
- Cephalotus follicularis
- Cosmelia rubra
- Drosera glanduligera
- Drosera hamiltonii
- Drosera stolonifera subsp. stolonifera
- Prasophyllum drummondii
- Pterostylis vittata var. vittata
  - 100
- Reedia spathacea
- Schoenus acuminatus
- Tetratheca filiformis
- Xyris flexifolia

**SANPEAT**
- Acidania microcarpa
- Diasporis filifolia
- Stylium assimile
- Xyris lanata
- Gymnoschoenus anceps
- Melaleuca preissiana
  - 50

**LOSWAM**
- Boronia megastigma
- Brachysema sericeum
- Stylium luteum
- Meeboldina scariosa
- Melaleuca densa
  - 100

**WETLOAM**
- Eucalyptus patens
  - 50
- Gahnia trifida
- Poa serpens
  - 100
- Hibbertia cunninghamii
  - 100
- Leptocaropus sp. 3
- Hakea varia
- Melaleuca rhapisphylla
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- Lepidosperma tetraquetrum
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**WETCLAY**

- Drosera nesii: 100
- Hakea ceratophylla: 100
- Juncus planifolius: 100
- Chaetanthera aristata: 100
- Hibbertia stellaris: 100
- Boronia denticulata: 100

- Melaleuca cicutularis: 100
- Acacia crispula: 100
- Leucopogon distans: 100
- Leucopogon gilbertii: 100
- Melaleuca pauiciflora: 100
- Utricularia tenella: 60 50

**WETROC**

- Viminaria juncea: 50 100
- Baumea juncea: 100
- Anarthria laevis: 100 60 50

**HIROC**

- Dodonaea aptera: 100
- Melaleuca diosmifolia: 100
- Synaphea petiolaris subsp. petiolaris: 100
- Agonis marginata: 100
- Banksia verticillata: 100
- Cyrtostylis huegelii: 100
- Diuris laevis: 100
- Pterostylis barbata: 100
- Ricinocarpus glaucus: 100

**BROROC**

- Gastrolobium bilobum: 100 50
- Pterostylis pyromidalis: 100 50
- Thelymitra antennifera: 100 50 100
- Leucopogon unilateralis: 100 50 100
- Microtis media: 100 50 100
- Andersonia sprengeloides: 100 50 100 100 100
- Pimelea imbricata: 100 50 50 100 60

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**LOWROC**

- Calectasia grandiflora: 60
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- Thelymitra crinita: 60 50
- Allocasuarina humilis: 80 67
- Darwinia vestita: 60 50
- Daviesta horrida: 60 67
- Lagenifera huegelii: 100
- Hakea andulata: 100
- Amphipogon amphipogonoides: 60 100 100 67 50
- Astroloma pallidum: 60 50 100 58

**DRYVAL**

- Lepidosperma tenue: 100
- Hibbertia microphylla: 100
- Levehookia dubia: 100
- Schoenus brevisetus: 100
- Thyasurus thysoides: 100
- Caesia micrantha/occidentalis: 100 100
- Dampiera alata: 100
- Tricoryne elatior: 50 100
- Hibbertia aff. pulchella: 100 100
- Sylidium diversifolium: 50 100 100
- Gongylotium polyornorphum: 100 50 100 67 67
- Hibbertia amplexicaulis: 50 100 87 85 67
- Hypocalyma angustifolium: 100 50 100 67 67
- Sylidium spathulatum subsp. spathulatum: 50 100 67 58
- Bacceea camphorosmae: 100
- Lepidosperma sp. GWJ 5257: 100
- Eucalyptus wandoa: 100 67
- Scaevola thesioides: 100
- Thomasia foliosa: 100

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**EXKAR**

- *Poa drummondiana*
- *Hibbertia furfuracea* 100
- *Gahnia filum* 100
- *Acacia alata* 100

* *Acaena echinata var. retrorsimpilosa*
* *Aira caryophyllea* 100 100 50
* *Anagallis arvensis var. arvensis* 50 100
* *Anagallis arvensis var. caerulea* 100
* *Bellardia tricaga* 100
* *Brisa maxima* 50 100
* *Brisa minor* 100 100
* *Centaurium erythropus* 100
* *Centella asiatica* 100
* *Gratiola pubescens* 100
* *Holcus lanatus* 100
* *Hypochoeris glabra* 50 100 100 100 100
* *Lotus uliginosus* 100 50
* *Monadenia bracteata* 100 100
* *Oxalis corniculata* 100
* *Oxalis purpurea* 100
* *Parennucellia latifolia* 100
* *Polypogon monspeliensis* 100
* *Rumex rosea* 100
* *Rumex pulcher subsp. pulcher* 100
* *Solanum nigrum* 100
* *Sonchus oleraceus* 100 100
* *Trifolium dubium* 100
APPENDIX 2.7: LINKAGE BETWEEN VEGETATION CLASSIFICATION OF WARDELL-JOHNSON ET AL. (1995) AND OTHER CLASSIFICATIONS

The comparison of the Wardell-Johnson et al. (1995) classification with other near-by classifications proved a major task. In the subsequent discussion it is referred to as WJ 95.

In the case of Strelein (1988), the comparison is governed by the fact that Strelein concentrated his work on the forest of Eucalyptus marginata subsp. marginata, and did not specifically sample more extreme sites. He has covered only a limited counterpart of WJ 95’s more extreme sandy sites, characterised by the species sets EXSAN and DRYSAN. Only one species, Melaleuca thymoides of DRYSAN, also occurs among Strelein’s indicators, where it is placed into SOSAM (southern sands, moist). The more widely ranging species groups of WJ 95, such as BROGRA, contains several species also identified as indicators by Strelein. Two of these, Eucalyptus marginata subsp. marginata and Persoonia longifolia, have only negative value in Strelein’s classification, in that they are only absent from the most extreme sites. Another two have been placed in broad indicator groups, namely Xanthorrhoea preissii in BROMO (broadly moist) and Anarthria scabra in SOBROSAN (southern broadly sandy).

There is close correspondence between the two classifications in Adenanthos obovatus and Dasypogon bromellifolius, which are placed in both classifications in SAMORG (sandy, moist, organic enriched). The broader group of WJ 95’s also contains species which in the more detailed classification of Strelein are placed into other groups, such as Anarthria prolifera of SOWET (southern wet), Pultenaea reticulata of SOSAM (southern sandy moist) and Agonis parviceps of SOSALOM (southern sandy loams). The MOFES group of WJ 95 shares with Strelein Acacia myrtifolia of SOGRA (southern gravels) and Patersonia umbrosa of SOGRAF (southern gravels, fertile).

The BROMOF group of WJ 95 shares Agonis flexuosa and Anigozanthos flavidus with Strelein’s SOBROSAN group. Both SOBROSAN and BROMOF are broad southern groups consisting of species from sandy moist soils of moderate fertility.

The SOHUMP group has one match with Strelein’s group GRAMED in Leptomeria cunninghamii.

Similarly, the SOMOL group has one match with Strelein’s BROMO in Kingia australis. Strelein did not use the other important member of the BROMO group of Havel (1975), Mesomelaena tetragona, which also features prominently in the SOMOL group.

The MOLGRA group, similar to SOMOL but with a broader range, shares Lepidosperma squamatum with Strelein’s BROMO, Leucopogon australis with SOBROSAN, Leucopogon propinquus with FREGRA and Corymbia calophylla, which in Strelein’s classification is so widespread as to have only a negative indicator value.
APPENDIX 2.7 (Continued)

The sand dune species groups DUSAN, BRODUN and DUNON include several species of relatively broad edaphic range which are shared with Strelein, such as Desmoclados fuscatus of BROMO, Bossiaea linophylla of FREGRA and Acacia pulchella of BROFER. One additional species, Banksia littoralis of VERWET, is an unlikely match as it normally occurs in swamps. The many species characteristic of sand dunes which were recorded by WJ 95 have no match in Strelein as he did not sample sand dunes.

There is a strong match between WJ 95 and Strelein in Homalospernum firmum and Beaufortia sparsa of the SOWET group of freshwater swamps. Other prominent swamp species are Melaleuca preissiana of WJ 95 SANPEAT and Strelein’s VERWET, and Eucalyptus patens of WJ 95’s WETLOAM and Strelein’s SOFERO. The majority of swamps species are represented in WJ 95 only.

There are relatively few matches with Strelein for the WJ 95 groups covering rocky sites, such as MEDROC, LOWROC and DRYVAL. Those species recorded by both WJ 95 and Strelein are not rock specialists, but generalists which extend on to rocks, such as Trymalium lichicolium, Astroloba pallidum, Hypocalymma angustifolium and Eucalyptus wandoo of Strelein’s DRYGRA. The same is true of Hakea lissocarpha of WJ 95’s DRYLOG and Strelein’s BROFER. The many rock specialists recorded by WJ 95 have no counterpart in Strelein as he did not sample rock outcrops.

The closest correspondence between Wardell-Johnson et al. (1995) and Strelein (1988) is on uplands, as this is where Strelein’s sampling was centred. The matches are particularly strong in WJ 95 species groups SOGRA, SOGRAM, characteristic of uplands with lateritic gravelly soils. These contain Crowea angustifolia var. platyphylla, Xanthorrhoea gracilis, Sphaerolobium medium and Petrophile diversifolia of Strelein’s SOGRA, Macrozamia riedlei of FREGRA and Banksia grandis and Hovea chorizemifolia of Strelein’s GRAMED.

There is also good correspondence between WJ 95 groups SOFER and SOFREG, indicative of loamier and more fertile sites, and Strelein’s groups SOFERO. The final group of WJ 95, EXKAR, which defines pure forest of Eucalyptus diversicolor with floristically simple understorey, has no counterpart in Strelein’s classification. This is reflected in just one weak match involving Acacia alata of Streelins’ SOFER.

As could be expected, the main match between Wardell-Johnson et al. (1995) and Inions (1990b) is for species groups associated with the karri forest.
APPENDIX 2.7 (Continued)

The HILOG species group of WJ 95 matches Inions’ SOLOAM in *Chorilaena quercifolia* and *Eucalyptus guilfoylei* and SOFERO in *Eucalyptus jacksonii* and *Acacia pentadenia*. Additional species matches for HILOG are *Opercularia volubilis* of Inions’ SOVAL and *Dampiera hederacea* of HEATECO.

The SOFER species group of WJ 95 matches Inions’ SOFERO in *Allocasuarina decussata* and in addition has *Hovea elliptica* of SOGRA, *Leucopogon verticillatus* of HIGRA, *Billardiera variifolia* of DRYKA and *Lasiopetalum floribundum* of FREGRA.

The SOFREG species group of WJ 95 matches Inions’ SOFER in *Tremandra stelligera* and *Clematis pubescens* and in addition also has *Pteridium esculentum* of HIGRA. It is the group containing *Eucalyptus diversicolor*, which is universally distributed in Inions’ classification.

The EXKAR species group of WJ 95, which defines the purest karri forest with the floristically simplest understorey, has only one match in *Hibbertia furfuracea* of Inions’ HEATECO.

The SOGRAM and SOGRAF species groups of WJ 95 have matches with *Boronia gracilipes* and *Podocarpus drouynianus* of Inions’ SOSALOM, *Banksia grandis* of GRAMED, *Acacia divergens* of HEATECO, *Logania serpyllifolia* and *Tremandra diffusa* of DRYKA and *Lomandra drummondi* of HIGRA. Most of these species are essentially species of the jarrah rather than karri forest and define the karri-jarrah transition or the edaphically marginal sites for karri.

Many other of WJ 95 species groups which are essentially associated with jarrah rather than karri forest define sub-optimal karri types of Inions and match their associated indicator species groups such as INFEKA, DRYKA and NOREKA. These include the BROGRA group of WJ 95 with *Eucalyptus marginata* subsp. *marginata*, *Persoonia longifolia* and *Agonis parviceps*, BROMOF group with *Leucopogon capitellatus*, *Opercularia hispidula*, *Agonis flexuosa* and *Anigozanthos flavidus*, MOLGRA group with *Leucopogon australis*, *Leucopogon propinquus* and *Corymbia calophylla* and DUSAN group of *Lepidosperma effusum* and *Acacia pulchella*.

There is considerable linkage between Wardell-Johnson *et al.* (1995) and Gibson\(^1\) (personal communications)

Gibson’s community 2 has links with WJ 95 in *Acacia littorea* and *Olearia axillaris* of BRODUN, *Spyridium globulosum* of DUNON, *Isolepis nodosa* of DUSAN, *Leucopogon parviflorus* of LIMDUN, *Rhagodia baccata* of WEDUN, and *Lepidosperma squamatum* of MOLGRA.

\(^1\) Department of Conservation and Land Management WA, Woodvale
APPENDIX 2.7 (Continued)

Gibson’s community 4, described as community on skeletal limestone, has as its characteristic species *Hibbertia grossulariifolia* of WEDUN, *Desmocladus flexuosus* of DUSAN, *Agonis flexuosa* of BROMOF, *Lysineema ciliatum, Lepidosperma gladiatum, Phyllanthus calycinus* and *Acacia littorea* of BRODUN.

Gibson’s community 5, described as herb-rich *Agonis* forests and heaths, has links with WJ 95 in *Leucopogon parviflorus, Dryandra sessilis* var. *sessilis* and *Logania vaginalis* of LIMDUN, *Senecio lautus* and *Rhodanthe citrina* of DUNON, *Desmocladus flexuosus* of DUSAN and *Hakea prostrata* of DRYDUN.

Gibson’s community 7, described as coastal *Agonis* forests and heaths, has links with WJ 95 in *Agonis flexuosa* of BROMOF, *Acacia littorea, Phyllanthus calycinus* and *Olearia axillaris* of BRODUN, *Spyridium globulosum* of DUNON, *Leucopogon parviflorus* of LIMDUN, *Rhogodia baccata, Hardenbergia comptoniana* and *Hibbertia grossulariifolia* of WEDUN, *Lepidosperma squamatum* of MOLGRA, *Desmocladus flexuosus* of DUSAN, but especially in *Hibbertia cuneiformis* of DRYDUN, *Clematis pubescens* of SOFREQ and *Macrozamia riedlei* of SOGRAF.

Gibson’s community 8, described as inland *Agonis* forest and heath, has links with WJ 95 in *Agonis flexuosa, Anigozanthos flavidus* and *Opercularia hispidula* of BROMOF, *Lepidosperma gladiatum* and *Pimelea rosea* of BRODUN, *Hakea oleifolia* of DUNON, *Leucopogon propinquus* of MOLGRA, *Hibbertia grossulariifolia* and *Muehlenbergia adpressa* of WEDUN and *Desmocladus flexuosus* of DUSAN.

Gibson’s community 9, described as western *Jacksonia horrida* heath and woodland, is linked with WJ 95 in the common dune species shared by the communities described above, but has in addition *Rhodanthe citrina, Lobelia tenuior* and *Senecio lautus* of DUNON and *Logania serpyllifolia* subsp. *angustifolia* of SOGRAM and *Sollya heterophylla* of DUSAN.

Gibson’s community 10, described as eastern *Jacksonia horrida* heath and woodland, has links to WJ 95 in the strong development of *Patersonia occidentalis, Bossiaea linophylla, Anarthria prolifer* of SAMORG, *Andersonia caerulea* of BROGRA, *Lyginia barbata* and *Melaleuca thymoides* of DRYSAN, *Adenanthes cuneatus* of WEDUN, *Lysineema ciliatum* and *Velleia trinervis* of BRODUN and *Allocasuarina humilis* of LOWROC. The presence of these species suggests longer leaching and less fertile acid soils.

Gibson’s community 11, described as *Agonis – Banksia – Eucalyptus* heathland and woodland has links with WJ 95 in *Olearia axillaris, Phyllanthus calycinus, Conostylis aculeata* subsp. *aculeata* and *Pimelea rosea* of BRODUN, *Spyridium globulosum* of DUNON and *Leucopogon parviflorus* of LIMDUN. *Agonis flexuosa* of BROMOF, *Hibbertia grossulariifolia* and *Hardenbergia comptoniana* of WEDUN.

Gibson’s community 13, described as wet scrub and woodland, has links with WJ95 in *Agonis flexuosa* and *Opercularia hispidula* var. *pauciflora* of BROMOF, *Anarthria*
APPENDIX 2.7 (Continued)

*prolifera, Dasypogon bromeliifolius* and *Adenanthis obovatus* of SAMORG, *Bossiae rufa* of EXSAN and *Lepidosperma squamatum* of MOLGRA, suggesting moist, leached and organically enriched sands.

Gibson's community 14, described as *Banksia ilicifolia* has links with WJ 95 in some of the indicators of community 13, but especially *Pimelea longiflora* subsp. *longiflora* of EXSAN, *Lyginia barbata* and *Melaleuca thymoides* of DRYSAN and *Eucalyptus marginata* subsp. *marginata*, *Anarthria scabra* and *Andersonia caerulea* of BROGRA, suggesting leached sands.

Gibson's community 15, described as *Banksia attenuata* woodlands, has links with WJ95 in *Lepidosperma squamatum* of MOLGRA, *Melaleuca thymoides* of DRYSAN. This suggest dry, leached sands.

Gibson's community 20, described as *Hakea linearis* wet flats, has links with WJ 95 in *Acacia hastulata* of FLADUN, *Agonis parviceps* of SAMORG, *Boronia magastigma* of LOSWAM, *Xanthorrhoea preissii* of BROG and *Melaleuca pauciflora* of WETCLAY. These are indicative of heavier textured soils than community 15 and impeded drainage.

Gibson's community 22, described as ironstone communities, has links with WJ 95 in *Melaleuca preissiana* of SANPEAT, *Hakea varia* of WETOAM and *Melaleuca pauciflora* of WETCLAY. These are also indicative of impeded drainage and seasonal waterlogging.


Gibson's community 26, described as western shallow wetlands, has links with WJ 95 in *Melaleuca pauciflora* of WETCLAY and *Melaleuca incana* subsp. *incana* of HEADLAND.

Gibson’s community 27, described as moderately deeply inundated sedgelands, has links with WJ 95 in *Astartea fascicularis* of SOWET and *Meeboldina scariosa* of LOSWAM.

Gibson’s community 28, described as very deeply inundated wetlands, has links with WJ 95 in *Agonis juniperina* of SOWET and *Meeboldina scariosa* of LOSWAM and *Melaleuca rhaphiophylla* of WETOAM.

Gibson’s community 29, described as heathy sedgelands, has links with WJ 95 in *Astartea fascicularis, Evandra aristata, Homalospermum firmum* and *Beaufortia sparsa* of SOWET, *Anarthria prolifera* of BROGRA, *Acacia hastulata* of FLADUN,
APPENDIX 2.7  (Continued)

_Agonis parviceps_, _Dasypogon bromeliifolius_ and _Adenanthis obovatus_ of SAMORG, _Diaspasis filifolia_, _Xyris lanata_ and _Gymnoschoenus aniceps_ of SANPEAT. These are indicative of wet, organically enriched sites.

Gibson’s community 30, described as _Melaleuca thymoides_ wet heaths, has links with WJ 95 in _Andersonia caerulea_, _Lyginia barbata_ and _Melaleuca thymoides_ of DRYSAN, _Kunzea recurva_ of SOHUMP, _Xanthorrhoea preissii_ of BROGRA, _Hibbertia stellaris_ of WETCLAY and _Gymnoschoenus aniceps_ of SANPEAT. These are indicative of less wet and more sandy sites than Gibson’s 29.
APPENDIX 3.1: RELATIONSHIP BETWEEN PRINCIPAL COMPONENTS, INDICATOR SPECIES AND ENVIRONMENTAL FACTORS IN SOUTHERN JARRAH FOREST (STRELEIN 1988)

Strelein (1988) generated a set of two-dimensional diagrams, based on the principal component analysis of the southern jarrah forest, in which he displayed both the distribution patterns of individual plant species, and the underlying patterns of the factors of environment, such as soil fertility.

In his descriptions of the principal components he referred to the first component as reflecting both fertility and texture, the extremes being fertile loamy soils at -C1 (high carbon, high nitrogen, high phosphate and high potassium) and infertile gravelly soils at +C1 (low carbon, low nitrogen, low phosphate and low potassium). The combination of fertility and texture reflects the fact that the lateritic gravels of the plateau uplands have been through a cycle of acute leaching, leaving them chronically deficient in phosphate and potassium, whereas the loamier soils of the valley slopes are continually being renewed by erosion and breakdown of the granitic or dioritic country rock.

The second component was described by Strelein (1988) as a combination of the degree of dissection and magnitude of rainfall, the extremes being the weakly dissected headwaters of rivers in low rainfall zone (-C2) and strongly dissected lower valleys in the high rainfall zone close to the Darling Scarp (+C2). In more specific terms, -C2 is associated with higher carbon and high nitrogen.

The third component reflects the percentage of gravel in the soil, +C3 being associated with a high proportion of gravel, and -C3 with a low proportion of gravel in the soil.

The fourth component reflects the degree of drainage, + C4 being linked to poor drainage and -C4 to good drainage. This is reflected in such soil parameters as high pH, high carbon, high phosphate, potassium and nitrogen on well drained, steep slopes of -C4, and the reverse on mild slopes and depressions of +C4.

From this it can be inferred that certain combinations of components would be associated with particular portions of the regional landscape, such as -C1+C2–C4 with steeply sloping valleys slopes in the strongly dissected high rainfall zone, and +C1-C2+C4 with the weakly dissected low rainfall zone of the Darling Plateau.

As not only the factors of the environment, but also the distribution of individual species and groups of species can be displayed within the four-dimensional component space by means of the CORD diagrams, the diagrams can be used to establish linkage between the environment and the species.

Some of the more prominent linkages are:
-C1+C2 (steep fertile slopes in high rainfall) - Acacia urophylla, Clematis pubescens, Pteridium esculentum
APPENDIX 3.1 (Continued)

±C1+C2 (moderately fertile slopes in high rainfall) - Eucalyptus patens, Bossiaea linophylla, Acacia alata, Hovea elliptica, Leucopogon verticillatus

+C1+C2 (infertile gravels in high rainfall) - Hovea chorizemifolia, Hypocalymma robustum, Gompholobium ovatum

-C1-C2 (fertile mild slopes in low rainfall – Dryandra lindleyana (formerly D. nivea)

+C1-C3 (infertile non-gravelly soils) – Allocasuarina decussata, Pultenaea reticulata

±C1±C3 (fertile gravelly, or non-fertile non-gravelly soils) - Anigozanthus flavidus, Chorizema ilicifolium, Eucalyptus patens, Dasyypogon bromeliifolius

+C1±C3 (infertile moderately gravelly soils) - Boronia gracilipes, Petrophile diversifolia

+C1+C3 (infertile gravelly soils) - Acacia browniana

±C1+C3 (moderately fertile gravelly soils) - Hakea amplexicaulis, Acacia pulchella

-C1+C3 (fertile gravelly soils) – Pteridium esculentum

+C1+C4 (poorly drained infertile soils) - Hakea ruscifolia, Agonis parviceps, Kingia australis

+C1±C4 (infertile, moderately drained soils) - Adenanthis obovata

±C1+C4 (moderately fertile poorly drained soils) – Anigozanthus flavidus, Xanthorrhoea preissii

±C1-C4 (moderately fertile well-drained soils) Bossiaea laidlawiana, Hovea elliptica, Patersonia umbrosa, Leucopogon verticillatus

-C1-C4 (fertile well-drained soils) Clematis pubescens

-C1±C4 (fertile moderately drained soils) – Leucopogon propinquus

-C1+C4 (fertile poorly drained soils) - Dasyypogon bromeliifolius.

It is possible to link the threefold combination of environmental factors with corresponding species groups, such as:

-C1+C2–C4 of steeply sloping valleys slopes in the strongly dissected high rainfall zone of the Darling Plateau with Clematis pubescens, Acacia urophylla, Pteridium esculentum, Bossiaea laidlawiana, Hovea elliptica, Patersonia umbrosa, Leucopogon verticillatus and Leucopogon propinquus, and
APPENDIX 3.1 (Continued)

+C1-C2+C4 of the weakly dissected low rainfall zone of the Darling Plateau with Hakea ruscifolia, Agonis parviceps, Kingia australis, Adenanthes obovatus, Anigozanthus flavidus and Xanthorrhoea preissii.

Similarly, the combination of +C1+C2+C3 of the infertile lateritic uplands of the high rainfall zone is linked with Hovea chorizemifolia, Hypocalymma robustum, Gompholobium ovatum, Boronia gracilipes, Petrophile diversifolia and Acacia browniana.

These combinations are the most readily identifiable. There are however more subtle combinations such as ±C1±C3 (fertile, gravelly or infertile, non-gravelly soils) with Anigozanthus flavidus, Chorizema ilicifolium, Eucalyptus patens and Dasypogon bromeliifolius. In this case the species have a double (split) occurrence within the coordinate framework, making it easier to predict where they will not occur, namely on infertile gravelly soils (+C1+C3), where they are unable to compete with the dominant Eucalyptus marginata subsp. marginata and its associates Hovea chorizemifolia, Hypocalymma robustum, Gompholobium ovatum, Boronia gracilipes, Petrophile diversifolia and Acacia browniana.
APPENDIX 3.2: LINKAGE OF LANDFORM, SOILS, HYDROLOGY AND VEGETATION IN COLLIE EXPERIMENTAL CATCHMENTS (BETTENAY ET AL. 1980)

The chief contribution of Bettenay et al. (1980) is the linking of hydrology, pedology and plant ecology. The catchments mapped by them in the Collie District in the centre of the Jarrah bioregion spanned a wide climatic range, from annual rainfall 700 to 1100 mm, and equally wide geomorphic range from weakly to strongly dissected valleys. They defined four hydrologic provinces, namely:

HP1 – valley slopes adjacent to stream lines, with moderate (less than 30%) slopes, with shallow heavy textured soils, winter saturated and contributing to stream flows
HP2 – valley sides and heads with gentle to moderate (less than 12%) slopes, with sandy soils receiving water from upslope and waterlogged in winter, sometimes in form of permanent swamps
HP3 – mid slopes and divides with gentle to moderate (less than 15%) slopes, with sandy to gravelly soils with mottled or pallid zones at less than 1m depth, which are barriers to water penetration, so that winter saturation results in lateral flows
HP4 – upper slopes and divides with gentle (less than 15%) slopes, with earthy or sandy gravels, with mottled or pallid zones at less than 2m, which are highly permeable and are not subject to perching or winter run-off.

On the whole, the wetter western catchments were more strongly dissected, with stony and shallow soils in HP1.

The vegetation was mapped according to Havel’s (1975a,b) classification, but with finer definition using intermediate types. The vegetation of the eastern catchments was as follows:
Site vegetation type A in HP1,
types Z, D, Y, M and transitional types R-M, D-B and F-B in HP2,
types Z, Y and transitional types P-Z, Z-M, D-Z, D-R in HP3
types Z and P-Z in HP4.

Type A consists of poorly developed tree stratum of Eucalyptus rudis and Melaleuca preissiana over a shrub storey of Melaleuca viminalis, Hakea varia and Viminaria juncea, located on low-lying drainage lines.

Transitional type F-B consists of open forest of Eucalyptus marginata and Corymbia calophylla, with second storey of Allocasuarina fraseriana and Banksia grandis and shrub storey of Lysinema ciliatum, Bossiaea linophylla, Bossiaea eriocarpa, Lyginia tenax, Meeboldina scariosa, Hibbertia hypericoides and Hypocalymma angustifolium, located on leached sands in valley heads.

Type D consists of open forest of Eucalyptus marginata and Corymbia calophylla with shrub storey of Baeckea camphorosmae, Hypocalymma angustifolium, Hakea lisocarpha and Macrozamia riedlei, located on finer textured soils in valley heads and on lower valley sides.
APPENDIX 3.2 (Continued)

Type M consists of woodland of *Eucalyptus wandoo* and *Eucalyptus marginata*, with shrub storey of *Macrozamia riedlei*, *Hakea lissocarpha*, *Phyllanthus calycinus*, *Hibbertia commutata*, *Bossiaea ornata*, *Leucopogon capitellatus* and *Petrophile striata*, located on mid slopes.

Transitional type R-M differs from M in shallower soils, less dense overstorey and the occurrence of *Eucalyptus decipiens* subsp. *chalara* in mallee form, and of shrubs *Dryandra armata* and *Allocasuarina humilis*.

Type Y consists of woodland of *Eucalyptus wandoo* and *Corymbia calophylla*, with shrub storey of *Baeckea camphorosmae*, *Hypocalymma angustifolium* and *Dampiera alata*, located on lower valley slopes.

Type Z is open forest of *Eucalyptus marginata* with some *Corymbia calophylla*, with a shrub storey *Macrozamia riedlei*, *Hakea lissocarpha*, *Leucopogon capitellatus*, *Petrophile striata*, *Trymalium ledifolium*, *Phyllanthus calycinus*, *Styphelia tenuiflora*, *Bossiaea ornata* and *Hibbertia commutata*, located on laterite mantled crests and gravelly slopes.

Transitional type P-Z differs from Z in the presence of *Allocasuarina fraseriana* in the second storey, and reduced levels of *Macrozamia riedlei* and *Hakea lissocarpha* in the shrub storey, indicative of coarser textured soils than Z.

The vegetation of the western catchments was as follows:
Types Q, T-U and G-R in HP1,
Types D, Q and C in HP2,
Types T, Q-T, O-F and T-S in HP3,
Type T-S in HP4.

Type Q is open forest of *Corymbia calophylla*, *Eucalyptus patens* and *Eucalyptus marginata*, with shrub storey of *Hypocalymma angustifolium* and *Xanthorrhoea preissi*, located on more lower slopes.

Type G-R consists of shrubland of *Grevillea bipinnatifida*, *Diplolaena drummondii*, *Hakea lissocarpha*, *Hypocalymma angustifolium* and *Baeckea camphorosmae* with variable overstorey of *Corymbia calophylla*, located on shallow stony sites.

Type C is woodland to open forest of *Eucalyptus patens* and *Corymbia calophylla*, with tall understorey of *Lepidosperma tetraquetrum*, *Agonis linearifolia* and *Astartea fascicularis*, located on the valley floor.

Type T consists of open forest of *Eucalyptus marginata* with some *Corymbia calophylla*, with understorey of *Pteridium esculentum*, *Leucogon verticillatus*, *Leucopogon capitellatus* and *Persoonia longifolia*, located on crests and upper slopes.

Transitional type S-T differs from T in the development of second storey of *Banksia grandis*. 
APPENDIX 3.2 (Continued)

Transitional type T-U differs from T in the strong development of Xanthorrhoea preissii and Macrozamia riedlei in the understorey, and in occurring on steeper slopes lower down in the landscape.

Transitional type O-F consists of open forest of Eucalyptus marginata with some Corymbia calophylla, with an understorey of Hakea ruscifolia and Conospermum capitatum, located on milder valley heads and upland depressions.

It will be seen from the above information that the vegetation mainly reflects climate and landform, which between them determine the hydrologic regime. Differences in soils texture separate vegetation type D (sandy) from Y (loamy), Z (gravelly) from M (loamy). The soils with coarsest texture are found in transitional types which contain B, F or P, and are associated with milder slopes. Depth of soils separates M from R-M and Q from G-R. The vegetation types with shallower, stonier slopes (G, R) are associated with steeper slopes.

The sequence of hydrologic provinces from 1 to 4 parallels toposquence from ridge crests to valley floors, with T, S, P and Z occurring high in the landscape and being best drained, and A and C occurring low in the landscape and having some drainage impediment and seasonal waterlogging. Vegetation types M, Y, D and Q are intermediate in position and adequacy of drainage. The vegetation toposquences differ between the wet western and dry eastern catchments, eg Z, P, M, D, Y, B and A in the eastern low rainfall catchments, and S, T, U, Q, D and C in the high rainfall western catchments.

There is parallel between the catchments surveyed by Bettenay et al. (1980) and Havel (1975b), in that both contain a range from western deeply dissected, high rainfall catchments and eastern weakly dissected, low rainfall catchments.

Havel's (1975b) easternmost catchment (Flint) does not fit the pattern, in that it is a low rainfall catchment with strong dissection. This is due to the fact that it drains eastward towards the southwest's largest river system, the Swan-Avon. Consequently, it has a higher proportion of shallower and heavier textured soils than any of the other catchments surveyed by Bettenay et al. (1980) or Havel (1975b). This is reflected in the very high proportion of the catchment carrying woodland of Eucalyptus wandoo (types Y, M and L). The match between vegetation types and hydrological provinces is:

Types L and A in HP1,
types Y, L and M in HP2,
types M and Z in HP3,
types H, HM and Z in HP4.
APPENDIX 3.3: TOPOSEQUENCES DESCRIBING VEGETATION COMPLEXES OF THE SOUTH WEST FOREST REGION AND THE RELATIONSHIP BETWEEN THEM

This Appendix is presented in Digital Form on Compact Disk in Word 97 Format.

The title (Appendix D) and page numbering (D1, D2) of this Appendix, is that used in a draft of a report submitted for publication as a CALMScience Supplement which covers the contents of the first three chapters of this thesis.

File Names are as follows:
- Appendix D1.doc = Appendix D1
- Appendix D10.doc = Appendix D10
- Appendix D100.doc = Appendix D100
- proceeding to ...
- Appendix D2.doc = Appendix D2
- Appendix D20.doc = Appendix D20
- Appendix D200.doc = Appendix D200
APPENDIX 3.4: MAPS OF REGIONAL FOREST AGREEMENT VEGETATION COMPLEXES - PERTH, PINJARRA, COLLIE, BUSSELTON-AUGUSTA, PEMBERTON AND MOUNT BARKER SHEETS

The Maps are located at the back of this Volume.
APPENDIX 3.5:  MAP OF REGIONAL FOREST AGREEMENT
ECOLOGICAL VEGETATION SYSTEMS

The Map is located at the back of this Volume.
APPENDIX 3.6: MID-LENGTH LEGEND FOR THE MAP OF REGIONAL FOREST AGREEMENT ECOLOGICAL VEGETATION SYSTEMS

INTRODUCTION

The following text provides an expanded legend for the map of the ecological vegetation systems. The order of the ecological vegetation systems is arranged in the sequence that the agglomeration of the vegetation complexes was carried out, that is from the high to low rainfall in each of the main subregions namely, southern, western, central and northern.

On the ecological vegetation system map, the legend represents a further stage of condensation, in that all dune systems of the southern and western sub-regions, as well as coastal plains and plateaus were dealt with together. Similarly, in the central and northern subregions, comparable landforms, such as lateritic uplands, were dealt with together.

This expanded version of the legend provides not only greater detail on the components of the ecological vegetation systems (in bold), the landforms, structure and composition of the vegetation, but also traces the process of agglomeration, documenting the vegetation complexes (in italics and bold) that contributed to a particular ecological vegetation system. The asterisk (*) denotes an introduced species which has become naturalised.

SOUTHERN SUBREGION

Southern dune systems

Qu9 Component vegetation complex *Mu.*
Unstable dunes in hyperhumid zone. Mixture of bare sand, Coastal Complex and Grassland of *Ammophila arenaria,* mats of *Arctotheca populinifolia* and Closed Heath of *Olearia axillaris* and *Acacia cyclops.* Other associated species include *Senecio laetus* and *Carpobrotus* sp.

Py9 Component vegetation complexes *Mc, Mp, Mr, My and E.*
Young stabilised dunes in hyperhumid zone. Coastal Complex and Closed Heath of *Acacia cochlears,* *Hibbertia cuneiformis,* *Spyridium globulosum,* *Leucopogon parviflorus,* *Pimelea ferruginea,* *Acacia littorea* to Low Woodland of *Agonis flexuosa.*

Po9 Component vegetation complexes *Ms and Mf.*
Old stabilised dunes in hyperhumid zone. Woodland of *Agonis flexuosa* to Open Forest of *Corymbia calophylla,* *Eucalyptus marginata* subsp. *marginata,* *Eucalyptus cornuta,* *Eucalyptus megacarpa.* On optimum sites, Tall Open Forest of *Eucalyptus diversicolor.* The understorey shrub and herb species include *Hibbertia furfuracea,* *Lepidosperma effusum,* *Bossiaea linophylla,* *Billardiera varifolia,* *Tremandra stelligera,* *Leucopogon australis* and *Macrozamia riedlei.*

Overlay of coastal dunes over inland landforms

Jc8 Component vegetation complex *HK.*
Sheets of aolian sand overlying crystalline rocks at the south western margin of the Darling Plateau in the hyperhumid zone. Soils range from humus podzols to red brown loamy sands over hardpan. Vegetation ranges from Woodland of *Banksia*
APPENDIX 3.6  (Continued)

littoralis and Melaleuca preissiana, through Open Forest of Eucalyptus marginata subsp. marginata and Corymbia calophylla to Tall Open Forest of Eucalyptus diversicolor. Second storey of Agonis flexuosa, Banksia grandis, Persoonia longifolia. Shrub and herb storey Adenanthes obovatus, Dasyypogon bromeliifolius, Agonis parviceps, Anarthria prolifera, Evandra aristata, Leucopogon australis on moist leached sands to Bossiaea linophylla, Hovea elliptica, Clematis pubescens, Leucopogon verticillatus, Leucopogon capitellatus, Leucopogon propinquus, Pteridium esculentum and Tremandra stelligera on better drained loamy sands.

Southern coastal swamps and damlands - Estuarine swamps

Zv9 Component vegetation complex OW.
Estuarine swamps in hyperhumid zone. Sedgeland of Meeboldina scariosa, Baumea vaginalis, Lepyrodia drummondiana, Closed Heath of Hakea varia, Hakea ceratophylla, Astairea fasicularis to Open Woodland of Melaleuca cuticularis and Tall Shrubland of Agonis juniperina. Associated shrub and herb species include Patersonia occidentalis, Anathotium humble and Pericalymma ellipticum.

Southern coastal swamps and damlands - Swampy depressions and plains of the southern coastal plain and hinterland

Gw9 Component vegetation complexes BW, BWp, Wp and KO.
Fresh water swamps and damlands with sandy rises in hyper humid zones. Vegetation ranges from Sedgeland of Anarthria scabra, Anarthria prolifera, Lyginia barbata, Evandra aristata and Heath of Agonis parviceps, Acacia hastata, Beaufortia sparsa, Adenanthes obovatus, Dasyypogon bromeliifolius, Acacia myrtifolia to Woodland of Banksia ilicifolia, Banksia littoralis, Nuytsia floribunda, Eucalyptus patens and Eucalyptus megacarpa. On rises, Woodland of Eucalyptus marginata subsp. marginata, Allocasuarina fraseriana, Banksia attenuata.

Sv9 Component vegetation complexes BU and Pi.
Swampy plains with granitic and lateritic rises in hyperhumid zone. Vegetation ranges from Sedgeland of Anarthria prolifera, Hypolaena exsulca, Empodisma gracillimum, Lepidosperma leptostachyum, Xyris lanata, Evandra aristata through Heath of Pultenaea reticulata, Adenanthes obovatus, Agonis linearifolia, Agonis parviceps, Homalospermum firmum to Woodland of Eucalyptus patens, Eucalyptus megacarpa, Melaleuca preissiana on flats and Eucalyptus marginata subsp. marginata, Corymbia calophylla on rises. Understorey on rises Acacia pentadenia, Agonis hypericifolia, Podocarpus drouynianus, Bossiaea linophylla.

Bw8 Component vegetation complexes A, CT, F, HA and Q.
Subcoastal swamps and damlands in hyper and perhumid zones. Vegetation ranges from Sedgeland of Evandra aristata, Anarthria scabra, Xyris lanata, Alexgeorgea ganopoda, Leptocarpus elegans ms, Anarthria prolifera, Heath of Pericalymma crassipes, Homalospermum firmum, Agonis parviceps, Agonis linearifolia, Banksia quercifolia, Kunzea sulphurea to Woodland of Melaleuca preissiana, Eucalyptus patens, Nuytsia floribunda, Banksia littoralis and Banksia ilicifolia.
APPENDIX 3.6  (Continued)

Shallow coastal valleys

K19  Component vegetation complexes S1 and V4.
Shallow valleys on coastal plain in hyperhumid zone. Vegetation ranges from Tall Shrubland of *Agonis juniperina* through Woodland and Open Forest of *Eucalyptus* *patens*, *Eucalyptus megacarpa* to Tall Open Forest of *Eucalyptus diversicolor*, *Corymbia calophylla*. Second storey of *Allocasuarina decussata*, *Callistachys lanceolata*, *Agonis flexuosa*. Shrub understorey of *Agonis linearifolia*, *Astartea fascicularis*, *Acacia pentadenia*, *Trymalium floribundum*, with *Anigozanthos flavidus*, *Lepidosperma tetraquetrum*.

Iw8  Component vegetation complexes S3 and S4.
Shallow valleys in swampy terrain at the interface between the southern coastal plain and the hilly hinterland in the hyperhumid zone. Soils range from humus podzols in depressions to yellow duplex soils on slopes. Vegetation ranges from Open Woodland of *Melaleuca preissiana*, *Banksia littoralis* and *Nuysia floribunda* in depressions to Woodland of *Eucalyptus marginata* subsp. *marginata* on the slopes. Shrub and sedge storey consists of *Astartea fascicularis*, *Agonis parviceps*, *Hakea varia*, *Beaufortia sparsa*, *Homalospermum firmum*, *Adenantheros obovatus*, *Anarthria scabra*, *Anarthria prolifer*, *Evandra aristata*, *Sphenotoma gracile* and *Mesomelaena tetragina*.

Iw6  Component vegetation complexes, S5 and S6.
Moderately incised headwater gullies at the southern margin of the Darling Plateau in the humid perhumid climate. Soils range from deep sands to yellow duplexes. The vegetation ranges from Shrubland and Sedgeland of *Agonis parviceps*, *Adenantheros cuneatus*, *Adenantheros obovatus*, *Dasyypogon bromeliifolius*, *Anarthria prolifer*, *Anarthria scabra*, *Meeboldina coangustata*, *Homalospermum firmum*, *Evandra aristata*, *Leptocarpus tenax* through emergents or Open Woodland of *Melaleuca preissiana*, and *Banksia littoralis* to Woodland of *Allocasuarina fraseriana*, *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla* on slopes. Understorey on slopes *Melaleuca thymoides*, *Xanthorrhoea preissii*, *Hakea amplexicaulis*, *Xanthorrhoea preissii*.

Valleys in southern crystalline plateau with steep to moderate slopes

Ks8  Component vegetation complexes DO, WA, LF, VI, Vh2 and Vh3.
Deeply incised valleys in hilly coastal hinterland and southern margin of the Darling Plateau in hyper and perhumid zones. Dominant vegetation, Tall Open Forest of *Eucalyptus jacksonii*, *Eucalyptus guilfoylei* (within the vicinity of Walpole only), *Eucalyptus diversicolor*, *Eucalyptus patens*, *Corymbia calophylla* (throughout the range). Second storey of *Agonis juniperina*, *Callistachys lanceolata* (on stream lines only), *Allocasuarina decussata*, *Agonis flexuosa*, *Banksia grandis* and *Persoonia longifolia* (on slopes). Tall shrub storey of *Trymalium floribundum*, *Chorilaena quercifolium*, *Bossiaea aquifolium* subsp. *laidlawiana*, *Acacia pentadenia*.

Km8  Component vegetation complexes PM1, WH1 and YN1.
Mildly to moderately incised valleys in the southern margin of the Darling Plateau in perhumid zone. Dominant vegetation, Tall Open Forest of *Eucalyptus diversicolor*, *Eucalyptus patens* and *Corymbia calophylla*. Second storey of *Banksia seminuda*, *Callistachys lanceolata*, *Agonis juniperina* on stream lines, *Agonis flexuosa*, *Allocasuarina decussata*, *Banksia grandis* and *Persoonia longifolia* on slopes. Shrub
understorey of *Hovea elliptica*, *Bossiaea webbii*, *Bossiaea linophylla*, *Leucopogon verticillatus*, *Chorizema quercifolia*, *Trymalium floribundum*, with sedge *Lepidosperma effusum*.

**Mm5** Component vegetation complexes, *CCI* and *GR*.
Moderately incised valleys in the Darling Plateau both south and north of the Blackwood River, in the humid zone. Soils range from shallow gritty loams on the steeper slopes through red brown and yellow duplex soils to yellow brown loamy sand on the milder slopes. Vegetation ranges from Open Forest of *Eucalyptus patens* on valley floors to Open Forest of *Corymbia calophylla* and *Eucalyptus marginata* subsp. *marginata* on slopes. Shrub and herb storey consists of *Hakea amplexicaulis*, *Pteridium esculentum*, *Xanthorrhoea preissii*, *Macrozamia riedelii*, *Phyllanthus calycinus*, *Bossiaea aquifolioides* subsp. *aquifolioides*, *Leucopogon propinquus*, *Leucopogon capitellatus*, *Clematis pubescens*, *Hibbertia hypericoides*, *Hakea amplexicaulis*, *Leucopogon propinquus*, *Pteridium esculentum*, *Hibbertia amplexicaulis*, *Acacia urophylla*, *Trymalium floribundum*, *Hibbertia commutata* and *Lasiopetalum floribundum*.

**Nm5** Component vegetation complexes, *PM2, Va2, Va3, WH2* and *WL*.
Moderately to mildly incised valleys at the southern margin on the Darling Plateau in the humid zone, with red and yellow earths and duplex soils. Vegetation ranges from Woodland of *Eucalyptus rudis*, *Eucalyptus patens*, *Hakea oleifolia*, *Callistachys lanceolata* on the valley floor to Open Forest of *Eucalyptus marginata* subsp. *marginata*, *Corymbia calophylla*, more rarely *Eucalyptus cornuta*, with second storey of *Banksia grandis* and *Persoonia longifolia* on slopes. Shrub and herb storey of *Lepidosperma effusum*, *Chorizema illicifolium*, *Agonis linearifolia*, *Baumea juncea*, *Tremaandra diffusa* and *Xanthorrhoea preissii* on the valley floor and *Leucopogon verticillatus*, *Pteridium esculentum*, *Acacia urophylla*, *Hibbertia amplexicaulis*, *Macrozamia riedelii*, *Tremaandra stelligera*, *Leucopogon capitellatus*, *Leucopogon propinquus*, *Hakea lissocarpa*, *Lomandra drummondii* and *Lomandra sericea* on slopes.

**NM5** Component vegetation complexes, *CB, ST* and *YN2*.
Mildly dissected valleys in the southern margin of the Darling Plateau in the humid zone, with yellow duplex soils. Vegetation ranges from Woodland of *Eucalyptus patens* and *Eucalyptus rudis* with second storey of *Banksia seminuda*, *Banksia littoralis*, *Callistachys lanceolata*, *Hakea oleifolia* and *Melaleuca preissiana* on the valley floor. Woodland of *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla* on slopes, with second storey of *Banksia grandis*, *Persoonia longifolia* and *Agonis flexuosa*. Shrub and herb storey consists of *Astartea fascicularis*, *Melaleuca viminalis*, *Melaleuca incana*, *Anigozanthos flavidus*, *Trymalium floribundum*, *Leucopogon australis*, *Acacia saligna* on valley floor and *Pteridium esculentum*, *Leucopogon capitellatus*, *Hovea elliptica*, *Bossiaea ornata* and *Bossiaea linophylla* on slopes.

**Uplands on southern crystalline plateau, with red earths carrying Karri Forest**

**Ta8** Component vegetation complexes *COb, Kb* and *MTb*.
Mild to moderately sloping uplands with red brown loamy soils, rising above the plateau and coastal plain in hyper and perhumid zones. Dominant vegetation, Tall Open Forest of *Eucalyptus jacksonii*, *Eucalyptus guilfoylei*, *Eucalyptus brevistylis*
APPENDIX 3.6 (Continued)

(near Walpole only), *Corymbia calophylla*, *Eucalyptus marginata* subsp. *marginata*. Second storey of *Agonis flexuosa*, *Allocasuarina decussata*, *Banksia grandis*. Tall shrub understorey of *Chorilaena quercifolia*, *Acacia pentadenia*, *Trymalium floribundum*, *Pteridium esculentum*, *Hovea elliptica*, *Clematis pubescens* and *Billardiera floribunda*.

Kp8  Component vegetation complexes *BEb* and *CRb*. Ridges and upper slopes with red brown earths and duplexes, at the southern margin of Darling Plateau, in perhumid zone. Dominant vegetation Tall Open Forest of *Eucalyptus diversicolor*, *Corymbia calophylla* and *Eucalyptus marginata* subsp. *marginata*. Second storey of *Banksia grandis*, *Persoonia longifolia* and *Allocasuarina decussata*. Tall shrub storey of *Bossiaea aquifolium* subsp. *laidlawiana*, *Chorilaena quercifolia*, *Tremandra stelligera*, *Acacia urophylla*, *Bossiaea linophylla*, *Leucopogon verticillatus*, *Hovea elliptica*, *Hardenbergia comptoniana* and *Pteridium esculentum*.

Uplands on southern crystalline plateau, yellow duplex and lateritic soils carrying Jarrah Forest

Mp8  Component vegetation complexes *BE1*, *BEy1*, *CO1*, *COy1*, *CRy*, *MT1* and *MTy1*. Mildly sloping uplands with lateritic and yellow duplex soils at the southern margin of Darling Plateau and south coast hinterland in the hyper and perhumid zones. Dominant vegetation, Open Forest to Tall Open Forest of *Eucalyptus guilfoylei*, *Eucalyptus brevistylis* (near Walpole only), *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla* (through the range). Some minor intrusions of *Eucalyptus diversicolor*. Second storey of *Banksia grandis*, *Persoonia longifolia* and *Allocasuarina fraseriana*. Shrub storey of *Leucopogon verticillatus*, *Hovea chorizemifolia*, *Hovea elliptica*, *Hakea amplexicaulis*, *Macrozamia riedlei*, *Podocarpus drouynianus*, *Bossiaea linophylla*, *Grevillea trifida*, *Leucopogon verticillatus*, *Acacia urophylla* and *Clematis pubescens*.

Ja8  Component vegetation complexes, *Ky* and *Ly*. Mildly to moderately sloping uplands with lateritic and yellow duplex soils, on the hilly south coast hinterland in the perhumid hyperhumid zones. Dominant vegetation, Open Forest of *Eucalyptus guilfoylei*, *Eucalyptus brevistylis* (near Walpole only) *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla*. Second storey of *Banksia grandis* and *Persoonia longifolia*. Shrub and herb storey of *Kingia australis*, *Leucopogon capitellatus*, *Leptomeria cunninghamii*, *Opercularia hispidula*, *Hibbertia amplexicaulis*, *Macrozamia riedlei*, *Hakea lissocarpha*, *Boronia gracilipes*, *Leucopogon verticillatus* and *Hovea elliptica*.

Ip8  Component vegetation complexes, *COD* and *CRd*. Mildly to moderately sloping uplands with some yellow duplex soils on the plateau and the rises above the plateau at the southern margin of the Darling Plateau in the perhumid zone. Dominant vegetation, Open Forest to Tall Open Forest of *Eucalyptus marginata* subsp. *marginata* and *Corymbia calophylla*. Second storey of *Banksia grandis* and *Persoonia longifolia*. Shrub and herb storey of *Agonis parviceps*, *Agonis linearifolia*, *Lindsaea linearis*, *Xanthorrhoea preissii*, *Anarthria scabra*, *Patersonia umbrosa*, *Leucopogon australis*, *Bossiaea webbii*, *Lepidosperma effusum*, *Macrozamia riedlei*, *Adenantheros obovatus*, *Podocarpus drouynianus*. 
APPENDIX 3.6 (Continued)

Jp5 Component vegetation complexes, BE2, BEy2, CO2, COp2, COy2, MT2, MTP2, MTY2, and UC3.
Mildly sloping uplands with lateritic and yellow duplex soils in the southern Darling Plateau in humid zone. Dominant vegetation is Open Forest of Eucalyptus marginata subsp. marginata and Corymbia calophylla, with second storey of Banksia grandis, Persoonia longifolia and Allocasuarina fraseriana. Shrub and herb storey consists of Bossiaea linophylla, Hakea amplexicaulis, Agonis parviceps, Xanthosia rotundifolia, Leucopogon capitellatus, Acacia myrtifolia, Bossiaea ornata, Macrozamia riedlei, Leucopogon verticillatus and Clematis pubescens.

JP3 Component vegetation complexes, BE3 and FH1.
Uplands (upperslopes and ridges) at the southern margin of the Darling Plateau in the subhumid semi-arid zones, with gravelly yellow duplex soils with some lateritic outcrops. Dominant vegetation is Woodland of Eucalyptus marginata subsp. marginata and Corymbia calophylla with some Eucalyptus wandoo and Eucalyptus astringens at the margins. There is weakly developed second storey of Persoonia longifolia. Shrub and herb storey consists of Bossiaea ornata, Daviesia preissii, Hibbertia commutata, Macrozamia riedlei, Hakea lissocarpa, Dryandra sessilis and Lepidasperma tenue.

Uplands in southern Darling Plateau and south coast hinterland, other than deep duplex soils with laterite

Ia8 Component vegetation complexes, COp1, Kp, Lp and MTP1.
Moderate slopes with shallow gritty yellow duplex soils in the hilly south coast hinterland in the hyper humid zones. Dominant vegetation, Woodland to Open Forest of Eucalyptus marginata subsp. marginata, Corymbia calophylla and Eucalyptus megacarpa. Second storey of Banksia grandis, Persoonia longifolia to a lesser degree Banksia attenuata and Nuytsia floribunda. Shrub and herb storey of Petrophile longifolia, Agonis parviceps, Synaphea petiolaris, Daviesia decurrens, Anarthria scabra, Adenanthes obovatus, Xanthosia candida, Banksia verticillata, Conospermum huegelli, Leucopogon unilateralis, Xanthosia rotundifolia, Lepidasperma squamatum, Eutaxia obovata, Andersonia sprengelioides, Hakea amplexicaulis and Podocarpus drouinianus.

Ja4 Component vegetation complexes, BAl and PN.
Slopes of hills rising above the southern margin of the Darling Plateau with gravelly yellow duplex soils on upper slopes and yellow podzolic soils on lower slope, in the humid subhumid zones. Vegetation ranges from Low Woodland of Melaleuca rhaphiophylla and Callistachys lanceolata on springs to Woodland of Eucalyptus marginata subsp. marginata, Corymbia calophylla and Eucalyptus cornuta on slopes. Weakly developed second storey of Banksia grandis and shrub and herb storey of Agonis parviceps, Lepidasperma squamatum, Melaleuca thymoides and Mesomelaena tetragona.

Ac8 Component vegetation complexes, BEs, Ks and Ls.
Saddles and gentle slopes with sandy podzols in the hilly south coast hinterland in the perhumid hyperhumid zones. Vegetation ranges from Shrubland to Woodland of Eucalyptus marginata subsp. marginata and Allocasuarina fraseriana. Shrub and herb storey of Kingia australis, Agonis parviceps, Acacia divergens, Anarthria scabra,
APPENDIX 3.6 (Continued)

Anarthria prolifer, Xanthosia candida, Burchardia umbellata, Adenanthes obovatus, Allocasuarina humilis, Johnsonia lupulina, Xanthosia rotundifolia, Mesomelaena tetragona, Leucopogon australis and Beaufortia decussata.

Southern rocky steep slopes

Ra8 Component vegetation complexes, Gg and Kg.  
Steep slopes and crests of hills rising above the southern coastal plain with shallow gritty soils or bare rock in the perhumid hyperhumid zones. Vegetation is a mosaic of Lithic Complex (lichens, mosses), Herbfield, Heath and Woodland of Eucalyptus brevistylis (near Walpole only), Eucalyptus megacarpa, Corymbia calophylla. Shrub and herb storey of Agonis linearifolia, Agonis marginata, Verticordia plumosa, Chamaescilla corymbosa, Cheilanthes austrotenuefolia, Dodonea ceratocarpa, Andersonia sprengelioideae, Pimelea ferruginea and dwarfed Banksia grandis.

Ms8 Component vegetation complexes WS2 and WSv.  
Moderate to steep slopes of the southern Darling Scarp with yellow and red duplex soils and earths in the humid to hyper humid zones. Vegetation ranges from Heath through Woodland to Open Forest of Corymbia calophylla and Eucalyptus marginata subsp. marginata. Second storey of Banksia grandis and Persoonia longifolia. Shrub and herb storey of Xanthorrhoea preissii, Acacia pulchella, Acacia myrtifolia, Bossiaea linophylla, Bossiaea ornata, Hakea lissocarpa, Hakea amphlexicaulis, Macrozamia riedlei, Leucopogon verticillatus, Leucopogon capitellatus, Hibbertia amplexicaulis and Acacia extensa.

Rs7 Component vegetation complex DS (southern).  
Moderately sloping spurts and slopes of the southern Darling Scarp, with granite outcrops. Open Forest of Corymbia calophylla, Eucalyptus marginata subsp. marginata, with weakly developed second storey of Persoonia longifolia, Leucopogon verticillatus, Leucopogon capitellatus, Hakea amplexicaulis, Chorizema ilicifolium and Macrozamia riedlei.

Rs5 Component vegetation complexes, BAg and Lg.  
Steep slopes and crests of hills rising above the southern Darling Plateau in the humid subhumid zones, with shallow skeletal soils. Vegetation is a mosaic of Lithic Complex, Herbfield, Heath and Low Woodland of Corymbia calophylla. Components of the shrub layer consists of Daviesia horrida, Hakea trifurcata, Dodonea ceratocarpa, Hakea undulata, Trymalium floribundum, Desmoclados flexuosus, Verticordia plumosa and Eutaxia obovata.

Semi-swampy uplands of southern Darling Plateau

Kv7 Component vegetation complex CP.  
Undulating terrain of low rises and shallow depressions near the southern margin of the Darling Plateau in the perhumid zone. Soils range from orange earth with bog iron pans and humus podzols in depressions to red and yellow earths and duplex soils on rises. Vegetation ranges from Woodland of Melaleuca preissiana, Banksia littoralis and Callistachys lanceolata in depressions to Tall Open Forest of Corymbia calophylla and Eucalyptus diversicolor with second storey of Banksia grandis and Persoonia longifolia. Shrub and herb storey of Leucopogon verticillatus, Hovea elliptica,
APPENDIX 3.6 (Continued)

_Pteridium esculentum, Podocarpus drouynianus_ on rises, _Anarthria prolifera, Agonis parviceps, Leucopogon australis_ in depressions.

**Jw7** Component vegetation complex _CL1_.
Gently undulating terrain of low rises and shallow depressions on the southern Darling Plateau in the perhumid zone. Soils range from gravelly yellow duplex soils on rises through sandy podzols to orange earth with bog iron pan in depressions. Vegetation ranges from Open Forest of _Eucalyptus marginata_ subsp. _marginata_ and _Corymbia calophylla_ with second storey of _Banksia grandis, Persoonia longifolia_ and _Allocasuarina fraseriana_ on rises to Woodland of _Melaleuca preissiana_ and _Banksia litoralis_ in depressions. Shrub storey of _Bos siaea linophylla, Bos siaea ornata, Hovea trisperma, Macrozamia riedlei, Hakea amplexicaulis_ and _Stirlingia latifolia_ on rises; _Astartea fascicularis, Agonis linearifolia, Hypocalymma angustifolium, Mesomelaena tetragona, Leucopogon australis_ and _Hakea varia_ in depressions.

**Jw5** Component vegetation complexes, _CL2_ and _PP_.
Gently undulating uplands with low rises and swampy depressions in the humid subhumid zones of the southern Darling Plateau. Soils are yellow sandy duplex soils on rises and sandy podzols in depressions. Vegetation ranges from Woodland of _Melaleuca preissiana, Banksia litoralis_ and _Hakea oleifolia_ in depressions to Woodland or Open Forest of _Eucalyptus marginata_ subsp. _marginata_ and _Corymbia calophylla_, with understory of _Persoonia longifolia, Allocasuarina fraseriana_ and _Banksia grandis_ on rises. Shrub and herb storeys consists of _Bos siaea linophylla, Leucopogon australis, Hibbertia amplexicaulis, Cyathochaeta avenacea_ on rises and _Boronia megastigma, Hypocalymma angustifolium, Leucopogon unilateralis_ in depressions.

**Shallow valleys and depressions with solonetzic soils**

**Sv6** Component vegetation complex _CA_.
Extensive flat floored swampy plains with solonetzic and humus podzol soils among the hilly south coast hinterland in the humid perhumid zones. Dominant vegetation types are Sedgeland and Shrubland with some emergent _Melaleuca cuticularis, Nyctisia floribunda_ and _Melaleuca preissiana_, with Woodland of _Banksia quercifolia, Banksia ilicifolia, Banksia attenuata_ and _Corymbia ficifolia_ (near Walpole only) on transition to uplands. Shrub and herb storey of _Agonis parviceps, Dampiera linearis, Leucopogon australis, Astartea fascicularis, Melaleuca densa, Chaetanthus aristatus, Hibbertia stellaris, Anarthria laevis, Evandra aristata, Homalospermum firmum, Callistemon glaucus, Meeboldina scariosa, Beaufortia sparsa, Adenanthos obovatus_ and _Lepidosperma squamatum_.

**Ev5** Component vegetation complex, _S2_.
Minor headwater valleys at the southern margin of the Darling Plateau in the humid subhumid zone with yellow solonetzic and yellow duplex soils. Vegetation ranges from Open Woodland of _Melaleuca cuticularis_ and _Eucalyptus occidentalis_ on valley floors to Woodland of _Eucalyptus marginata_ subsp. _marginata, Eucalyptus wando_ and _Eucalyptus cornuta_ on slopes. Shrub and herb storey consists of _Atriplex paludosa, Hakea varia, Hakea ceratophylla, Atriplex pumilio, Halosarcia sp. and Isolepis prolifera_ on valley floors and _Acacia pulchella_ subsp. _pulchella, Hakea lissocarpa, Hibbertia amplexicaulis, Astroloma pallidum, Baeckea camphorosmae_ and _Hypocalymma angustifolium_ on slopes.
APPENDIX 3.6 (Continued)

Yv4 Component vegetation complexes, *Bu, CM, MO* and *Wg.*
Shallow depressions in south coast hinterland and southern margin of the Darling Plateau in humid to semiarid zones. Soils range from unconsolidated clays and solonetz in depressions to sandy podzols on margins. Vegetation ranges from Open Woodland of *Melaleuca cuticularis* and *Eucalyptus occidentalis* in depressions to *Woodland of Banksia attenuata, Allocasuarina fraseriana* and *Eucalyptus marginata* subsp. *marginata* on margins. Shrub and herb vegetation ranges from *Juncus pallidus,* *Juncus bufonius, Samolus junceus,* *Harperia lateriflora,* *Baeckea astreoides* in depressions to *Pultenaea reticulata,* *Adenanthero obovatus,* *Dasypogon bromeliifolius* and *Melaleuca thymoides* on slopes.

Shallow valleys and depressions with solonetzic soils

Zv4 Component vegetation complexes *FH4, FH5, GD1, GD4, V5* and *st.*
Valley floors and depressions in the Unicup Basin and Frankland and Gordon Valleys in subhumid zone. Soils range from sodic clays to yellow duplex soils. Vegetation is mainly Open Woodland of *Eucalyptus occidentalis* with some *Melaleuca cuticularis* and *Melaleuca preissiana* with *Eucalyptus decipiens* subsp. *chalara* and *Eucalyptus wandoo* on the margins. The understorey ranges from *Sporobolus virginicus,* *Salicornia sp., Hakea varia,* *Pericalymma ellipticum* and *Melaleuca viminea* in depressions to *Acacia extensa,* *Allocasuarina humilis,* *Mesomelaena tetragona* and *Hakea prostrata* on margins.

Shallow valleys and depressions

Gw6 Component vegetation complexes *Nu, QN* and *SC.*
Swampy gullies and depressions with humus podzol and sandy yellow duplex soils near the southern margin of the Darling Plateau in the humid subhumid zones. Dominant vegetation is *Woodland of Eucalyptus marginata* subsp. *marginata,* *Melaleuca preissiana,* *Banksia littoralis* and *Corymbia calophylla.* Shrub and herb storey consists of *Agonis parviceps,* *Hakea varia,* *Astartea fascicularis,* *Synaphea reticulata,* *Beaufortia sparsa,* *Hibbertia amplexicalulis,* *Meeboldina scariosa,* *Lepidosperma squamatum,* *Hakea prostrata* and *Hypocalymma angustifolium.*

Jk6 Component vegetation complex, *UC2.*
Mild lower slopes with deep grey sands in humid zone of the Unicup Basin. Vegetation ranges from *Open Woodland of Melaleuca preissiana* and *Banksia littoralis* downslope to *Woodland of Eucalyptus marginata* subsp. *marginata* and *Nyotisa floribunda* upslope with tall shrub storey of *Kunzea ericifolia,* *Bossiaea linophylla,* *Pultenaea reticulata* with *Anigozanthos flavidus.*

Gw5 Component vegetation complexes, *KP* and *YR.*
Swampy plains with humus podzol and sandy yellow duplex soils (YR) and clays (KP only) on the southern Darling Plateau in the humid perhumid zones. Dominant vegetation is *Woodland of Banksia littoralis,* *Melaleuca preissiana* in depressions, *Banksia ilicifolia,* *Banksia grandis* and *Eucalyptus marginata* subsp. *marginata* on rises. There are also *Sedgeland of Meeboldina scariosa* and *Isoplepis nodosa* and Shrubland of *Melaleuca densa.* The shrub and herb storey in the woodlands consists of *Adenanthero obovatus,* *Kingia australis,* *Mesopoma tetragona,* *Hakea varia,* *Anarthria scabra,* *Agonis parviceps,* *Podocarpus drouynianus,* *Evandra aristata* and *Hypocalymma angustifolium.*
Appendix 3.6 (Continued)

Sw5  Component vegetation complexes, UC1 and UC4.
Swampy plains in the Unipol Basin with shallow sands over bog iron ore and shallow clay loams, in the humid subhumid zones. Vegetation ranges from Shrubland of Melaleuca spp. to Open Woodland of Banksia ilicifolia, Melaleuca preissiana, Nuytsia floribunda on sands and Woodland of Eucalyptus occidentalis and Eucalyptus decipiens subsp. chalara on the clay loams. The shrub and herb storeys consist of Agonis parviceps, Dasypogon bromeliifolius, Pultenaea reticulata, Anarthria prolifera, Adenantheros obovatus, Andersonia caerulea, Calytrix flavescens, Eucalyptus linearis, Hibbertia racemosa, Hibbertia stellaris, Xanthorrhoea preissii, Hakea varia, Hypocalymma angustifolium and Regelia ciliata.

Sedimentary deposits within and south of Darling Plateau – crests and ridges

Jk8  Component vegetation complex Dc1 and TR1.
Mildly sloping uplands with gravelly sandy yellow duplex soils on sedimentary plateau in the south coast hinterland, in the perhumid hyperhumid zones. Dominant vegetation Woodland to Open Forest of Eucalyptus marginata subsp. marginata, and Corymbia calophylla with second storey of Corymbia ficifolia (near Walpole only), Allocasuarina fraseriana, Nuytsia floribunda and Banksia grandis. Shrub and herb storey of Agonis parviceps, Adenantheros obovatus, Dasypogon bromeliifolius, Anarthria prolifera, Melaleuca thyoides, Strangalia stenocarpoides, Synapheoa obtusata, Petrophile longifolia, Xanthosia rotundifolia, Bossiaea linophylla, Leucopogon verticillatus and Leucopogon australis.

Jg6  Component vegetation complexes, Dc2, MI, R and TR2.
Broadly undulating uplands on sedimentary deposits south of the Darling Plateau in humid zone. Soils are gravelly sandy yellow duplex with some laterite outcrops. Dominant vegetation is Woodland to Open Forest of Eucalyptus marginata subsp. marginata and Corymbia calophylla with minor admixture of Eucalyptus staeri. Second storey of Banksia grandis, Allocasuarina fraseriana. Shrub and herb storey of Agonis hypericifolia, Agonis parviceps, Podocarpus drouynianus, Adenantheros obovatus, Adenanthes cuneatus, Lyginia barbata and Melaleuca thyoides.

Jc6  Component vegetation complexes, QP, QT and TP.
Crests and upper slopes of low hills of sedimentary material on the southern Darling Plateau in the humid subhumid zones. The soils are mainly podzols and sandy duplex soils with lateritic outcrops. Dominant vegetation is Woodland of Eucalyptus marginata subsp. marginata and Corymbia calophylla with second storey of Banksia grandis and Persoonia longifolia. Shrub and herb storey of Podocarpus drouynianus, Acacia extensa, Bossiaea linophylla, Leucopogon capitellatus, Leucopogon racemulosus, Melaleuca thyoides and Dasypogon bromeliifolius.

Sedimentary deposits within and south of Darling Plateau – slopes and valleys

Ak6  Component vegetation complexes, Ds, S7 and S8.
Lower slopes and depressions in sedimentary terrain south of the Darling Plateau in humid zone. Soils are deep sands and iron podzols. Vegetation ranges from Shrubland to Woodland of Eucalyptus staeri, Allocasuarina fraseriana, Banksia grandis, Banksia attenuata and Nuytsia floribunda. Shrub and herb storey consists of Callistemon glaucus, Beaufortia sparsa, Evanda aristata and Agonis parviceps in depressions and
APPENDIX 3.6  (Continued)

Adenanthis obovatus, Xanthosia rotundifolia, Hakea ruscifolia, Anarthria scabra, Leucopogon australis, Stirlingia latifolia and Dasypogon bromeliifolius on slopes.

Mn5  Component vegetation complexes, V7 and V8.
Broad shallow valleys in sedimentary terrain south of the Darling Plateau in perhumid to humid zones. Soils are sands, gravelly and loamy duplex. Vegetation ranges from Tall Open Forest with Eucalyptus diversicolor and Corymbia calophylla with a second storey of Agonis flexuosa, Allocasuarina decussata in the perhumid zone to Woodland of Eucalyptus occidentalis and Melaleuca cuticularis in the humid zone. Shrub and herb storey ranges from Bossiaea linophylla, Leucopogon verticillatus, Pteridium esculentum, Hovea elliptica under Tall Open Forest to Agonis parviceps, Evandra aristata, Callistemon glaucus and Gahnia trifida under the woodland.

Sw6  Component vegetation complexes f and t.
Floors and terraces of rivers in the humid perhumid zone of the south coast and hinterland. Soils are alluvial soils ranging from humus podzols and deep sands to yellow duplex soils. The vegetation ranges from Sedgeland of Evandra aristata, Anarthria prolifera, Anarthria scabra on the most severely waterlogged soils through Heath of Pultenaea reticulata, Adenanthis obovatus, Agonis parviceps, Callistemon glaucus, Beaufortia sparsa and emergents or Open Woodland of Melaleuca preissiana, Banksia littoralis, Eucalyptus occidentalis and Melaleuca cuticularis on better drained sites to Woodland of Eucalyptus marginata subsp. marginata, Corymbia calophylla, Allocasuarina fraseriana, Banksia grandis, Banksia attenuata and Eucalyptus staeri at transition to slopes.

Moderate valley slopes

Wm4  Component vegetation complexes, CC2, FH2, FH3, GD2, JP2, WH3, Ya, YE and Yef.
Mild to moderate valley slopes with some included swampy floors at the southern margin of the Darling Plateau in the subhumid semi arid zone. Soils are mainly yellow duplexes with sand to sandy loam topsoil. Vegetation ranges from Shrubland of Melaleuca vininea, Melaleuca incana, Hakea prostrata, Acacia saligna with emergents of Eucalyptus rudis and Melaleuca preissiana to Woodland of Eucalyptus wandoo and Corymbia calophylla, with some Eucalyptus marginata subsp. marginata and Eucalyptus astringens near uplands. Shrub and herb storey of the woodland consists of Hakea lissocarpha, Macrozamia riedlei, Leucopogon capitellatus, Trymalium ledifolium, Baeckea camphorosmae and Lepidoperma squamatum.

Ig3  Component vegetation complexes, Mn and Pu.
Low rises on the south eastern Darling Plateau in the subhumid semiarid zones with sandy and gravelly duplex soils derived from bog iron deposits. Dominant vegetation is Woodland of Eucalyptus marginata subsp. marginata and Corymbia calophylla with an understorey of Banksia grandis and shrub and herb storey of Bossiaea linophylla, Bossiaea ornata, Xanthorrhoea humilis, Macrozamia riedlei, Leucopogon capitellatus, Lepidoperma tenue, Hibbertia commutata and Petrophile serrulata.
APPENDIX 3.6  (Continued)

WESTERN SUBREGION

South western dunes

Qu8  Component vegetation complex, *DE5*.  
Unstable dunes in humid zone, consisting of deep lime-rich sand with low water holding capacity. Vegetation ranges from bare sand with mats of Carpodrrotus sp., *Arctotheca populifolia*, through Coastal Complex to Grassland of *Ammophila arenaria* to Heath of *Olearia axillaris* and *Spyridium globulosum*.

Py8  Component vegetation complexes, *D5, Dr* and *Drd*.  
Young stabilised sand dunes in humid zone, consisting of dark grey calcareous sands over limestone. Vegetation ranges from Shrubland to Low Woodland of Agonis flexuosa, with associated species such as the shrubs *Acacia littorea, Spyridium globulosum, Leucopogon parviflorus, Lobelia tenuior, Rhagodia baccata, Hibbertia cuneiformis* and sedges *Lepidosperma gladiatum, Lepidosperma squamatum* and *Anigozanthos flavidus*.

Po8  Component vegetation complexes, *D, Dd* and *Dd5*.  
Old stabilized dunes in humid zone, consisting of sandy podzols over pale brown non-calcareous sand. Vegetation ranges from Shrubland of *Agonis parviceps, Leucopogon australis, Hibbertia cuneiformis* with emergents of *Nuytsia floribunda* and *Banksia attenuata* through Woodland of *Agonis flexuosa, Eucalyptus cornuta* and *Eucalyptus megacarpa* to Open Forest of *Corymbia calophylla* and *Eucalyptus marginata* subsp. *marginata*. On optimum sheltered sites Tall Forest of *Eucalyptus diversicolor*. Associated shrub, climber and herb species in the forest *Hardenbergia comptoniana, Clematis pubescens, Pteridium esculentum, Macrozamia riedlei, Leucopogon capitellatus* and *Leucopogon verticillatus*.

Western dunes

Qu7  Component vegetation complexes, *KB, kBe* and *KE*.  
Exposed dunes in hyperhumid to humid zones, consisting of lime rich sands with low waterholding capacity. Vegetation mainly Shrubland of *Melaleuca huegelii, Pimelea ferruginea, Olearia axillaris, Spyridium globulosum, Acacia littorea* with sedges *Lepidosperma gladiatum* and *Isolepis nodosa*.

Py7  Component vegetation complexes, *GE, Ge, KEf, Kf* and *Kr*.  
Young stabilised dunes of brownish yellow sand overlying limestone. Vegetation ranges from Shrubland of *Spyridium globulosum, Scaevola crassifolia, Rhagodia baccata, Melaleuca huegelii* and *Dryandra sessilis* to Woodland of *Agonis flexuosa* with understorey of *Hibbertia potenilliflora, Hibbertia cuneiformis, Hardenbergia comptoniana, Phyllanthus calycinus, Macrozamia riedlet* and *Xanthorrhoea pressii*.

Ko9  Component vegetation complexes, *G2, G3, Gk* and *Gv*.  
Lee side of old stabilized dunes consisting of deep brown sand over limestone at depth, in hyperhumid humid zones. Vegetation mainly Tall Open Forest of *Eucalyptus diversicolor* with admixture of *Corymbia calophylla*. Second storey of *Agonis flexuosa*. Shrub and herb storey of *Pteridium esculentum, Clematis pubescens*. 
APPENDIX 3.6  (Continued)

Hardenbergia comptoniana, Hibbertia potenilliflora, Bossiaea linophylla, Podocarpus drouynianus, Chorizena quercifolia, Acacia alata, Hibbertia grossulariifolia and Macrozamia riedlei.

Estuarine swamps

Sv8  Component vegetation complex, Bwy.
Fringing estuarine flats in perhumid zone consisting of mixed clays, loams and sands. Vegetation ranging from Sedgeland of Baumea juncea, Baumea vaginalis, Lepyrodia drummondiana, Meeboldina scariosa through Heath of Hakea varia and Hakea ceratophylla to Woodland of Melaleuca cuticularis.

Swampy depressions and plains

Sw7  Component vegetation complexes, Bw, CV, Sw, Swd and Swi.
Low lying coastal plain in perhumid zone, subject to seasonal inundation, with leached grey sands over ironstone. Vegetation mainly Sedgeland of Anarthria prolifera, Anarthria scabra, Meeboldina scariosa, Schoenus efoliatus, Phlebocarya ciliata, Lyginia barbata and Heath of Adenantheros obovatus, Adenantheros detmoldii, Boronia spathulata, Hakea ceratophylla, Hakea sulcata, Calothamnus lateralis, Hibbertia stellaris, Homalospermum firmum, Philotheca spicata, Agonis parviceps, Agonis linearifolia, Pericalymma ellipticum. Emergents and Open Woodland of Nuytsia floribunda, Viminaria juncea, Melaleuca preissiana, Banksia ilicifolia, Banksia littoralis, stunted Eucalyptus marginata subsp. marginata.

Sw4  Component vegetation complexes, Adw, Aw, Lw and Qw.
Shallow gullies and depression in humid zone with seasonally waterlogged sandy duplex soils. Vegetation ranges from Shrubland of Melaleuca viminalis, Melaleuca teretifolia, Hakea varia, Pericalymma ellipticum with low emergents of Viminaria denutata to Woodland of Eucalyptus rudis, Melaleuca raphaelphylla and Agonis linearifolia. The components of the understorey include Gahnia trifida, Baumea juncea, Lepidosperma longitudinale, Lobelia alata and Isolepis producta.

Sandy rises above plains and plateaus

Ac7  Component vegetation complexes, Ad, Bd, Cd, Hd, Nd, Sd, Sd2, Td, Wd and Yd.
Low sandy rises above coastal plains and plateaus in humid to perhumid zones with deep bleached sands. Vegetation ranges from Low Woodland of Banksia attenuata, Banksia ilicifolia, Nuytsia floribunda, Agonis flexuosa to Open Forest of Eucalyptus marginata subsp. marginata and Corymbia calophylla with second storey of Banksia grandis and Xylomelum occidentale. The shrub and herb storey is composed of Melaleuca thyoides, Leucopogon reflexus, Leucopogon australis, Petrophile linearis, Calytrix flavescent, Lyginia barbata, Pullenaea reticulata, Agonis parviceps, Xanthorrhoea preissii, Podocarpus drouynianus, Mesemelaena tetragona, Dasyypogon bromeliifolius and Adenantheros obovatus.

South western flats

Mk8  Component vegetation complexes, B, Ba, Bf and JA.
Moderately well drained sub coastal flats and terraces in perhumid zone, with soils ranging from sandy duplexes to alluvial loams. Vegetation ranges from Woodland of
APPENDIX 3.6 (Continued)

*Corymbia calophylla* with *Agonis flexuosa* through Open Forest of *Corymbia calophylla* and *Eucalyptus marginata* subsp. *marginata* to Tall Open Forest of *Eucalyptus diversicolor* on optimum sites. Second storey consists of *Agonis flexuosa*, *Persoonia longifolia*, *Hakea oleifolia* and *Xylomelum occidentale*. The associated shrub and herb species are *Hovea elliptica*, *Pteridium esculentum*, *Anigozanthos flavidus*, *Kennedia coccinea*, *Hakea amplexicaulis*, *Leucopogon capitellatus*, *Leucopogon propinquus*, *Acacia urophylla* and *Bosistea linophylla*.

Mb5 Component vegetation complexes, *AB, AF, As* and *Yf*.
Better drained and more fertile portions of the southern Swan Coastal Plain, with sandy to loamy yellow duplex soils. Dominant vegetation is Woodland to Open Forest of *Corymbia calophylla* with second storey of *Agonis flexuosa*, *Banksia grandis*, *Persoonia longifolia*, *Acacia saligna*, and understorey of *Kingia australis*, *Pteridium esculentum*, *Acacia extensa*, *Acacia pulchella*, *Brachysema praemorsum*, *Leucopogon capitellatus*, *Hypocalymma angustifolium*, *Billiardiera variifolia*.

South western rocky slopes

Qm7 Component vegetation complexes, *We WE* and *WEw*.
Seaward slopes of crystalline plateau in hyperhumid to humid zones with shallow loamy duplex soils or bare rock. Vegetation is reduced to Low Open Woodland of *Corymbia calophylla*, *Eucalyptus marginata* subsp. *marginata* and *Agonis flexuosa* or in extreme cases to Heath or Sedgeland. Shrubs and herb species are *Pteridium esculentum*, *Tremandra stelligera*, *Tetrarrhena laevis*, *Acacia alata*, *Xanthorrhoea preissii*, *Bosistea disticha* and *Lepidosperma leptostachyum*.

Ms6 Component vegetation complexes, *Cr, Mv* and *Wr*.
Steep rocky slopes associated with valleys incised into the Margaret River Plateau in the humid perhumid zones. Soils are mainly shallow duplex soils. Vegetation ranges from Lithic Complex, Herbfield through Heath to Woodland of *Corymbia calophylla* with *Agonis flexuosa* and *Banksia grandis*. Shrubs and herb storey consists of *Hakea lissocarpa*, *Hibbertia hypericoides*, *Gastrolobium spinosum*, *Calothamnus sanguineus*, *Hypocalymma*, *angustifolium*, *Hemigenia incana*, *Hakea trifurcata*, *Dodonaea ceratocarpa*, *Verticordia plumosa* and *Cryptandra arbutiflora*.

Valleys in south western crystalline plateau

Km9 Component vegetation complexes, *CwI, Hw, WI* and *WwI*.
Mildly to moderately incised valleys in the Margaret River Plateau, in the perhumid to hyperhumid zones with red brown earths, red brown duplex and yellow duplex soils. Vegetation ranges from Tall Shrubland of *Agonis linearifolia*, *Mirbelia dilatata*, *Callistachys lanceolata* and *Trymalium floribundum* (on valley floors) to Tall Open Forest of *Eucalyptus diversicolor* with second storey of *Agonis flexuosa*, *Allocasuarina decussata*, *Banksia grandis* and *Persoonia longifolia*. Shrubs and herb storey species are *Lepidosperma tetraquetrum*, *Lepidosperma effusum*, *Agonis linearifolia*, *Trymalium floribundum* on valley floor and *Chorilaena quercifolia*, *Acacia urophylla*, *Bosistea linophylla*, *Tremandra stelligera*, *Pteridium esculentum* and *Leucopogon verticillatus* on valley slopes.
APPENDIX 3.6  (Continued)

Valleys in south western crystalline plateau

Mm6 Component vegetation complexes, Cw2, W2 and Ww2.
Valleys incised into the Margaret River Plateau in the humid to perhumid zones with soils ranging from yellow duplex soils to red earths. Dominant vegetation is Open Forest of Corymbia calophylla with admixture of Eucalyptus patens on lower slopes and Eucalyptus marginata subsp. marginata on upper slopes. The second storey consists of Hakea lasianthoides, Agonis flexuosa, Banksia grandis and Persoonia longifolia. The understorey components include Agonis linearifolia, Mirbelia dilatata, Acacia alata, Astarea fassiculalis on the floor and Pteridium esculentum, Hovea elliptica, Leucopogon verticillatus, Macrozamia riedlei, Logania vaginalis and Opercularia hispida on the slopes.

South western crystalline uplands

Jp9 Component vegetation complexes, C1 and H.
Uplands of the Margaret River plateau in hyperhumid to perhumid zones, mainly with gravelly yellow brown duplex soils. Dominant vegetation Open Forest of Eucalyptus marginata subsp. marginata and Corymbia calophylla with second storey of Banksia grandis and Persoonia longifolia. Shrub and herb storey species are Leucopogon verticillatus, Leucopogon capitellatus, Pteridium esculentum, Bossiaea linophylla, Bossiaea ornata, Hovea elliptica, Macrozamia riedlei, Hibbertia hypericoides and Agonis parviceps.

Jp6 Component vegetation complexes, C2 and M.
Mildly undulating uplands in humid perhumid zones, with gravelly duplex soils and outcrops of laterite. Dominant vegetation is Open Forest of Eucalyptus marginata subsp. marginata and Corymbia calophylla with second storey of Persoonia longifolia, Banksia grandis, Xylometum occidentale. Shrub and herb storey consists of Xanthorrhoea preissii, Xanthorrhoea gracilis, Adenanthos barbigér, Hakea amplexicaulis, Daviesia incrassata and Hakea lissocarpha.

Jm8 Component vegetation complexes, MP and SS.
Uplands and slopes on basaltic parent material in the perhumid zone of the Blackwood Plateau, with soils ranging from gravelly sandy duplex on uplands to red earths on slopes. Vegetation is Open Forest of Eucalyptus marginata subsp. marginata and Corymbia calophylla, with second storey of Banksia grandis and Persoonia longifolia. Shrub and herb components of the understorey are Leucopogon verticillatus, Pteridium esculentum, Bossiaea linophylla, Hovea triflora, Macrozamia riedlei, Clematis tubescens, Leucopogon capitellatus, Acacia urophylla and Hibbertia amplexicaulis.

Blackwood sedimentary Plateau - valleys and depressions

Bk7 Component vegetation complexes, BD, CE, JN, Nw, Tw and Yw.
Shallow valleys in the humid, perhumid zone of the Blackwood Plateau, predominantly with humus podzols on floors and sandy yellow duplex soils on slopes. Vegetation is mainly Woodland of Eucalyptus patens, Allocasuarina fraseriana, Agonis flexuosa, Hakea lasianthoides, Eucalyptus marginata subsp. marginata, Corymbia calophylla, Melaleuca preissiana, Banksia littoralis. Shrub and herb species are Mirbelia dilatata, Agonis linearifolia, Agonis parviceps, Hakea lissocarpha,
APPENDIX 3.6 (Continued)

_Podocarpus drouynianus, Acacia divergens, Dasypogon hookeri, Kingia australis_ and _Adenanths obovatus_.

Blackwood sedimentary Plateau – uplands and slopes

**Jn5** Component vegetation complexes, **CSa** and **WC**.
Slopes of the Whicher Scarp, with sands, sands over laterite and gravelly yellow duplex soils. Dominant vegetation is Woodland to Open Forest of _Eucalyptus marginata_ subsp. _marginata_ and _Corymbia calophylla_ with second storey of _Corymbia haematoxylon, Allocasuarina fraseriana, Banksia grandis, Banksia attenuata, Banksia ilicifolia, Xylomelum occidentale_ and _Persoonia elliptica_. The components of the understorey include _Hakea ruscifolia, Stirlingia latifolia, Bossiaeae eriocarpa, Adenanths meisneri, Melaleuca thymoides, Podocarpus drouynianus, Dasypogon bromeliifolius, Mesomelaena tetragona_.

**Mn6** Component vegetation complexes, **BK, JL, RO** and **WCv**.
Slopes of valleys moderately to strongly incised into the Blackwood Plateau in the humid perhumid zones, with gravelly or sandy yellow duplex soils. Dominant vegetation is Open Forest of _Corymbia calophylla_ and _Eucalyptus marginata_ subsp. _marginata_, with second storey of _Banksia grandis, Persoonia longifolia_ and _Xylomelum occidentale_. Shrub and herb storey consists of _Hakea lissocarpha, Macrozamia riedlei, Mesomelaena tetragona, Bossiaeae ornata, Podocarpus drouynianus, Bossiaeae linophylla, Leucopogon capitellatus_ and _Adenanths barbiger_.

**Jg5** Component vegetation complexes, **BN, GA, KI, N, T, TL** and **Y**.
Undulating uplands and upper slopes in the humid-perhumid zones, with yellow duplex and humus podsol soils. Dominant vegetation is Open Forest of _Eucalyptus marginata_ subsp. _marginata_ and _Corymbia calophylla_, with second storey of _Banksia grandis, Allocasuarina fraseriana, Persoonia longifoli and, Xylomelum occidentale_. Shrub and herb storey consists of _Bossiaeae ornata, Hovea chorizemifolia, Isopogon sphaerocephalus, Podocarpus drouynianus, Adenanths obovatus, Leucopogon australis, Lindsaea linearis, Leucopogon verticillatus_ and _Dasypogon hookeri_.

Blackwood sedimentary Plateau – valley floors

**Fw5** Component vegetation complexes **DP, LY, PR** and **SW**.
Floors and lower slopes of major valleys dissecting the Blackwood Plateau in the humid perhumid zone. The soils are alluvials ranging from sands to loams. Vegetation ranges from Woodland of _Eucalyptus rudis_ with _Banksia seminuda_ on valley floor to Open Forest of _Corymbia calophylla_ and _Eucalyptus patens_ with _Agonis flexuosa_ on terraces and lower slopes. Shrub and herb species are _Agonis linearifolia, Trymalium floribundum, Astartea fascicularis, Lepidosperma effusum, Hypocalymma angustifolium_ on the floor and _Pteridium esculentum, Acacia urophylla, Bossiaeae linophylla, Bossiaeae ornata_ on lower slopes.
APPENDIX 3.6  (Continued)

CENTRAL SUBREGION

Mild lower slopes and floors of major valleys

**Fv5**  Component vegetation complexes, *BLf*, *BTf*, *ML* and *SP*.
Valley floors and lower slopes in the humid zone of the central Darling Plateau, with alluvial and colluvial soils ranging from sandy loams to clay loams. Vegetation ranges from Woodland of *Eucalyptus rudis* with *Melaleuca rhaphiophylla* on the floors to Open Forest of *Eucalyptus patens* and *Corymbia calophylla* with *Hakea lasianthoides* on lower slopes. Shrub and herb storey consists of *Astartea fascicularis*, *Lepidosperma squamatum*, *Lepidosperma tetraquetrum*, *Agnis linearifolia*, *Gahnia trifida* on the floor and *Pteridium esculentum*, *Trymalium floribundum*, *Chorizema ilicifolium*, *Leucopogon capitellatus*, *Leucopogon propinquus*, *Hibbertia amplexicaulis* and *Hakea lissocarpa* on lower slopes.

**Fv4**  Component vegetation complexes, *CPI* and *NWf1*.
Valley floors, terraces and lower slopes of the major valleys incised into the subhumid zone of the central Darling Range. Soils range from sandy and loamy alluvials on the floors to red brown earths on slopes. Vegetation ranges from Woodland of *Eucalyptus rudis* with *Melaleuca rhaphiophylla* and *Acacia saligna* on floors to Open Forest of *Corymbia calophylla* and *Eucalyptus marginata* subsp. *marginata* on terraces and lower slopes. Shrub and herb storey ranges from *Melaleuca viminalis*, *Hakea australis* and *Isolepis nodosa* on valley floors to *Macrozamia riedlei*, *Phyllanthus calycinus*, * Clematis pubescens*, *Hibbertia amplexicaulis*, *Leucopogon capitellatus* on slopes.

**Fv3**  Component vegetation complexes, *BR*, *CP2*, *GW* and *NWf2*.
Valley floor, terraces and lower slopes of major streams in subhumid and semi-arid zones of the central Darling Plateau. Soils range from saline wet soils through deep sandy duplexes to brown loamy earth. Vegetation ranges from Woodland of *Eucalyptus rudis* with *Melaleuca rhaphiophylla* frequently affected by salinity, to Woodland of *Eucalyptus wandoo*, *Corymbia calophylla* and *Acacia saligna*. Shrub and herb storey consists of *Astartea fascicularis*, *Juncus pallidus*, *Hypocalymma angustifolium* and *Hakea prostrata* on valley floor and *Phyllanthus calycinus*, *Bossiae eriocarpa*, *Brachysera praemorsum* and *Hakea lissocarpa* on slopes.

**Cv1**  Component vegetation complexes, *Dk5*, *Dk5f*, *Fa4* and *Fa5*.
Near level broad depressions and valley floors in the semi-arid to arid zones of the central Darling Plateau, with some lunettes. Soils range from solonet and yellow duplex soils in depressions to deep sands on lunettes. Vegetation ranges from Shrubland through Woodland of *Eucalyptus rudis* and *Casuarina obesa* to Woodland of *Corymbia calophylla*, *Banksia prionotes* and *Acacia acuminata* on lunettes. Shrub and herb storey consists of *Atriplex punicea*, *Cyperus tenellus*, *Harperia lateriflora*, *Hakea prostrata*, *Hakea varia*, *Melaleuca viminalis*, *Salicornia* sp. on depressions, *Jacksonia furcellata*, *Jacksonia sternbergiana*, *Conostylis serrulata* and *Dianella revoluta* on lunettes.

Valleys deeply incised into the central Darling Plateau

**Ms5**  Component vegetation complexes, *BL*, *BT* and *Lo*.
Moderate to steep slopes of major valleys in the humid zone of central Darling Plateau with red and yellow earths and duplex soils. Vegetation ranges from Woodland of
APPENDIX 3.6 (Continued)

_Eucalyptus wandoo_ to Open Forest of _Corymbia calophylla, Eucalyptus patens_ and _Eucalyptus marginata_ subsp. _marginata_, with weakly developed second storey of _Banksia grandis_ and _Persoonia longifolia_. Shrub and herb storey consists of _Leucopogon verticillatus, Macrozamia riedlei, Hakea lissocarpha, Hibbertia ampeloxicaulis, Kennedia coccinea, Leucopogon capitellatus, Clematis pubescens, Chorizema illicifolium, Pteridium esculentum._

**Ms4** Component vegetation complexes, _DMg_ and _NWg1_.
Steep rocky slopes of major valleys incised into the subhumid zone of the central Darling Range. Soils range from bare rock to yellow and red brown duplexes with loamy topsoil. Vegetation ranges from Herbfied and Heath through Woodland of _Allocasaurina huegeliana, Acacia acuminata_ and _Eucalyptus wandoo_ to Open Forest of _Corymbia calophylla_. Shrub and herb storey ranges from _Hakea undulata, Borya sphaerocephala, Darwinia citriodora_ and _Phyllanthus calycinus_ near rock to _Macrozamia riedlei, Hakea lissocarpha, Clematis pubescens, Xanthorrhoea preissii, Leucopogon capitellatus_ on slopes.

**Ds2** Component vegetation complexes, _Dk3, Fa3_ and _NWg2_.
Steep valley slopes in semiarid to arid zones of the central Darling Plateau with red brown gravelly duplex soils and shallow skeletal soils. Vegetation ranges from Lithic Complex, Herbfied and Heath through Low Woodland of _Allocasaurina huegeliana, Acacia acuminata_ and _Eucalyptus rudis_ to Woodland of _Eucalyptus wandoo_ and _Eucalyptus astringens_. Shrub and herb storey ranges from _Hakea undulata, Borya sphaerocephala, Cheilanthes austrotenuiolia, Hypocalymma angustifolium_ on skeletal soils to _Gastrolobium calycinum, Hakea lissocarpha, Phyllanthus calycinus, Macrozamia riedlei_ and _Trymalium ledifolium_ on deeper soils.

Valleys moderately incised into the central Darling Plateau

**Mm4** Component vegetation complexes, _Lk1_ and _NW1_.
Moderate slopes of valleys incised into the subhumid zone of the central Darling Range. Soils are mainly red brown duplexes and earths and yellow duplexes. Dominant vegetation is Open Forest of _Corymbia calophylla_ with _Eucalyptus marginata_ subsp. _marginata_ near uplands and _Eucalyptus wandoo_ and _Eucalyptus rudis_ near streamlines. Shrub and herb storey consists of _Macrozamia riedlei, Phyllanthus calycinus, Leucopogon capitellatus, Hibbertia ampeloxicaulis, Hakea lissocarpha_ and _Acacia pulchella_.

**Wm2** Component vegetation complexes, _Dk2, Dk4, Fa2, NW2_ and _Lk2_.
Moderate slopes of valleys in the semiarid to arid zones of the central Darling Plateau with yellow brown duplex soils, less frequently deep leached sand. Dominant vegetation is Woodland of _Eucalyptus wandoo_ with second storey of _Acacia acuminata, Acacia microbotrya_ and _Hakea prostrata_, with _Eucalyptus rudis_ downslope and _Eucalyptus marginata_ subsp. _marginata_ and _Eucalyptus astringens_ upslope. Shrub and herb storey consists of _Allocasaurina humilis, Pilularia manglesii, Solya heterophylla, Hakea lissocarpha, Macrozamia riedlei_ on duplex soils. Woodland of _Banksia attenuata_ and _Eucalyptus marginata_ subsp. _marginata_ with _Mesemelaena tetragona, Stirlingia latifolia, Phlebocarya ciliata, Petrophile linearis_ on sands.
APPENDIX 3.6  (Continued)

Lateritic Uplands in the central Darling Plateau

Jp4  Component vegetation complex, DM1.
Upper slopes and ridges in the subhumid zone of the central Darling Range with
gravelly yellow and red duplex soils. Dominant vegetation is Open Forest of
Corymbia calophylla and Eucalyptus marginata subsp. marginata with second storey
of Banksia grandis and Persoonia longifolia. Shrub and herb storey consists of
Dryandra sessilis, Macrozamia riedlei, Bossiaea ornata, Hakea lissocarpha, Hibbertia
commutata and Leucopogon capitellatus.

Jp3  Component vegetation complexes, DM2 and SD.
Upper slopes and ridges in the semiarid zone of the central Darling Range with
gravelly yellow and red duplex soils. Dominant vegetation is Woodland to Open
Forest of Corymbia calophylla, Eucalyptus marginata subsp. marginata and
Eucalyptus wandoo, with second storey of large Dryandra sessilis. Shrub and herb
storey consists of Macrozamia riedlei, Bossiaea ornata, Hakea lissocarpha, Hibbertia
commutata and Leucopogon capitellatus. Also some Borya sphaerocephala on granite
outcrops.

Jp2  Component vegetation complexes, Bo1, Dk1 and Fa1.
Upper slopes, ridges and minor plateaus in the semiarid arid zones of the central
Darling Plateau, with gravelly or loamy duplex soils and outcrops of laterite.
Dominant vegetation is Woodland of Eucalyptus marginata subsp. marginata and
Corymbia calophylla with weakly developed second storey of Persoonia longifolia and
large Dryandra sessilis, with enclaves of Eucalyptus drummondii mallee and with
Eucalyptus wandoo and Eucalyptus astringens on transition to slopes. Shrub and herb
storey consists of Gastrolobium spinosum, Dryandra armata, Xanthorrhoea preissii,
Trymalium ledifolium, Bossiaea ornata, Bossiaea eriocarpa, Hakea lissocarpha,
Hibbertia commutata and Hovea chorizemifolia.

Swampy uplands in the central Darling Plateau

Jv4  Component vegetation complex, KU1.
Mildly undulating upland of low rises and swampy depressions in the subhumid zone
of the central Darling Range. Soils range from gravelly duplexes on rises to sandy
podzols in depressions. Vegetation ranges from Woodland of Eucalyptus rudis,
Eucalyptus decipiens subsp. chalara and Melaleuca preissiana in depressions to
Woodland of Eucalyptus marginata subsp. marginata, Corymbia calophylla and
Eucalyptus wandoo on rises. Second storey is Acacia saligna on depressions and
Dryandra sessilis on rises. Shrub and herb storey consists of Juncus pallidus, Hakea
varia in depressions and Macrozamia riedlei, Hakea lissocarpha, Bossiaea ornata and
Leucopogon capitellatus on rises.

Jv3  Component vegetation complex, KU2.
Mildly undulating upland of low rises and swampy depressions of the central Darling
Range in the semiarid to arid zone. Soils range from gravelly duplexes on rises to
sandy podzols in depressions. Vegetation ranges from Woodland of Eucalyptus rudis,
Eucalyptus decipiens subsp. chalara and Melaleuca preissiana in depressions to
Woodland of Eucalyptus marginata subsp. marginata, Corymbia calophylla and
Eucalyptus wandoo on rises. Second storey is Acacia saligna on depressions and
Dryandra sessilis on rises. Shrub and herb storey consists of Juncus pallidus, Hakea
APPENDIX 3.6 (Continued)

varia and Melaleuca viminea in depressions and Macrozamia riedlei, Hakea lissocarpha, Bossiaea ornata, Brachytime alypum and Bossiaea eriocarpa on rises.

Swamps of central Darling Plateau

Gw3 Component vegetation complexes, KUw and QUw.
Floors of upland depressions in the semi-arid zone of the central Darling Range with iron podzols and saline wet soils. Vegetation ranges from Sedgeland of Baumea articulata and Baumea juncea through Woodland of Melaleuca preissiana, Melaleuca cuticularis, Eucalyptus rudis, Banksia littoralis with Hakea sulcata, Hypocalymma angustifolium, Astereina fascicularis and Hakea varia to Woodland of Eucalyptus wandoo with Baeckea camphorosmae, Gastrolobium calycinum and Hakea lissocarpha.

Slopes and valleys in sedimentary deposits of the central Darling Plateau

Ac3 Component vegetation complexes, BoIs, QU and QUu.
Mild slopes between uplands and depressions in the semi-arid to arid zones of the central Darling Plateau, with deep sands and sandy podzols. Vegetation ranges from Low Woodland of Banksia attenuata and Nuytsia floribunda to Woodland of Eucalyptus marginata subsp. marginata and Corymbia calophylla with shrub and herb storey of Kunzea ericifolia, Patersonia occidentalis, Macrozamia riedlei, Stirlingia latifolia, Calytrix flavescens and Allocasuarina humilis.

NORTHERN REGION

Valleys deeply incised into the northern Darling Plateau

MS5 Component vegetation complex, He1.
Deeply incised, steeply sloping valleys at the western margin of the northern Darling Plateau, in the humid zone. Soils range from bare rock and skeletal sandy loams to yellow and brown duplex soils. Vegetation ranges from Lithic Complex, Herbfield and Heath to Woodland of Corymbia calophylla, Eucalyptus rudis, Eucalyptus laeolae and Allocasuarina huegeliana. Shrub and herb storey of Borya sphaerocephala, Darwinia citriodora, Grevillea bipinnatifida, Cheilanthes australoenufolia, Hakea undulata and Hakea trifurcata on shallow soils to Bossiaea aquifolium subsp. aquifolium, Hovea elliptica, Pteridium esculentum, Clematis pubescens, Acacia urophylla and Macrozamia riedlei on deeper soils.

WS2 Component vegetation complex, He2.
Deeply incised steeply sloping valleys at the western margin of the northern Darling Plateau in the subhumid to arid zones. Soils range from bare rock and skeletal gritty loams to yellow and brown duplex soils. Vegetation ranges from Lithic Complex, Herbfield and Heath to Woodland of Eucalyptus wandoo, Corymbia calophylla and Allocasuarina huegeliana. Shrub and herb storey of Borya sphaerocephala, Darwinia citriodora, Grevillea bipinnatifida, Cheilanthes australoenufolia, Hakea undulata and Hakea trifurcata on shallow soils to Trymaliun ledifolium, Hakea lissocarpha, Grevillea pilulifera, Phyllanthus calycinus and Macrozamia riedlei on deeper soils.
APPENDIX 3.6 (Continued)

Ds0  Component vegetation complex, Bi.
Steep slopes of major valleys in the arid perarid zones of the northern Darling Plateau, with soils ranging from shallow skeletal soils to red brown earths and duplexes. Vegetation ranges from Herbfied and Heath through Low Woodland of Acacia acuminata and Allocasuarina huegeliana to Woodland of Eucalyptus loxophleba and Eucalyptus wandoo, with Eucalyptus accedens on transition to uplands. Shrub and herb species are Dianella revoluta, Styphandra glauca, Cheilanthes austrotenufolia, Chamaescilla corymbosa and Haemodorum paniculatum.

Valleys deeply incised into the northern Darling Plateau

Wm1  Component vegetation complex, Mi.
Moderately steep slopes of valleys incised into the semiarid perarid zones of the northern Darling Plateau, with soils ranging from skeletal soils to yellow and red duplex soils. Vegetation ranges from Lithic Complex, Herbfield and Heath through Low Woodland of Allocasuarina huegeliana and Acacia acuminata to Woodland of Eucalyptus wandoo with Eucalyptus astringens and Eucalyptus accedens, Eucalyptus marginata subsp. thalassica and Corymbia calophylla on transition to uplands. Shrub and herb storey ranges from Borya sphaerocephala, Hakea undulata, Haemodorum laxum, Cheilanthes austrotenufolia, Dodonaea viscosa on shallow soils to Gastrolobium spinosum, Trymalium ledifolium, Bossiaea eriocarpa, Hibbertia commutata on deeper soils.

Valleys moderately incised into the northern Darling Plateau

NM6  Component vegetation complex, My1.
Major valleys moderately incised into the humid zone of the northern Darling Plateau, with red brown earth and red and yellow duplex soils. Vegetation ranges from Woodland of Eucalyptus patens over Banksia seminuda, Callistachys lanceolata and Agonis flexuosa on valley floor to Open Forest of Corymbia calophylla and Eucalyptus marginata subsp. marginata with second storey of Banksia grandis and Persoonia longifolia on slopes. Shrub and herb storey of Grevillea diversifolia, Trymalium floribundum, Hypocalymma cordifolium, Lepidosperma tetraquetrum and Chorizema ilicifolium on valley floor to Bossiaea aquifolium subsp. aquifolium, Leucopogon verticillatus, Leucopogon capitellatus, Macrozamia riedlei, Acacia urophylla and Pteridium esculentum on slopes.

WM2  Component vegetation complex, My2.
Major valleys moderately incised into the subhumid to arid zones of the northern Darling Plateau, with red brown earths and red and yellow duplex soils. Vegetation ranges from Woodland of Eucalyptus patens, Eucalyptus rudis with Melaleuca rhaphiophylla on valley floor to Woodland of Eucalyptus wandoo and Corymbia calophylla on slopes. Shrub and herb storey of Lepidosperma squamatum, Hypocalymma angustifolium, Astartea fascicularis on valley floor to Hakea lissocarpha, Diplolaena drummondii, Baucekea camphorosmae, Gastrolobium calycinum, Leucopogon capitellatus on slopes.
APPENDIX 3.6 (Continued)

Valleys mildly incised into the northern Darling Plateau

HI6 Component vegetation complexes, Yg1 and Yg2.
Minor valleys shallowly incised into the humid zone of the northern Darling Plateau, with soils ranging from orange earths and humus podzols on valley floor to red and yellow gravelly duplex soils on slopes. Vegetation ranges from Woodland of Eucalyptus megacarpa, Eucalyptus patens, with Banksia littoralis and tall shrub and sedge storey of Agonis linearifolia, Lepidosperma tetraquetrum, Astartea fassiculalis, Mesomelaena tetragona and Gahnia trifida on valley floor to Open Forest of Eucalyptus marginata subsp. marginata and Corymbia calophylla with second storey of Banksia grandis, Persoonia longifolia and Allocasuarina fraseriana on slopes. Shrub and herb storey under the forest consists of Grevillea wilsonii, Stypelia tenuiflora, Adenanthis barbigera, Hakea ruscifolia, Lechenaultia biloba, Baeckea camphorosmae and Hakea lissocarpha.

WI1 Component vegetation complex, Ck.
Minor valleys mildly to moderately incised into the semi-arid to periarid zones of the northern Darling Plateau, with mainly yellow and red duplex soils of varying depth. Vegetation mainly Woodland of Eucalyptus wandoo with Eucalyptus rudis in streamlines and Eucalyptus accedens on transition to uplands. Shrub and herb storey consists of Phyllanthus calycinus, Bossiaea eriocarpa, Bossiaea ornata, Macrozamia riedlei, Trymalium ledifolium, Lasiopetalum cardiophyllum.

WI2 Component vegetation complex, Pn.
Minor valleys shallowly incised into the subhumid to arid zones of the northern Darling Plateau, with soils ranging from sandy to gravelly duplexes. Vegetation is primarily Woodland of Eucalyptus wandoo and Corymbia calophylla with Eucalyptus rudis and Eucalyptus patens near streamlines and Eucalyptus accedens and Eucalyptus marginata subsp. thalassica on transition to uplands. Shrub and herb storey ranges from shrublands of Kunzea recurva, Lepidosperma leptostachyum, Hakea varia, Hakea ceratophylla, Melaleuca viminea, Melaleuca incana, Hypocalymma angustifolium and Meeboldina scariosa on valley floors to Hakea lissocarpha, Macrozamia riedlei, Patersonia rudis and Hakea incrassata on slopes.

Lateritic Uplands of the northern Darling Plateau

JP6 Component vegetation complexes, DI and HR.
Upland ridges and spurs in the humid zone of the northern Darling Plateau, with gravelly duplex soils and lateritic outcrops. Dominant vegetation is Open Forest of Eucalyptus marginata subsp. marginata and Corymbia calophylla with second storey of Allocasuarina fraseriana, Banksia grandis and Persoonia longifolia. Shrub and herb storey consists of Adenanthis barbigera, Hovea chorizemfolia, Stypelia tenuiflora on the sandier soils and Leucopogon verticillatus, Leucopogon capitellatus, Pteridium esculentum, Clematis pubescens, Hakea lissocarpha on the loamier soils.

JP4 Component vegetation complex, D2.
Upland ridges and spurs in the subhumid zone of the northern Darling Plateau, with gravelly duplex soils and lateritic outcrops. Dominant vegetation is Open Forest of Eucalyptus marginata subsp. marginata and Corymbia calophylla with second storey of Allocasuarina fraseriana, Banksia grandis and Persoonia longifolia. Shrub and
APPENDIX 3.6 (Continued)

herb storey consists of Adenanthes barbigera, Lechenaultia biloba, Hakea ruscifolia, Hovea chorisemifolia, Styphelia tenuiflora on the sandier soils and Leucopogon propinquus, Leucopogon capitellatus, Hakea lissocarpha on the loamier soils.

Ip3 Component vegetation complexes, D3, D4 and MH.
Upland ridges and spurs in the semi-arid zone of the northern Darling Plateau, with gravelly duplex soils and lateritic outcrops. Dominant vegetation is Woodland of Open Forest of Eucalyptus marginata subsp. thalassica in the north, Eucalyptus marginata subsp. marginata in the south, and Corymbia calophylla with weakly developed second storey of Allocasuarina fraseriana, Banksia grandis and Persoonia longifolia. Some intrusion from the slopes of Eucalyptus wandoo and Eucalyptus accedens. Shrub and herb storey consists of Patersonia rudis, Lechenaultia biloba, Hakea ruscifolia, Petrophile serruriae, Styphelia tenuiflora on the sandier soils and Gastrolobium calycinum, Leucopogon propinquus, Leucopogon capitellatus, Hakea lissocarpha, Macrozamia riedlei on the loamier soils.

Vp2 Component vegetation complex, Y5.
Upland ridges and spurs in the semi-arid to arid zones of the northern Darling Plateau, with gravelly duplex soils and lateritic outcrops. Dominant vegetation is Woodland of Eucalyptus marginata subsp. thalassica in the north, Eucalyptus marginata subsp. marginata in the south, Corymbia calophylla, Eucalyptus accedens and Eucalyptus wandoo, with weakly developed second storey of tall Dryandra sessilis. Some intrusion from the slopes of Eucalyptus astringens. Shrub and herb storey consists of Lechenaultia biloba, Petrophile serruriae, Styphelia tenuiflora on the sandier soils and Gastrolobium calycinum, Leucopogon capitellatus, Hakea lissocarpha and Macrozamia riedlei on the loamier soils.

Vp1 Component vegetation complex, Y6.
Upland ridges and spurs in the semi-arid to perarid zones of the northern Darling Plateau, with gravelly duplex soils and lateritic outcrops. Dominant vegetation is Woodland of Eucalyptus accedens, Eucalyptus wandoo, Corymbia calophylla and some Eucalyptus marginata subsp. thalassica. Weakly developed second storey of tall Dryandra sessilis. Some intrusion from the slopes of Eucalyptus astringens subsp. astringens. Shrub and herb storey consists of Daviesia preissii, Hibbertia commutata, Dryandra bipinnatifida, Leucopogon nutans, Lechenaultia biloba, Petrophile serruriae, Styphelia tenuiflora on the sandier soils and Gastrolobium calycinum, Leucopogon capitellatus, Hakea lissocarpha, Trymalium ledifolium, Hakea erinacea and Macrozamia riedlei on the loamier soils.

Rocky slopes on the northern Darling Plateau

Rs4 Component vegetation complex, DS.
Steep slopes of the northern Darling Scarp in the semi-arid to humid zone, with numerous granitic and doleritic outcrops and shallow skeletal soils. Vegetation ranges from Lithic Complex, Herbfield, Heath to Woodland of Corymbia calophylla, Eucalyptus wandoo, Eucalyptus laelae and Allocasuarina huegeliana. Common shrub and herb species are Borya sphaerocephala, Grevillea bipinnatifida, Hakea undulata, Hakea lissocarpha, Trymalium ledifolium, Hakea trifurcata, Calothamnus graniticus.
APPENDIX 3.6 (Continued)

Rs3 Component vegetation complex, Ce.
Moderate to steep slopes of monadnocks rising above the northern Darling Plateau in
the subhumid to semiarid zones. Soils range from bare rock and skeletal sandy loams
through red brown duplex soils to gravelly yellow duplexes. Vegetation ranges from
Lithic Complex, Herbfeld, Heath through Woodland of Corymbia calophylla,
Eucalyptus wandoo, Eucalyptus laeiue and Allocasuarina huegeliana to Open Forest
of Eucalyptus marginata subsp. marginata, Corymbia calophylla on milder slopes
with deep soils. Common shrub and herb species are Borya spherocephala, Grevillea
bipinnatifida, Hakea undulata, Hakea lissocarpa, Trymalium ledifolium, Hakea
trifurcata on shallow soils; Adenanthis barbiger, Grevillea wilsonii, Stypelia
tenuiflora and Hovea chorizenifolia on deep gravels.

Mild lower slopes and floors of major valleys in the northern Darling Plateau

Ev2 Component vegetation complexes, No and Wi.
Floors and terraces of major valleys incised into the semiarid to perarid zones of the
northern Darling Plateau. Soils represent a range of alluvial materials from loamy
sands to clay loams. Vegetation mainly woodland of Eucalyptus rudis and Casuarina
obesa with Melaleuca rhamphophylla with Eucalyptus wandoo, Eucalyptus loxophleba
and Acacia acuminata at transition to uplands. Shrub and herb storey consists of
Astartea fascicularis, Hypocalymma angustifolium, Meeboldina scariosa, Samolus
junceus, Halosarcia pergranulata, Frankenia tetrapetala, Isolepis setiformis,
Triglochin mucronata, *Juncus acutus and Cotula coronopifolia on valleys floors,
Gastrolobium calycinum, Hakea lissocarpa, Mesomelaena tetragona and Daviesia
preissii on transition to uplands.

Sedimentary uplands within the northern Darling Plateau including Collie and Wilga
Basins

JG4 Component vegetation complex, WG.
Undulating uplands in the subhumid zone of the central Darling Plateau, with sandy
duplex soils. Dominant vegetation is Woodland to Open Forest of Eucalyptus
marginata subsp. marginata and Corymbia calophylla, with weakly developed second
storey of Persoonia longifolia and Banksia grandis. Shrub and herb storey consists of
Bossiaeae ornata, Trymalium ledifolium, Lepidosperma tenue, Bossiaeae eriocarpa,
Adenanthis obovatus, Acacia extensa, Lepidosperma scabrum, Hypocalymma
angustifolium, Xanthorrhoea gracilis.

Jg4 Component vegetation complex, CI.
Mildly undulating uplands on sedimentary material of the Collie Basin in the humid
subhumid zones, with gravelly sandy duplex soils with some lateritic outcrop.
Vegetation is Open Forest of Eucalyptus marginata subsp. marginata and Corymbia
calophylla. Second storey of Allocasuarina fraseriana, Banksia grandis and
Xylomelum occidentale. Shrub and herb storey of Adenanthis barbiger, Bossiaeae
ornata, Hovea chorizenifolia, Daviesia incrassata, Hakea lissocarpa, Leucopogon
capitellatus.

Slopes and valleys in sedimentary deposits within the northern Darling Plateau
APPENDIX 3.6  (Continued)

Ac4  Component vegetation complex, CF.
     Mild valley slopes on the sedimentary material of the Collie Basin in the humid
     subhumid zones, with deep leached sands. Dominant vegetation is Woodland of
     Eucalyptus marginata subsp. marginata, Allocasuarina fraseriana, Banksia attenuata,
     Banksia ilicifolia. Shrub and herb storey of Banksia meisneri, Kunzea vestita,
     Lepidosperma squamatum, Leucopogon glabellus, Bossiaea eriocarpa, Stirlingia
     latifolia, Schoenus brevifolius, Adenanthes obovatus and Leptocarpus tenax.

Ac2  Component vegetation complex, G.
     Mild sandy slopes on the uplands of the northern Darling Plateau in the humid to arid
     zones, with deep pale leached soils. Vegetation ranges from Low Open Woodland of
     Melaleuca preissiana and Banksia littoralis on lower slopes to Woodland of
     Eucalyptus marginata subsp. (thalassica in the NE and marginata in the SW),
     Banksia attenuata, Banksia menziesii and Nuytsia floribunda. Shrub and herb storey is
     Hakea varia, Hakea ceratophylla, Pericalymma ellipticum, Leptocarpus tenax on lower
     slopes and Conospermum stoechadis, Stirlingia latifolia, Petrophile linears, Scholtzia
     involucrata, Hibbertia subvaginata, Eremaea pauciflora and Patersonia occidentalis
     on upper slopes.

Ic6  Component vegetation complexes, DB3 and QW.
     Moderate slopes and rises formed on sedimentary deposits in the humid zone of the
     central Darling Range. Soils are yellow brown gravelly duplexes. Vegetation is Open
     Forest of Eucalyptus marginata subsp. marginata and Corymbia calophylla with
     second storey of Persoonia longifolia and Banksia grandis, with Woodland of
     Eucalyptus rudis and Agonis flexuosa on streamlines. Shrub and herb storey consists
     of Leucopogon capitellatus, Hakea lissocarpha, Bossiaea ornata, Bossiaea eriocarpa,
     Hakea amplicaulis, Macrozamia riedlei and Acacia lateritica on slopes, Agonis
     linearifolia and Grevillea diversifolia on streamlines.

Ic5  Component vegetation complexes, BO, KR and QWf.
     Mild lower slopes and valleys on sedimentary deposits in the humid zone of the
     central Darling Range. Soils range from humus podzols through sands to yellow
     brown duplex. Vegetation ranges from woodland of Melaleuca preissiana, Banksia
     littoralis and Eucalyptus rudis in depressions to open forest of Eucalyptus marginata
     subsp. marginata and Corymbia calophylla, with second storey of Xylopium
     occidentale, Nuytsia floribunda and Banksia attenuata on slopes. Shrub and herb
     storey ranges from Melaleuca viminalis, Hakea varia, Agonis linearifolia, Astartea
     fascicularis in depressions to Bossiaea eriocarpa, Acacia extensa, Xanthorrhoea
     preissii, Anigozanthos manglesii, Melaleuca thymoides, Adenanthes meisneri and
     Stirlingia latifolia on slopes.

Swampy depressions and valleys

Gw4  Component vegetation complex, MJ and SK.
     Shallow valleys in the sedimentary material of the Collie and Wilga Basin in the
     humid subhumid zones, with humus podzols and deep leached sands. Vegetation
     ranges from Woodland of Eucalyptus patens, Melaleuca preissiana and Banksia
     littoralis on valley floors to Banksia ilicifolia, Banksia attenuata and Xylopium
     occidentale on lower slopes. Shrub and herb storey of Hakea ceratophylla, Agonis
     linearifolia, Hypocalymma angustifolium, Pericalymma ellipticum on floors and
APPENDIX 3.6 (Continued)

Adenantheros obovatus, Dasypogon bromeliifolius, Meeboldina scariosa, Phlebocarya ciliata, Conostephium pendulum and Lysinema ciliatum on lower slopes.

Sw3 Component vegetation complex, S.
Floors of broad valleys and depressions in the northern Darling Plateau with bleached loamy or sandy duplex soil, seasonally waterlogged. Dominant vegetation is Sedgeland of Baumea articulata, Meeboldina cana, Meeboldina scariosa, Shrubland of Melaleuca lateriflora, Melaleuca viminea, Melaleuca pauciflora, Melaleuca lateritia, Hakea marginata, Hakea varia, Hakea ceratophylla with emergents of Actinostrobus pyramidalis, Melaleuca preissiana and Banksia littoralis.

Footslopes of the Darling Scarp (Ridge Hill Shelf)

Ic2 Component vegetation complex, Fo.
Footslopes of the Darling Scarp, at the transition to the Swan Coastal Plain, in the form of sandy and gravelly spurs separated by valleys of streams draining the Darling Plateau in the subhumid to arid zones. Vegetation ranges from fringing Woodland of Eucalyptus rudis and Melaleuca rhaphiophylla on streamlines, through Woodland of Allocasuarina fraseriana, Banksia attenuata, Banksia menziesii, Banksia grandis, Xylomelum occidentale, Eucalyptus todiana and Nytsia floribunda on sands and Open Woodland to Open Forest of Eucalyptus marginata subsp. elegantella, Corymbia calophylla and Eucalyptus wandoon on loamier or more gravelly soils. The shrub and herb understorey ranges from Stirlingia latifolia, Petrophile linearis, Bossiaea eriocarpa, Conostephium pendulum on sands to Dryandra sessilis, Macrozamia riedleii and Mesomelaena tetragona on gravels.

Well drained alluvial plains of Northern Swan Coastal Plain

Mb2 Component vegetation complex, Gu.
Better drained and heavier textured portions of the eastern Swan Coastal Plain, in subhumid to semiarid zone with yellow duplex soils. Dominant vegetation is Woodland of Corymbia calophylla, with Eucalyptus wandoon and Eucalyptus marginata subsp. marginata as associates. There is a weakly developed second stratum of Banksia grandis and tall Kingia australis. Shrub and herb stratum is composed of Xanthorrhoea preissii, Dryandra lindleyana, Hibbertia hypericoides, Synaphaea petiolaris, Mesomelaena tetragona and Cyathochaeta avenacea. In the wetter portions there is Woodland of Eucalyptus rudis with understorey species such as Hakea ceratophylla and Pericalymma ellipticum. There is also restricted occurrence of Eucalyptus lane-poolei.

Depressions west of the Darling Plateau

Cv2 Component vegetation complexes, Br, Co and Yn.
Depressions and low rises in the subhumid arid zone of north eastern Swan Coastal plain, with wide range of soil from saline and solonetzi soils to deep sands. Vegetation ranges from Shrubland of Melaleuca teretifolia, Melaleuca hamulosa, Hakea varia, Hakea prostrata with emergents of Actinostrobus pyramidalis through Woodland of Casuarina obesa to Woodland of Banksia attenuata, Eucalyptus toditana, Banksia ilicifolia, Nytsia floribunda and Corymbia calophylla on sands. The understorey of the Casuarina Woodland consists of Cotula coronopifolia, Isolepsis producta and *Crassula natans.
APPENDIX 3.6 (Continued)

Cw0 Component vegetation complex, \textit{Wn}.
Low lying depression at the interface of the Dandaragan and Darling Plateaus in the perarid zone with leached grey sands over iron organic hardpan. Vegetation ranges from Sedgeland of \textit{Samo}lus \textit{jun}ceus and \textit{Meeboldina} \textit{coa}ngustata; Halophytic Complex of \textit{Halosar}cia \textit{per}granulata and \textit{Halosar}cia \textit{ind}ica subsp. \textit{bidens} through Shrubland of \textit{Hypocalymma} \textit{ang}ustifoli\textit{um}, \textit{Pericaly}m\textit{ma} \textit{ellipt}ic\textit{um}, \textit{Melaleu}ca \textit{teret}ifoli\textit{a}, \textit{Kunzea} \textit{vesti}ta, \textit{Regelia} \textit{cili}ata to Woodland of \textit{Casuarina} \textit{obesa}, \textit{Banksia} \textit{li}ttoralis and \textit{Melaleu}ca \textit{pre}issiana.

Uplands and valleys of the Dandaragan Plateau

Ano Component vegetation complexes \textit{Mh} and \textit{Re}.
Valleys and escarpments of the Dandaragan Plateau in the arid perarid zone with yellow brown gravelly sands. Dominant vegetation is Low Woodland of \textit{Banksia} \textit{attenuata}, \textit{Banksia} \textit{men}ziesii, \textit{Banksia} \textit{prion}otes and \textit{Eucalyptus} \textit{todd}iana with a shrub and herb storey of \textit{Petrophile} \textit{linearis}, \textit{Allocasuarina} \textit{humilis}, \textit{Mesokama} \textit{pseudo}stygia, \textit{Daviesia} \textit{grac}ilis, \textit{Conostephi}um \textit{pendulum}. There is an admixture of \textit{Corymbia} \textit{calophylla} on more fertile sites and woodland of \textit{Eucalyptus} \textit{rudis} and \textit{Melaleuca} \textit{rhaphiophylla} along streamlines.

Ig0 Component vegetation complexes, \textit{Cu}, \textit{K} and \textit{Mb}.
Sandy and gravelly uplands in the arid perarid zone of the Dandaragan Plateau. Dominant vegetation is Woodland of \textit{Corymbia} \textit{calophylla} with admixture of \textit{Eucalyptus} \textit{marg}inata subsp. \textit{thalassa} and a second storey of \textit{Nytesy}a \textit{flor}ibunda, \textit{Eucalyptus} \textit{todd}iana, \textit{Banksia} \textit{attenuata}, \textit{Banksia} \textit{men}ziesii, \textit{Banksia} \textit{prion}otes and \textit{Banksia} \textit{ili}cifoli\textit{a}. The shrub and herb understorey consists of \textit{Stirlingia} \textit{latifoli}a, \textit{Daviesia} \textit{dec}urrens, \textit{Calothammus} \textit{sanguineus}, \textit{Bossiaea} \textit{er}icarpa, \textit{Petrophile} \textit{linearis}, \textit{Leptocarpus} \textit{tenax}, \textit{Hakea} \textit{rusci}folia.

Lakes and Water

L Component vegetation complexes, Inlet, L, Lake, Water and WATER.
Waterbodies.
APPENDIX 3.7:  AN EXAMPLE OF A FULL LENGTH DESCRIPTION OF A VEGETATION SYSTEM

Title  
NM6 - Woodlands to open forests of marri - yarri and jarrah on moderate slopes of valleys in the subhumid to perhumid zone of the northern region. The main occurrence is in the humid zone.

Location  
Between Collie and Kelmscott.

Contributing Map Polygons  
My1.

Climatic Conditions  
NE Boundary:  R>900 if SE<550; R>1000 if SE<650; R>1100 if SE<750.  
SW Boundary:  Darling Scarp

Landform Description  
Moderate slopes of valleys incised into the Darling Plateau.

Soils  

Physical Properties  
Range of soil types, but mainly yellow and red duplex soils and earths, moderately water shedding on mid and upper slopes, mildly water gaining on lower slopes and floors, with moderate infiltration and water storage capacity.

Chemical Properties  
Moderately fertile to fertile.

Vegetation  

Structure and Composition of the Over Storey  
Open forest to tall open of marri (*Corymbia calophylla*), yarri (*Eucalyptus patens*), jarrah (*Eucalyptus marginata* subsp. *marginata*), *Eucalyptus rudis* on streamlines. Yarri is especially prominent in the perhumid zone, when it replaces karri (*Eucalyptus diversicolor*) which has not extended north of the Blackwood River.

Second Storey  
*Banksia grandis* and *Persoonia longifolia* on mid and upper slopes, *Banksia littoralis*, *Callistachys lanceolata*, *Banksia seminuda* and *Melaleuca rhaphiophylla* on stream lines.

Shrub and Herb Stratum  

Havel Land Consultants (1987) described this combination of landform and climate from their surveys of the Canning and North Dandalup valleys. The types encountered by them were S, T, U, R, Q, C, W and transitions between these such as ST, RQ, CQ, WS. The species entering into these site-vegetation types, arranged in sequence from upper slopes to valley floors, are:
### APPENDIX 3.7 (Continued)

<table>
<thead>
<tr>
<th>Species</th>
<th>S</th>
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<th>R</th>
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### APPENDIX 3.7 (Continued)

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<td>Mesomelaena tetragona</td>
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<td>Synaphea petiolaris</td>
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<td>Pericalymma ellipticum</td>
<td>/</td>
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<td>Dampiera alata</td>
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<tr>
<td>Agonis linearifolia</td>
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<tr>
<td>Baeckea camphorosmae</td>
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</tbody>
</table>

A "+" represents a common occurrence and a "/" represents a possible occurrence within the Vegetation Types.

In addition to the above species, Havel Land Consultants (1987) also recorded the following species in vegetation types Q, CQ and C which are typical of these combinations of landform and climate.

**Type Q**
Xanthorrhoea preissii, Xanthorrhoea gracilis, Hibbertia pilosa, Pentapeltis peltigera, Boronia fastigiata, Stylidium amoenum, Tetrarrhena laevis, Hibbertia amplexicaulis, Hibbertia hypericoides, Logania serpyllifolia.

**Type CQ**
Xanthorrhoea preissii, Acacia pulchella, Acacia divergens, Asterolasia pallida, Billardiera varifolia, Aotus cordifolium, Hypocalymma cordifolium, Gonocarpus benthamii, Dampiera hederacea, Paraserianthes loophantha subsp. lophantha, Conostylis aculeata, Lepidosperma tetraquetrum, Lepidosperma leptostachyum, Xanthosia candida, Banksia seminuda, Anthocercis sp. (humid zone only)

**Type C**
Melaleuca rhaphiophylla, Acacia alata, Lepidosperma longitudinal, Galenia decomposita, Callistachys lanceolata, Baumea vaginalis, Thomasia paniculata.

Griffin (1995) described two residual stands south east of Waroona, consisting of jarrah (Eucalyptus marginata subsp. marginata) and marri (Corymbia calophylla) forest. They occur on steep upper slopes on red brown loamy sand. Their shrub and herb understorey consists of Acacia latericola, Bossiaea aquifolium subsp. aquifolium, Lagenophora haegei, Lepidosperma leptophyllum, Leucopogon capitellatus, Lomandra micrantha, Macrozamia riedlei, Phyllanthus calycinus, Tetraria octandra and Xanthorrhoea preissii, Acacia pulchella var. pulchella, Bossiaea eriocarpa, Dryandra lindleyana, Grevillea wickhamii, Hakea lissocarpha, Hemiagenia canescens, Hibbertia hypericoides, Hypocalymma angustifolium, Scaevola calliptera and Synaphea gracillima occurs less consistently. The two stands are representative of the Myl vegetation complex, near its interface with D1 complex.
APPENDIX 4.1: COMPARISON OF MAP LEGENDS AND FLORABASE RECORDS FOR BANKSIA SPECIES

The appendix describes how the FloraBase records for individual species of *Banksia* relate to the maps of vegetation complexes (Appendix 3.4) and vegetation systems (Appendix 3.5).

The format in which the information is presented is given in Table 4.1.

The vegetation complexes enumerated are those with the highest number of records of that particular species, which is given in brackets.
## Appendix 4.1: Comparison of Map Legends and FloraBase Records for Banksia Species

<table>
<thead>
<tr>
<th>Species</th>
<th>N</th>
<th>Veg. Complex</th>
<th>E</th>
<th>Veg. System</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banksia attenuata</td>
<td>23</td>
<td>G (2), Mp (2), MTy1 (2), S (2) Sd (2), A, BD, CA, CF, MJ, Dk5</td>
<td>V</td>
<td>A P M S</td>
<td>banksia - peppermint - marri - swamp</td>
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<tr>
<td></td>
<td></td>
<td>L c y p w</td>
<td>C</td>
<td>2 9 8 3</td>
<td>sandy deposits - dunes - plateau - wet deposits</td>
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<tr>
<td>Banksia grandis</td>
<td>98</td>
<td>D1 (12), D2 (11), D4 (8), Yg1 (6), MTy1 (5), Yg2 (5), BD (4), S (4), G (3), Pi (3)</td>
<td>V</td>
<td>J J 1 H</td>
<td>mainly jarrah - some bullch</td>
</tr>
<tr>
<td></td>
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<td>L p p p l</td>
<td>C</td>
<td>6 4 2 6</td>
<td>upland plateau - valley slopes</td>
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<td>Banksia ilicifolia</td>
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<td>Mp (4), Mc (2), LF (2), Swd (2), Sd (2), DS2 (2), A, Ad, Br</td>
<td>V</td>
<td>P P A S</td>
<td>peppermint - banksia - swamp</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L y y c w</td>
<td>C</td>
<td>9 9 7 7</td>
<td>dunes - sandy deposits</td>
</tr>
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<td></td>
<td></td>
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<td>Banksia littoralis</td>
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<td>BD (3), S (3), Mp (3), Yg2 (3), MTy1 (3), My1 (3), Ms (3), D2 (3), BWp (2)</td>
<td>V</td>
<td>B S P H</td>
<td>banksia - swamp - peppermint - bullich</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L k w y l</td>
<td>C</td>
<td>7 3 9 6</td>
<td>valleys - dune swales</td>
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<td>semiarid - hyperhumid</td>
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<td>Banksia menziesii</td>
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<td>Fo (3), My1 (2), Yg1 (2), Ck, D2, G, Pn</td>
<td>V</td>
<td>I N H</td>
<td>jarrah - marri - bullch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>L</td>
<td>c m 1</td>
<td>sandy deposits - valley slopes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C</td>
<td>2 6 6</td>
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<td>Bo1, D2, Dk1</td>
<td>V</td>
<td>I J 1</td>
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<td>p p p</td>
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<td></td>
<td>C</td>
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<td>B G P B</td>
<td>banksia - swamp - peppermint</td>
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<td></td>
<td></td>
<td>L</td>
<td>w w y w</td>
<td>water logged deposits - dune swales</td>
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<td>P B J G</td>
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<td></td>
<td></td>
<td>L</td>
<td>y w p w</td>
<td>dunes - wet deposits - plateau</td>
</tr>
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<td>C</td>
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<td>P K B Z</td>
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<td>L</td>
<td>y l w v</td>
<td>dunes - valleys - salt paperbark</td>
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<td>C</td>
<td>9 9 8 4</td>
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APPENDIX 4.2: COMPARISON OF MAP LEGENDS AND BANKSIA ATLAS RECORDS

The appendix describes how the Banksia Atlas records for individual species of Banksia relate to the maps of vegetation complexes (Appendix 3.4) and vegetation systems (Appendix 3.5).

The format in which the information is presented is given in Table 4.1.

The vegetation complexes enumerated are those with the highest number of records of a particular species which is given in brackets.
## APPENDIX 4.2: COMPARISON OF MAP LEGENDS AND BANKSIA ATLAS RECORDS

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<th>Significance</th>
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<td>6</td>
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<td>B</td>
<td>J</td>
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<td>k</td>
<td>p</td>
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<td>Dd (13), Bw (12), Ki (12)</td>
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<td>c k w o</td>
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<td></td>
<td></td>
<td>V</td>
<td>S J B P</td>
<td>swamp - jarrah - banksia - peppermint</td>
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<td></td>
<td>L</td>
<td>w g w y</td>
<td>wet deposits - plateau - dunes</td>
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<td></td>
<td></td>
<td>C</td>
<td>7 5 8 7</td>
<td>humid - perhumid</td>
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<td>Banksia littoralis</td>
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<td>B (76), Bw (30), Ki (18)</td>
<td>V</td>
<td>M S J A</td>
<td>marri - swamp - jarrah - banksia</td>
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<td>C M S C</td>
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<td>L</td>
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<td>C</td>
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### APPENDIX 4.2 (Continued)

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APPENDIX 4.3: COMPARISON BETWEEN MAP LEGEND AND RECORDS OF FLORABASE AND BANKSIA ATLAS FOR BANKSIA SPECIES

The comparison is made in terms of vegetation systems on which a species is predicted (map legend) or recorded (FloraBase, Banksia Atlas) to occur.

<table>
<thead>
<tr>
<th>Species</th>
<th>Description in mid-length map legend</th>
<th>Record in FloraBase</th>
<th>Record in Banksia Atlas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banksia attenuata</td>
<td>Primarily on sandy deposits (Ac7, Ac5, Ac4, Ac2, Ic2, Ic5), uplands and slopes of sedimentary plateaus (An0, Ig0, Ak6, Jn5), older leached coastal dunes (Po8) and on sandy margins of swamps and depressions (Gw9, Sw6, Sv6, Gw4, Yv4, Cv2). To a lesser degree on sandy soils on crystalline uplands (Ia8).</td>
<td>Recorded from sandy deposits (Ac2, Ac4, Ac7) from slopes and uplands of sedimentary plateau (Bk7, Mn6, Jg5), from margins of swamps and depressions (Bw8, Sv6, Cv1, Sw6, Gw4, Sw3) and from younger coastal dunes (Py9). Also recorded from some crystalline uplands (Jp5, Mp8). Overall record inadequate, maximum of 2 records per climate-landform combination.</td>
<td>Recorded mainly from sandy deposits (Ac7), slopes and uplands of sedimentary plateaus (Ak6, Jg5, Jg6, Bk7, Jn5), margins of swamps and depressions (Sv6, Sw7). Also on crystalline plateau (Jp5) and on coastal plain (Mk8). At a lower level of occurrence on Bw8, Ac4, Mp8, Ig0, Wm2, Sw6, Ic2, Zv4, Py9, Sw3, Gw3, Jw5.</td>
</tr>
<tr>
<td>Species</td>
<td>Description in mid-length map legend</td>
<td>Record in FloraBase</td>
<td>Record in Banksia Atlas</td>
</tr>
<tr>
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<td>--------------------------------------------</td>
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<tr>
<td><em>Banksia grandis</em></td>
<td>Over a very wide range of climatic zones and landforms, but particularly strongly developed on laterite mantled uplands, both crystalline (Jp9, Mp8, Ja8, Jp6, Jp5, Jm8, Jp6, Jp4, Jp4) and sedimentary (Ig3, Jg5, JG4, Jg4). It also extends on to valley slopes, in both crystalline (Ms5, MS5, NM6, H16, Ms8, Mm6, Ms6, Ms5, Nm5, Nm6) and sedimentary (Mn6, Ak6, Bk7, Jn5) plateaus. It also occurs on sandy (Jc6, Ac7, Ic6, Jc8) and loamy deposits (Mb5). Generally is it associated with jarrah and marri open forest, but extends into karri-tingle tall open forest (Km8, Ks8, Ta8), and to semi swampy uplands and swamp margins (Sw6, Gw5, Jw5, Kv7, Jw7). On the south coast it occurs on steep slopes with shallow soils (Ra8) in a dwarfed form. It retreats from valley slopes with increasing aridity, persisting on plateau uplands but eventually disappearing even from there in arid climate (Vp2, Vp1)</td>
<td>The strongest representation within the FloraBase is on laterite mantled uplands in perhumid to subhumid zone (Mp8, Jp6, Jp4, Jp2) but also extending on to valley slopes (H16, Bk7) sandy deposits (Ac2) and on swamp plains and swampy margins (Sv9, SW3). At low level of 2 records also on Bw8, Jp9, Jg4, W11, Ko9, W12, Jg5 and Kl9. Single records on a wide range of climate-landform combinations. Occurrence on W11 and W12 is at odds with the usual non-association of the species with wandoo in arid zone valleys. At single record level, still wider occurrence.</td>
<td>The strongest representation in Banksia Atlas is on well-drained coastal plain (Mk8), laterite mantled uplands of crystalline (Jp6, Jp4, Jp5) and sedimentary (Jg5, Jg6) plateaus. Also on valley slopes (H16, Bk7) and on sandy deposits (Ac7). The high occurrence on Mk8, which is not an extensive landform, suggest collecting bias. It is also recorded at lower levels on Mb5, Mp8, Ms6, Mn6, Ms5, Sw7, Gw9, Jp9, Sv6, Mm5, Rs3, Jg4, Ja7, Jw5, Ta8, Kp8, Km9, Ip2, Lp2, Po8, Wm2, Fw5, Sw6, Wm4, Zv4, Ko9, Py7, MS4, Qu7, Ia8, Wm1, Jm8, Py9, NM6, Sv9, Km8, W12, Gw6, Sw3, Ak6, Ev3, Sw7, Nm5, JG4, Jn5, Ms6, Vp2, Vp1, Nm6. The record indicates that the species is very widespread across many climate – landform combination.</td>
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### APPENDIX 4.3 (Continued)

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<th>Species</th>
<th>Description in mid-length map legend</th>
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<th>Record in Banksia Atlas</th>
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<tbody>
<tr>
<td><em>Banksia ilicifolia</em></td>
<td>Primarily on moist sandy deposits (Ac7, Ac4) and sandy margins of swamps (Gw9, Bw8, Sv6, Gw5, Sw5, Sw7, Gw4, Cv2). It is also described from sedimentary plateau uplands (Ig0) and slopes (Jn5).</td>
<td>The strongest representation is from swales of coastal dunes in high rainfall (Py9), from moist coastal sandy deposits (Ac7) and swamps (Sw7) but also from crystalline uplands (Ia8) and valleys (Ks8) in perhumid zone. It is also recorded twice from the northern escarpment (Rs4), which is at odds with known bias of the species toward moist sands and is a drift from the near-by coastal plain. There are single occurrences over a wide range of climate-landform combinations.</td>
<td>The strongest occurrence is on moist deposits (Ac7, Mk8), swamp margins (Gw9, Zv9, Bw8, Sw7, Jw5, Sw5, Zv4), from sedimentary plateaus (Jg5) and from swales in coastal dunes (Po8, Py7). It is also recorded at lower level from sedimentary valleys (Bk7, Ak6), from crystalline slopes in perhumid zone (Ta8) from arid sandy deposits (Ig0) and foot of escarpment (Jn5).</td>
</tr>
<tr>
<td><em>Banksia littoralis</em></td>
<td>Occurring primarily in swamps (Gw9, Sw8, Gw6, Sw7, Gw5, Gw4, Gw3, Sw3, Cw0) and on floors of valleys (Iw8, Bk7, Hl6, NM6, Ic5), and on mosaics of uplands and swamps (Jc8, Kv7, Jw7, Jk6). Its occurrence is largely independent of climate, being determined by topographic and edaphic factors.</td>
<td>Occurring primarily in swamps (Sw3, Cw0, Gw9, Gw5) dune swales (Py9, Po9), valley floors (Bk7, Hl6, Km8, Zv4, Wl2, NM6). It is also recorded from plateau uplands (Mp8, JP4) which is at odds with known bias of the species toward water-gaining sites, and may be due to drift from adjacent valley floors.</td>
<td>Strongest representation on coastal plain deposits (Mk8, Ac7), in swamps (Sw7, Zv4) sedimentary (Jg5) and crystalline (Jp5) plateau, mosaic of swamp and upland (Jw7) and in coastal dunes (Py9). Also occurs at lower levels in Bw8, Bk7, Ac7, Gw9, Jp9, Jw5, Yv4, Ta8, JP6, JP4, Po8, Mn6, Zv9, Gw6, Sw5, JG4, Ms6, Gw5.</td>
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### APPENDIX 4.3 (Continued)

<table>
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<th>Record in Banksia Atlas</th>
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</thead>
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<tr>
<td><em>Banksia menziesii</em></td>
<td>On sandy deposits (Ac2, Ic2) and sedimentary plateaus (An0, Ig0) in arid to perarid zone.</td>
<td>On sandy deposits (Ac2, Ic2) in arid zone but also in crystalline valleys in humid (Nm6, Hl6) and arid (Wl1, Wl2) zones, and on subhumid uplands (Jp4). The occurrences on crystalline landforms in subhumid – humid zone are likely to be drifts from Ic2 on adjacent coastal plain.</td>
<td>On crystalline (Vp1) and sedimentary (Ig0, An0) uplands, on sandy deposits on coastal plain (Ic2, Mb2) and on sandy margins of swamps (Cv2, Sw3, Cw0) in semi-arid to perarid zone.</td>
</tr>
<tr>
<td><em>Banksia prionotes</em></td>
<td>On lunettes in broad valley floors (Cv1) on crystalline plateau, and on sedimentary plateau slopes and uplands (An0, Ig0), in arid to perarid zone.</td>
<td>On sandy deposits on crystalline plateau in arid zone (Ip2) and from lateritic upland in subhumid zone (Jp4). The latter is at odds with known occurrence of the species on sands of the northern coastal plain, northern sedimentary plateau and east of the forest (Marchant et al., 1987), and maybe due to drift in geographic reference.</td>
<td>On sandy deposits on crystalline plateau (Ip2) and in valleys and in depressions (Wm1, Vl2, Ev2, Cv1, Cw0) in arid zone.</td>
</tr>
<tr>
<td><em>Banksia quercifolia</em></td>
<td>On margins of swamps (Bw8, Sv6) in the humid to perhumid zone of the south coast and hinterland. The description is too restrictive and should be broadened to include uplands and coastal dunes.</td>
<td>In swamps (Gw9, Bw8, Sw6, Yv4) on hillslopes (Ta8, Ks8, Ja8) on plateaus (Kp8, Jg6, Jp5) and on coastal dunes (Po9, Py9) on the subhumid to hyperhumid south coast and hinterland.</td>
<td>In swamps (Sv6, Bw8, Gw9, Sw6, Zv9, Sv9), coastal dunes (Po9) and uplands (Ta8) of the humid to hyperhumid south coast and hinterland. At lower level also on Mp8, Jg6, Ak6, Ia8, Ks8.</td>
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### APPENDIX 4.3 (Continued)

<table>
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<th>Species</th>
<th>Description in mid-length map legend</th>
<th>Record in FloraBase</th>
<th>Record in Banksia Atlas</th>
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</thead>
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<tr>
<td><em>Banksia seminuda</em></td>
<td>On floors of valleys in humid to perhumid zone (Fw5, Nm6, NM6, Km8). The record may be too restrictive, especially with reference to coastal swamps and dune swales.</td>
<td>In coastal swamps (Gw9, Bw8), coastal sand dunes (Py9) and shallow valleys (KI9), and uplands (Mp8, Ta8) of the perhumid – hyperhumid zone, in valleys (HI6, Nm5) and uplands (JP6) of the humid zone.</td>
<td>In valleys of the humid to hyperhumid zone (Km8, Nm6, Ks8, HI6), on uplands (Mp8, Jp5), and upland swamp mosaic (Jw7) and swamps (Gw9, Bw8) of the humid – hyperhumid zone.</td>
</tr>
<tr>
<td><em>Banksia verticillata</em></td>
<td>On hillslopes with shallow soils in perhumid zone of the south coast hinterland (Ia8). It is likely that the description is too restrictive, and swamps and sand dunes should be included for the perhumid zone.</td>
<td>In shallow valleys (KI9), on rocky hill slopes (Ra8), on hillslopes with normal soils (Ta8), in swamps (Gw9, Bw8) and on coastal dunes (Py9) of perhumid – hyperhumid zone. Also in swamps of the subhumid zone (Zv4). The latter is likely to be an error in geographic referencing.</td>
<td>On rocky (Ra8) hill slopes and in sandy saddles (Ac8) in the perhumid zone of the south coast hinterland.</td>
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APPENDIX 4.4: ENUMERATION OF FLORABASE RECORDS OF INDIVIDUAL SPECIES AGAINST MAP CATEGORIES

The format in which the information is presented is given in Table 4.1. The vegetation complexes enumerated are those with the highest number of records of that particular species, which is given in brackets.

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<td>deposits - slopes - plateau</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ce (4), A (4), Ck (3), He1 (3)</td>
<td>C 2 4 4 2</td>
<td>arid - subhumid</td>
</tr>
<tr>
<td><em>Styphelia tenuiflora</em></td>
<td>122</td>
<td>D2 (18), Pn (10), D4 (9)</td>
<td>V J W I V</td>
<td>jarrah - wandoo - powderbark</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Y6 (7), D1 (6), My2 (6)</td>
<td>L p l p p</td>
<td>plateau - mild slopes</td>
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<td></td>
<td>Y5 (6), Fo (4), DS2 (3)</td>
<td>C 4 2 2 1</td>
<td>arid - subhumid</td>
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<tr>
<td><em>Tremaandra stelligera</em></td>
<td>91</td>
<td>A (13), CRb (5), Ks (5)</td>
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<td>banksia - karri - tingle</td>
</tr>
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<td>LF (5), Cl (4), PM1 (4)</td>
<td>L w p a s</td>
<td>deposits - plateau - hills - slopes</td>
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<td>V4 (4), W1 (4), WH1 (4)</td>
<td>C 8 8 8 8</td>
<td>perhumid</td>
</tr>
<tr>
<td><em>Triglochin mucronatum</em></td>
<td>6</td>
<td>Ck, Lw, Qwy, S</td>
<td>V W S S S</td>
<td>wandoo - swamp</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>L l w w w</td>
<td>slopes - wet deposits</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>C 1 4 4 3</td>
<td>arid - subhumid</td>
</tr>
<tr>
<td><em>Trymalium floribundum</em> (T)</td>
<td>4</td>
<td>A (1), My2 (1), Tw (1)</td>
<td>V B W B H</td>
<td>banksia - wandoo - bullich</td>
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<tr>
<td></td>
<td></td>
<td>Yg2 (1)</td>
<td>L w m k l</td>
<td>deposits - valleys</td>
</tr>
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<td></td>
<td></td>
<td>C 8 2 7 6</td>
<td>arid - perhumid</td>
</tr>
<tr>
<td><em>Trymalium ledifolium</em> (T)</td>
<td>4</td>
<td>LK2 (2)</td>
<td>V W J J</td>
<td>wandoo - jarrah</td>
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<td></td>
<td>D2 (1), DM2 (1)</td>
<td>L m p p</td>
<td>slopes - plateaus - deposit</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C 2 4 3</td>
<td>arid - subhumid</td>
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<td>Species</td>
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<td>Veg. Complex</td>
<td>E</td>
<td>System</td>
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<td><em>Verticordia plumosa</em></td>
<td>5</td>
<td>BWp (1), A (1), FH5 (1), MTb (1), NW1 (1), Yg2 (1)</td>
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<td>G B Z</td>
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<td>L</td>
<td>w w v</td>
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<td>C</td>
<td>9 8 4</td>
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<td><em>Xanthorrhoea drummondii</em></td>
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<td>Y6 (5)</td>
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<tr>
<td><em>Xanthorrhoea gracilis</em></td>
<td>96</td>
<td>D1 (13), D2 (9), D4 (7), Pn (5), Fo (4), Yg1 (4), Yg2 (4), Pi (3), Y5 (3)</td>
<td>V</td>
<td>J J I W</td>
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<td>L</td>
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<tr>
<td><em>Xanthorrhoea preissii</em></td>
<td>153</td>
<td>Pn (14), D1 (11), D4 (9), D2 (8), Mi (6), Y6 (6), Y5 (5), My2 (4), Yg2 (4)</td>
<td>V</td>
<td>W J I J</td>
</tr>
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<td></td>
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<td>L</td>
<td>p p p</td>
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<td>2 6 2 4</td>
</tr>
<tr>
<td><em>Xanthosia rotundifolia</em></td>
<td>21</td>
<td>Kb (3), BAf (2), A (2), BEy1, CA, KO, Ky, Lp, MTp2, MTy1, MTy2</td>
<td>V</td>
<td>T J B</td>
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<td>L</td>
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<td>C</td>
<td>8 4 8</td>
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<tr>
<td><em>Xylomelum occidentale</em></td>
<td>43</td>
<td>Yg2 (4), BD (3), BK (3), He1 (3), Fo (2), CF (2), KI (2), TL (2), BE1, CO1, GA</td>
<td>V</td>
<td>H B M M</td>
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<td>L</td>
<td>1 k n s</td>
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### APPENDIX 4.5: COMPARISON OF PREDICTIONS IN MAP LEGEND AND RECORD IN FLORABASE FOR TREES AND LARGE SHRUBS

<table>
<thead>
<tr>
<th>Species</th>
<th>Prediction in mid-length map legend</th>
<th>Record in FloraBase</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia acuminata</em></td>
<td>On shallow but fertile valley slopes of the arid to periarid zone (Wm2, Wm1, Ds2, Ds0) in the north east with extension onto the shallow valley slopes in subhumid zone of the Blackwood valley (Ms4) and on to deeper soils of the valley floor in the arid zone (Ev2, Cv1).</td>
<td>Valley floors (Ev2) and shallow valley slopes (Ds0, Wm1), but also extending on to lateritic uplands in the arid zone (Vp1). The latter appears to be a drift in geographic referencing or map boundary error, as the species is normally restricted to shallow but fertile soils.</td>
</tr>
<tr>
<td><em>Acacia cyclops</em></td>
<td>Component of shrublands on recent coastal dunes (Qu9) in hyperhumid zone. The description is too restrictive, as the species is known to extend on to dunes in arid zone (Marchant et al. 1987).</td>
<td>Coastal dunes, mainly recent (Qu9, Qu7) but also on to older dunes (Py9) and even inland swamps (Sw3). The latter appears to be an error in geographic referencing, as this species is mainly known from coastal dunes. (Marchant et al. 1987).</td>
</tr>
<tr>
<td><em>Acacia littorea</em></td>
<td>On coastal dunes in perhumid to hyperhumid zones (Py9, Py8, Py7, Qu7, Pu9). The omission of non-dune occurrences is not serious, as they are all close to dunes and maybe due to geographic reference drift.</td>
<td>Mainly on coastal dunes in perhumid to hyperhumid zones (Py9, Py8, Py7, Qu9, Qu7) but also from nearby swamps (Bw9, Gw8) and crystalline uplands (Jp8) and valleys (Km9). At a lower level on Ac7, Ms6. The inland occurrences (off dunes) are at odds with known occurrence of the species on coastal dunes and limestone (Marchant et al. 1987).</td>
</tr>
<tr>
<td><em>Acacia microbotrya</em></td>
<td>On valley slopes in arid zone (Wm2) The description is too restrictive with respect to landform.</td>
<td>On valley slopes (Wm1, W11), valley floors (Ev2), sandy deposits (Ac2) and uplands (Jp3) in semiarid to arid zone. Also a single occurrence on uplands of humid zone (Jp6), which is likely to be an error in geographic referencing.</td>
</tr>
<tr>
<td><em>Acacia pentadenta</em></td>
<td>On hillslopes (Ta8) and valleys (Ks8, Ki9) and swamp/upland mosaic (Sv9) in perhumid to hyperhumid zone The description is restrictive with respect to landforms and to a lesser degree climate.</td>
<td>Main occurrence on hill slopes (Ta8) swamps (Bw8), plateau uplands (Mp8) and valleys (Ks8) in perhumid to hyperhumid zone, but also extending onto humid sedimentary valley (Ak6) and at lower level to Gw9, Sv9, Ki9.</td>
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### APPENDIX 4.5 (Continued)

<table>
<thead>
<tr>
<th>Species</th>
<th>Prediction in mid-length map legend</th>
<th>Record in FloraBase</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acacia saligna</em></td>
<td>Valley floors in subhumid to semiarid zones (Fv3, Jv3, Fv4, Jv4) and coastal plain deposits in humid zone (Mb5). The prediction is too restrictive with respect to both climate and landform. However, the species is rarely a prominent component of vegetation.</td>
<td>Main occurrence in valleys (WM2, Wm1, Wl2), coastal plain deposits (Mb2, Ic2) and plateau uplands (Ip2). Also on steep escarpment (Rs4) and swamps (Sw3) in semiarid to subhumid zone, and to a lesser degree on dunes (Py7), semi-swampy uplands (Jw5) and swamps (Sw5) and valleys (Hl6) in humid zone.</td>
</tr>
<tr>
<td><em>Actinostrobus pyramidalis</em></td>
<td>In swampy depressions in semiarid to arid zone (Sw3, Cv2). The prediction is too restrictive.</td>
<td>In swamps (Sw3, Zv4), swampy uplands (Jw7) and broad swampy valleys (Wl2) from arid to perhumid zone. Single occurrences on Cv2, Yv4.</td>
</tr>
<tr>
<td><em>Agonis flexuosa</em> and <em>Agonis flexuosa var. flexuosa</em></td>
<td>On crystalline hillslopes (Ta8) and valleys (Kl9,Kc8,Km8,Km9,NM5, Mm6, Ms6), in valleys in sedimentary plateau (Mk8,Mn5, Bk7, F25), on loamy (Mb5) and sandy deposits (Ac7, Jc8, Ic6) and coastal dunes (Ko9,Py9,Po8,Py8, Py7,Qu7) in humid to hyperhumid zones.</td>
<td>In swamps (Bw8, Gw9, Sw4, Yv4) crystalline hillslopes (Ta8) and valleys (Km9, Ks8, Kl9) and plateau uplands (Kp8, Jp9). On sandy deposits (Ac7) and on coastal dunes (Ko9, Py9, Po8, Py7) in humid to hyperhumid zone.</td>
</tr>
<tr>
<td><em>Agonis juniperina</em></td>
<td>In swamps (Zv9) and on valley floors (Kl9, Ks8, Km8) of the perhumid to hyperhumid zone. The description is restrictive with respect to coastal dunes.</td>
<td>In dunes (Py9, Po8) in crystalline valleys (Ks8) and on uplands (Kp8) of the perhumid - hyperhumid zone and swamps (Sw7) in perhumid zone. The record for uplands (Kp8) is at odds with known bias of the species toward swampy sites.</td>
</tr>
<tr>
<td><em>Agonis linearifolia</em></td>
<td>On crystalline hillslopes (Ra8) and uplands (Ip8) in perhumid - hyperhumid zone. On floors of valleys, both crystalline and sedimentary, (Kl9, Nm5, Km9, Mm6, Bk7, Fw5, Fv5, Hl6, Ic6, Ic5) and in swamps (Bw8, Sw7, Sw4, Gw4) across a range of climatic zones from subhumid to hyperhumid zone.</td>
<td>In crystalline (MS4, Ks8, NM6, Wm2, Kl9, Hl6) and sedimentary (Bk7) valleys across a range of climatic zones. Also on crystalline (Mp8, JP6, JP4) and sedimentary Jg5) uplands, and in swamp and swamp / upland mosaic (Bw8, Gw4, Sv9). The records for subhumid to humid uplands go against known bias of the species toward watercourses and winter wet depressions (Marchant et al. 1987) and are probably due to drift of geographic references from Hl6, MS5, Nm6.</td>
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## APPENDIX 4.5  (Continued)

<table>
<thead>
<tr>
<th>Species</th>
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<th>Record in FloraBase</th>
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</thead>
<tbody>
<tr>
<td><em>Allocasuarina decussata</em></td>
<td>On crystalline hillslopes (Ta8), on uplands (Kp8) and valleys (Ki9, Ks8, Km8, Km9) in perhumid – hyperhumid zone, with minor extension on to sedimentary valleys in humid zone (Mn5).</td>
<td>On crystalline hillslopes (Ta8), uplands (Mp8, Kp8) and valleys (Ks8, Ki9, Km8) with extension on to coastal swamps (Bs8).</td>
</tr>
<tr>
<td><em>Allocasuarina fraseriana</em></td>
<td>On gravelly – sandy plateau uplands, both crystalline (JP6, JP4, Ip2) and sedimentary (Jg5) with extension on to sandy deposits (Ac4, Ac8, Ic2) and sandy swamp margins (Gw9, Jw7, Sw6, Iw6, Jw5), across most climatic zones.</td>
<td>On gravelly – sandy crystalline (JP6, JP4, Ip2) and sedimentary (Jg5) plateau uplands, on slopes of broad valleys (Hl6, Wl2, Bk7), on sandy deposits (Ac4), in swamps (Bw8, Sv9) and on steeper hill and valley slopes (Rs3, Wm2) across most climatic zones. Minor occurrence on coastal dunes (Py9). The occurrence on steeper slopes with shallow soils is at odds with known bias of the species toward sandy and gravelly soils (Marchant et al. 1987).</td>
</tr>
<tr>
<td><em>Allocasuarina huegeliana</em></td>
<td>On rocky slopes with shallow soils in semiarid to humid zones (Ms4, MS5, Rs4, Rs3) and on valley slopes in arid to perarid zone (WS2, Ds2, Wm1, Ds0). This prediction is broader than the FloraBase record.</td>
<td>On valley slopes (WM2, Wm1) and uplands (Vp1, Ip3) of crystalline plateaus in arid zone. The upland records go against known bias of the species to shallow rocky soils associated with granitic outcrops (Marchant et al. 1987) and suggest drift in geographical references, e.g. from WS2 or Ds0 to Vp1 and Rs3 to Ip3.</td>
</tr>
<tr>
<td><em>Casuarina obesa</em></td>
<td>On saline valley floors and swampy depressions in arid to perarid zone (Ev2, Cv2, Cw0, Cv1)</td>
<td>Only three records from valleys (W11, Ds0) and uplands (Vp1) in arid to perarid zone. These are at odds with known bias of the species toward saline flats and winter wet depressions (Marchant et al. 1987), and probably represent a drift in geographic reference from nearby Cw0 or Ev2.</td>
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<td>Species</td>
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<tr>
<td><em>Callistachys lanceolata</em></td>
<td>On valley floors (K19, Ks8, Km8, Nm5, NM5, Km9), on mosaic of uplands and swamps (Kv7) and in swamp surrounding a spring (Ja4), over a range of climatic zones from subhumid to hyperhumid. The description is restrictive for dunes and uplands.</td>
<td>In valleys (Ks8, K19), on crystalline slopes and uplands (Kp8, Jp9, Ta8), dunes (Py9) in perhumid to hyperhumid zone. At lower level in swamps (Bw8, Sw7, Gw9), old dunes (Po8) crystalline uplands (Jp6, Mp8), sandy deposits (Ac2) and valleys (Km8, Nm5). The upland occurrences go against known bias of the species toward damp sites (Marchant et al. 1987), but are too numerous to be ignored.</td>
</tr>
<tr>
<td><em>Corymbia calophylla</em></td>
<td>Range extends virtually over all landform - climate combinations from hyperhumid to perarid zone, and from coastal dunes to rock outcrops and heavy textured loams of inland valleys. The only landforms from which it is absent are young unconsolidated dunes and deep swamps. It is associated with all other major tree species and most of the minor ones except perhaps <em>Agonis juniperina</em>, <em>Casuarina obesa</em>, <em>Eucalyptus occidentalis</em> and <em>Melaleuca cuticularis</em>, which occur mainly on extreme sites. By contrast, it is dominant only in subhumid to humid crystalline valleys and heavier textured coastal plain deposits.</td>
<td>Comparable in range covering most combinations of landform and climate, with highest records on lateritic uplands where it is associated with <em>Eucalyptus marginata</em> and valleys of the sub-humid to humid zones. Not recorded from Qu9, Qu2, Qu7, Py9, Py8, Zv9, Sw5, Sw7, Iw6, Zv4, Sv8, Sw4, Gw3, Gw4, Ds2, Ds0, most of which are extreme sites, but the record is not so complete as to provide a proof.</td>
</tr>
<tr>
<td><em>Corymbia ficifolia</em></td>
<td>Swamps of the southern coastal plain and its hinterland (Sv6) and low lying sedimentary deposits (Jk8) in the humid to hyperhumid zone. Description in legend is too restrictive.</td>
<td>Recorded from a broader range of landforms, such as swamps (Gw9, Sv6, Bw8) coastal dunes (Py9, Po9), crystalline uplands (Mp8), shallow valleys (Iw8, K19) and hillslopes (Ta8, Ia8, Ja8).</td>
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## APPENDIX 4.5 (Continued)

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<th>Species</th>
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<tr>
<td><em>Corymbia haematoxylon</em></td>
<td>On slopes of Blackwood sedimentary plateau (Jn5) in humid zone. The prediction is too restrictive.</td>
<td>Recorded from uplands (Jg5), slopes (Jn5, Mn6) of Blackwood plateau, from sandy deposit within it (Ac7) and swamp below it (Sw4). Two records from humid crystalline plateau (JP6) probably refer to near-by Darling Scarp (Rs4), where the species is known to occur.</td>
</tr>
<tr>
<td><em>Eucalyptus accedens</em></td>
<td>Arid to perarid uplands (Vp1, Vp2, Ip2) and upper valley slopes of crystalline plateau (Wm1, Ds0).</td>
<td>Arid to perarid uplands (Vp1, Vp2, Ip3), valley slopes, W11, W12, Ds0, Rs4, Wm1, WM2, valley floor (Ev2, Cw0), also humid upland (JP6). The last two categories are likely to be drifts in geographic referencing, as it is described as a species of arid lateritic uplands and of Darling Scarp (Marchant et al. 1987).</td>
</tr>
<tr>
<td><em>Eucalyptus astringens</em></td>
<td>Interface between lateritic uplands (Vp1, Vp2, Jp2, Jp3) and valley slopes (Wm1, Wm2, Wm4, Ds2) in semiarid to perarid zone.</td>
<td>Valley slopes in arid zone (W11). The FloraBase record is inadequate. One day’s collection along a third of eastern periphery of the RFA area increased it by 400%.</td>
</tr>
<tr>
<td><em>Eucalyptus astringens</em></td>
<td>Lateritic uplands (Mp8, Ja8) and hillslopes (Ta8, Ra8) in the southern perhumid zone. The omission of swamps and swamp margins is an error as the species does descend downslope.</td>
<td>Hillslopes (Ta8, Ra8, Ia8) and lateritic uplands (Ja8) as well as swamps or swamp margins (Bw8, Gw9) in perhumid zone. Also swamps (Sw6) and valleys (Ev5) in humid zone.</td>
</tr>
<tr>
<td><em>Eucalyptus cornuta</em></td>
<td>Coastal dunes (Po9, Po8, Ko9) in perhumid zone, colluvium below rocky hills (Ja4) and valleys (Nm5, Ev5) in the southeast subhumid to humid zone. The omission of hill slopes is an error.</td>
<td>Coastal dunes (Py9, Po8), plateaus (Jp9) and sedimentary valleys (Bk7) in perhumid zone, hill slopes in hyperhumid to subhumid zone (Ta8, Rs5), valleys in semiarid to humid zones (Nm5, Mn5, Ev5).</td>
</tr>
<tr>
<td><em>Eucalyptus decipiens</em></td>
<td>Valley slopes and floors, mostly with fine textured soil, in semiarid to humid zone of the south east (Sw5, Zv4, Jv4, Jv3). There is some omission of moister and more upland occurrences.</td>
<td>Very wide range of landforms, from south eastern valleys (Jw5, Yv4, Jv4, Ak6, Mn5) to uplands (Jp5, JP6, JP3, JG6) and steep slopes (Ms4, Rs5), mostly as single records.</td>
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<tr>
<td>Species</td>
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<tr>
<td><em>Eucalyptus diversicolor</em></td>
<td>On crystalline hillslopes and valley slopes (Kl9, Ks8, Km8, Km9), to a lesser degree on uplands (Mp8, Kp8), mosaic of rises and depressions (Kv7, Jc8), well drained riverine terraces (Mk8) and sheltered old dunes (Po9, Po8, Ko9) in perhumid to hyperhumid zones. A minor occurrence in valleys of humid zone (Mn5) but within known range of the species also included.</td>
<td>On similar combination of landform and climate such as crystalline valleys (Kl9, Ks8, Km8, Ta8), uplands (Mp8, Ja8, Jp9) mosaic of rises and depressions (Jw7) and sheltered dunes (Py9, Ko9) but also in swamp (Bw9, Zv9) in perhumid – hyperhumid zone. Two seemingly aberrant records from swamp in humid to subhumid zones (Gw5, Zv4) outside known range.</td>
</tr>
<tr>
<td><em>Eucalyptus drummondii</em></td>
<td>On lateritic uplands in arid zone (Jp2). The description appears to be too restrictive, both in term of landform and climate.</td>
<td>On rocky slopes in semiarid zone (Rs3), in valleys and uplands in arid – perarid zone (Wm1, Wl2, Vp1).</td>
</tr>
<tr>
<td><em>Eucalyptus gilfoylei</em></td>
<td>Hillslopes (Ks8, Ta8) and plateau uplands (Ja8, Mp8) in the perhumid zone in south coast hinterland. The description is too restrictive with respect to landform.</td>
<td>On similar combination of landforms and climate (Ta8, Ks8, Mp8, Ra8, Ja8) but also valley slopes (Kj9) and swamps (Bs8, Gw9) and sand deposits (Ac8) in the same zone. Two abnormal occurrences in swamps of subhumid zone (Zv4) which appear to be due to error in geographic reference.</td>
</tr>
<tr>
<td><em>Eucalyptus jacksonii</em></td>
<td>Hillslopes (Ks8, Ta8) in the perhumid – hyperhumid zone in south coast hinterland. The description is too restrictive with respect to landform</td>
<td>In similar combination of landform and climate (Ks8, Ta8) but also in valleys (Kj9, Nm5) swamps (Bs8, Gw9) and on plateau uplands (Jk8, Ja8). Also abnormal records in swamps of humid to subhumid zones (Zv4, Gw5) which appear to be due to error in geographic reference.</td>
</tr>
<tr>
<td><em>Eucalyptus laeliae</em></td>
<td>Steep slopes of monadnocks (Rs3), deeply incised valleys (MS5) and Darling Scarp (Rs4), in semiarid to humid zone. Perhaps too restrictive, but some record doubtful.</td>
<td>On similar combination of landform and climate (Rs3, WS2, WM2, Ms5), but also on lateritic uplands (JP6, JP4) and mildly incised valleys (H16) and a valley in arid zone (W11).</td>
</tr>
<tr>
<td><em>Eucalyptus lane-poolei</em></td>
<td>Eastern margin of the northern coastal plain (Mb2), in arid to subhumid zone. This description is erroneous, it should be the neighbouring Ic2.</td>
<td>On Darling Scarp (Rs4) and Ridge Hill Shelf (Ic2), as well as two abnormal records (Ta8).</td>
</tr>
</tbody>
</table>
### APPENDIX 4.5  (Continued)

<table>
<thead>
<tr>
<th>Species</th>
<th>Prediction in mid-length map legend</th>
<th>Record in FloraBase</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Eucalyptus loxophleba</em></td>
<td>Perarid to arid valley slopes (Ds0) and floors (Ev2).</td>
<td>Similar combination of landform and climate (Ev2, Wm1, W11) but also perarid uplands (Vp1). The latter is at variance with known ecological bias of the species toward fertile soils in valleys, and may be due to drift in geographic reference. The species is inadequately represented in the FloraBase.</td>
</tr>
<tr>
<td><em>subsp. loxophleba</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Eucalyptus marginata</em></td>
<td>On the Ridge Hill Shelf (Ic2) at the interface between Darling Scarp and northern Swan Coastal Plain, in semiarid to subhumid zone.</td>
<td>On Darling Scarp (Rs4) in semiarid to humid zone, and in a shallowly incised valley on the Darling Plateau in humid zone (Hl6). These records are not in accord with known occurrence of the species below the Darling Scarp and a drift in geographic references is likely.</td>
</tr>
<tr>
<td><em>subsp. elegantella</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Eucalyptus marginata</em></td>
<td>On most landforms across all climatic zones, with the exception of recent dunes, deep swamps and valleys in perhumid to hyperhumid and semiarid to perarid zones. Predicted to be replaced in arid zone by <em>Eucalyptus marginata</em> subsp. <em>thalassica</em>. Predicted to occur in 69 vegetation systems.</td>
<td>Similar combination of landforms and climate, but also extending on to steep scarps (Rs4, Ra8, Rs5) swamps (Sw3, Sv6, Gw9, Yv4, Cv1) arid valley slopes (W11, Ev2, Wm1), recent dunes (Qu7) and perhumid valleys (Km8, Kj9). Many of these are singletons and are probably due to drift in geographic references.</td>
</tr>
<tr>
<td><em>subsp. marginata</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Eucalyptus marginata</em></td>
<td>On uplands (Vp1, Vp2, Ip2, Ig0) valleys (Wm1, W12) and sandy deposits (Ac2) in the perarid to semiarid zones of the Darling and Dandaragan Plateaus. Description too restrictive in terms of climate.</td>
<td>Similar combination of landform and climate (Vp1, Vp2, Ip2, W11, Wm1, W12, Ac2), but also on subhumid and humid uplands (Jp6, Jp4) and valleys (NM6, Hl6) which suggest that the distribution of the species extends further south and west than assumed.</td>
</tr>
<tr>
<td><em>subsp. thalassica</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Eucalyptus megacarpa</em></td>
<td>On old dunes (Po9, P08), in shallow valleys (Kj9), in swamps (Sv9) and on hillslopes with shallow soil (Ia8, Ra8) in perhumid to hyperhumid zones, and in shallow valleys (Hl6) in humid zone. Landform description somewhat restrictive.</td>
<td>On comparable combination of landform and climate (Py9, Po9, Ko9, Ra8, Ia8, Hl6) but also on uplands (Mp8, Ja8, Mp8), hillslopes and valleys with deeper soils (Kp8, Ta8, Ks8, Km9) and wider range of swamps (Gw9, Sw6, Gw4, Zv9). Some drift in geographic references likely.</td>
</tr>
<tr>
<td>Species</td>
<td>Prediction in mid-length map legend</td>
<td>Record in FloraBase</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-----------------------------------------------------------------------------------------------------</td>
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<tr>
<td><em>Eucalyptus occidentalis</em></td>
<td>Mainly in salt-affected swampy valleys and depressions, in the semiarid to humid zones (Sw6, Sw5, Mn5, Yv4, Zv4, Ev5), in the south east.</td>
<td>In comparable landform and climate combinations (Yv4, Zv4, Sw6), but also on semi-swampy uplands (Jw5) and uplands (Jp5). The latter is probably due to drift in geographic reference, and is outside the known ecological range of the species. The FloraBase record is inadequate (6 records only).</td>
</tr>
<tr>
<td><em>Eucalyptus patens</em></td>
<td>Mainly in valleys (Ki9, Ks8, Km8, Bk7, Mn6, NM5, Mm5, Nm5, NM6, Ms5, Fw5, Fv5) and swamps (Sv9, Bw8) in humid to hyperhumid zone. Landform description is restrictive, focusing on those landforms on which <em>Eucalyptus patens</em> is a significant component, and inadequately covering those on to which the species extends marginally.</td>
<td>In comparable combination of landforms and climates (Km8, Ki9, Ks8, Bk7, NM6, Nm5, NM5, MS4, Ms5, Hl6, Sv9, Zv9, Bw8, Gw9, Sv6, Sw3, Yv4, Gw4) but also extending into other landforms and drier climatic zones, such as lateritic uplands (JP6, MP8, JP4), hillslopes (Ta8, Ia8, Rs4) and arid valleys (Wl2, Wm2, Wm1) and uplands (Vp1). Some of these entries are probably due to drift in geographic references, as they do not match the known bias of the species toward alluvial loams and clays in valleys and depressions (Marchant <em>et al</em>. 1987).</td>
</tr>
<tr>
<td><em>Eucalyptus rudis</em> and <em>Eucalyptus rudis</em> subsp. <em>rudis</em></td>
<td>Mainly on valley floors and streamlines (Nm5, NM5, Wm4, Fw5, Fv5, Fv4, Mm4, Ic6, Ic5, Fw5, Mn6, Fv3, MS5, WM2, Wm2, Ev2, Sl1, An0), swamps (Gw3, Sw4, Cv1), swampy uplands (Jv4, Jv3), rocky slopes (Ds2) and coastal plain deposits (Lc2, Mb2). Largely independent of climate, but less prominent in perhumid - hyperhumid zone. Some of these may refer to the rarer <em>Eucalyptus rudis</em> subsp. <em>crayanthha</em>.</td>
<td>Mainly on valley floors (Ki9, Mn6, NM5, Nm5, Yv4, Fv3, Wm4, Wm1, WM2, WM1, Ev2, Wl2, but also on rocky slopes (Rs3, Ds0, Ds2), uplands (Jg5, Ip2), dunes (Po9 and swamps (Gw4). Some of these maybe due to drift in geographic references, such as uplands (Jg5, Ip2).</td>
</tr>
</tbody>
</table>
### APPENDIX 4.5 (Continued)

<table>
<thead>
<tr>
<th>Species</th>
<th>Prediction in mid-length map legend</th>
<th>Record in FloraBase</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Eucalyptus staeri</em></td>
<td>On uplands and slopes of sedimentary deposits in the humid south east (Jg6, Ak6) and swampy floors and terraces of rivers passing through them (Sw6).</td>
<td>Apart from Jg6, on a different and widely divergent set of landforms such as crystalline uplands (Jp5, Ia8, Mp8), in crystalline valleys (Ks8) swamp (Zv4, Bw8, Gw9) and dunes (Py9), many of which do not match known ecological bias of the species (Booker and Kleinig 1990). Drift in geographic referencing is suspected in some cases (Ks8, Mp8).</td>
</tr>
<tr>
<td><em>Eucalyptus todtiana</em></td>
<td>On sandy deposits (Ic2) and swamp/upland mosaic (CV2) of northern Swan Coastal Plain and on the Dandaran sedimentary plateau (An0, Ig0) in the arid perarid north west of the RFA region.</td>
<td>On sandy deposits (Ic2) and other (Mb2) portions of the northern Swan Coastal Plain, in depressions on Dandaran Plateau (Cw0) and on uplands (Jp4) and valleys (WM2) of the crystalline Darling Plateau. The latter two records are at odds with known ecological bias of the species toward coastal sands and sedimentary plateau (Marchant et al. 1987).</td>
</tr>
<tr>
<td><em>Eucalyptus wandoo</em> and <em>Eucalyptus wandoo</em> subsp. <em>wandoo</em></td>
<td>The two taxa, considered to be overlapping, have not been described separately. They are predicted for steep slopes (MS5, Rs4, Ds2, WS2, Rs3, Ds0) from arid to humid zone, from milder valley slopes and floors in perarid to subhumid zone (Mm4, Wm4, Zv4, Ev5, Iv3, Jv4, Fv3, Wm2, WM2, Ev2, Wm1, W11, W12), from semiarid to perarid uplands (Jp3, Jp2, Ip2, Vp1, Vp2), from semiarid swamp margins (Gw3) and arid coastal plain deposits (Ic2, Mb2).</td>
<td>Comparable range of landform - climatic combinations, from steep slopes (Rs3, WS2, Ds0), valley slopes and floors (Wm4, Jv3, Fv3, WM2, Wm2, Wm1, W12, W11, Ev2), arid uplands (Ip2, Lp2, Vp2, Vp1), swamp margins (Sw3) and arid coastal deposits (Ic2). In addition also on humid swamp upland mosaic (Jw5) on subhumid uplands (Jp4), on sandy deposits (Ac2). Some of these may be due to drift in geographic references from steeper to milder landforms (Jp4, Ac2). For this highly significant species the Florabase record (65 entries) is barely adequate.</td>
</tr>
</tbody>
</table>
### APPENDIX 4.5  (Continued)

<table>
<thead>
<tr>
<th>Species</th>
<th>Prediction in mid-length map legend</th>
<th>Record in FloraBase</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Melaleuca curricularis</em></td>
<td>In swampy depressions and valley floors (Sw6, Sw6, Mn5, Yv4, Zv4, Ev5) in semiarid to humid zone and on periphery of estuaries (Zv9, Sv8) in perhumid to hyperhumid zone. The prediction maybe restrictive, but is in line with known ecological bias of the species.</td>
<td>In lakes (L), on crystalline hillslopes (Ta8) and shallow valleys (Kl9) and swamp (Gw9) in perhumid and in swampy depressions in semiarid (Yv4) zones. Single records for a number of other climate – landform combinations (Sw4, Mp8, Cv2, Gw9, Jp9, Sv6, Jp3, Zv4, Zv9, Ac3, Ev5, Sw5, Nm5). The records for lakes (L) and crystalline hillslopes (Ta8) are due to drift in geographic references.</td>
</tr>
<tr>
<td><em>Melaleuca preissiana</em></td>
<td>Over a broad range of swampy (winter wet) sites on coastal plains (Bw8, Sw7, Sw4), broad crystalline (Iw8, Iw6, NM5) and sedimentary (Jk6, Bk7, Ic5, Gw4), valleys, mosaics of swamp and uplands (Sv9, Jc8, Kv7, Jw7, Jw5, Jv4, Jv3), depressions and flats (Sv6, Gw6, Gw5, Sw5, Zv4, Gw3, Ac2, Sw3).</td>
<td>Main occurrences in shallow sedimentary valleys (Gw4, Bk7, Ic5), swampy depressions (Sw3, Yv4, Gw9) and sandy coastal deposits (Ac7), but also on sedimentary plateaus (Jg5) and crystalline plateaus (Jp5) and valleys (WM2). The latter are at odds with known bias of the species toward winter wet depressions (Marchant et al. 1987). There are also numerous single occurrences across a wide range of climate – landform combinations.</td>
</tr>
<tr>
<td><em>Melaleuca rhaphiophylla</em></td>
<td>On floors of valleys (Bk7, Fv5, Fv3, Wm2, Ev2) and on streamlines and springs (Ja4, Ic2). The description is too restrictive with respect to estuarine and coastal swamps.</td>
<td>In estuarine (Zv9) and coastal (Bs8, Sw4) swamps, in crystalline (WM2) and sedimentary (Gw4) valleys, on coastal plain deposits (Mk8, Mb2), largely independently of climate. Also on crystalline uplands (Jp5), though this goes against the known bias of the species toward watercourses and permanent swamps (Marchant et al. 1987).</td>
</tr>
</tbody>
</table>
APPENDIX 4.5  (Continued)

<table>
<thead>
<tr>
<th>Species</th>
<th>Prediction in mid-length map legend</th>
<th>Record in FloraBase</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Nuytsia floribunda</em></td>
<td>On sandy deposits (Ac7, Ac2), in swamps (Gw9, Bw8, Sw7), on sedimentary slopes (Ak6, Jk6), hillslopes with shallow soils (Ia8), on old sand dunes (Po8), on sedimentary uplands (Jk8), in swampy depressions (Sv6, Sw5) and swampy valleys (Iw8).</td>
<td>On sandy deposits (Ac7), in swamps (Gw4), on crystalline uplands (JP4), in crystalline valleys (Wm2). Single occurrences on (Bk7, Ta8, Ip2, Po8, Ac2, Gw9, Jp5, Sw3, Sw5, Nm5 and Jg5). The species is poorly represented in the database (22 records). The occurrence in forest on crystalline plateau uplands (JP4) is at odds with known occurrence of the species, which is in damp sandy habitats and rocky slopes (Marchant et al. 1987).</td>
</tr>
<tr>
<td><em>Persoonia elliptica</em></td>
<td>On sedimentary slopes in humid zone (Jn5). The prediction is too restrictive with respect to crystalline valleys and uplands and old coastal dunes. The species is rarely a prominent component of the second storey.</td>
<td>On crystalline uplands (JP6, Vp2, JP4, Ip2) in crystalline valleys (NM6, WM2, Km8, Hi6), on old dunes (Ko9), sedimentary slopes (Bk7) and upland (Jg5). Single occurrences on Mh5, Mn6, Rs3, Rs4, Ic2, WS2, Nm5, Gw4 and Jn5.</td>
</tr>
<tr>
<td><em>Persoonia longifolia</em></td>
<td>On a very wide range of sites, including crystalline uplands (Kp8, Ip8, Mp8, Jp5, Jp3, Jp9, Jp6, JP6, JP4, Ip2, Jp4, Lp2) and slopes (Ks8, Km8, Ja8, Ia8, Ms8, Nm5, Kk9, Jm8, Mn6, Ms5, NM6, HI6), mosaics of swamps and uplands (Jc8, Kv7, Jw7, Jw5), on sedimentary slopes (Mk8, Mn6) and uplands (Jc6, Jg5, Ic6), and on coastal deposits (Mb5). However, it is not predicted for deep leached sands, shallow rocky slopes in arid zone and from swamp. The prediction is mildly restrictive with respect to swamps.</td>
<td>Main occurrence (8+ records) on crystalline uplands (JP6, JP4, Ip2). At moderate level (4-7) in valleys (NM6, HI6), in swamps (Bw8, Sw4), sedimentary valleys (Bk7) and crystalline slopes (Ta8), valleys (Ks8, Nm6, Wl2) and uplands (Mp8). At low levels from a very wide range of climate – landform combinations.</td>
</tr>
<tr>
<td><em>Xylomelum occidentale</em></td>
<td>Main occurrence on sedimentary plateau uplands (Jg5, Jg4) and slopes (Jn5, Mn6), on coastal plain deposits (Mk8, Ac7, Ic2) and within sedimentary basin (Ic5). Description restrictive with respect to crystalline valleys, but this maybe justifiable.</td>
<td>In crystalline valleys (MS5, HI6), valleys (Mn6, Bk7) and uplands (Ig5) in sedimentary plateau, sedimentary deposits on coastal plain (Ic2) and in basins (Ac4). The record for deeply dissected crystalline valleys (MS5) with shallow loamy soils goes against the known bias of the species toward sandy sites (Marchant et al. 1987).</td>
</tr>
<tr>
<td>CLIMATIC ZONE</td>
<td>PERARID TO ARID</td>
<td>SEMIARID TO SUBHUMID</td>
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</tr>
<tr>
<td>LANDFORM TYPE</td>
<td>Floors and terraces of major valleys</td>
<td>Floors and terraces of major valleys</td>
</tr>
<tr>
<td>VEGETATION COMPLEX</td>
<td>Wi, No, Dk5, Fa4, Fa5</td>
<td>CP1, CP2, NWf1, NWf2, BR, GW</td>
</tr>
<tr>
<td>VEGETATION SYSTEM</td>
<td>Ev2, Cv1</td>
<td>Fv3, Fv4</td>
</tr>
<tr>
<td>SOILS</td>
<td>Alluvials ranging from loamy sands to clay loams, mostly salt affected</td>
<td>Alluvials ranging from loamy sands to clay loams, sometimes salt affected</td>
</tr>
<tr>
<td>STRUCTURAL FORMATIONS</td>
<td>Woodland, shrubland and sedgeland</td>
<td>Open forest, woodland, shrubland and sedgeland</td>
</tr>
<tr>
<td>OVERSTOREY COMPONENTS</td>
<td>Eucalyptus rudis subsp. rudis Casuarina obesa Eucalyptus loxophleba subsp. loxophleba Eucalyptus wando</td>
<td>Eucalyptus rudis subsp. rudis Eucalyptus patens Eucalyptus wando Eucalyptus calophylla</td>
</tr>
<tr>
<td>SECOND STOREY COMPONENTS</td>
<td>Melaleuca rhaphiophylla on streamlines Acacia acuminata on slopes</td>
<td>Melaleuca rhaphiophylla Acacia saligna Hakea prostrata</td>
</tr>
<tr>
<td>UNDERSTOREY SPECIES</td>
<td>Hypocalymma angustifolium Samolus juncus *Juncus acutus Gastrolobium calycinum</td>
<td>Hypocalymma angustifolium Astrebla fascicularis Hakea lissocarpa Phyllanthus calycinus</td>
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<tr>
<td>CLIMATIC ZONE</td>
<td>PERARID TO ARID</td>
<td>SEMIARID TO SUBHUMID</td>
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<td>--------------------------------------</td>
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<tr>
<td>LANDFORM TYPE</td>
<td>Moderate valley slopes</td>
<td>Moderate valley slopes</td>
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<td>VEGETATION COMPLEX</td>
<td>Mi, My2, LK2, NW2, Dk2</td>
<td>LK1, NW1</td>
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<td>VEGETATION SYSTEM</td>
<td>Wm1, WM2, Wm2</td>
<td>Mm4</td>
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<tr>
<td>SOILS</td>
<td>Red earths, red and yellow duplex soils</td>
<td>Red earths, red and yellow duplex soils</td>
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<td>Woodland to open forest</td>
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<tr>
<td>OVERSTOREY COMPONENTS</td>
<td>Eucalyptus wandoo subsp. wandoo</td>
<td>Corymbia calophylla</td>
</tr>
<tr>
<td></td>
<td>Corymbia calophylla, some Eucalyptus loxophleba</td>
<td>Eucalyptus wandoo subsp. wandoo</td>
</tr>
<tr>
<td></td>
<td>Eucalyptus astringens</td>
<td>Eucalyptus marginata subsp. marginata</td>
</tr>
<tr>
<td>SECOND STOREY COMPONENTS</td>
<td>Largely absent, some Acacia acuminata, Acacia microbotrya in perarid zone</td>
<td>Banksia grandis</td>
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<tr>
<td></td>
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<td>Persoonia longifolia</td>
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<tr>
<td>UNDERSTOREY SPECIES</td>
<td>Gastrolobium calycinum</td>
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<td>Trymalium ledifolium</td>
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<td>Hakea lissocarpa</td>
<td>Macrozamia riedlei</td>
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<td></td>
<td>Bossiaea eriocarpa</td>
<td>Phylianthus calycinus</td>
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<td>Leucopogon capitellatus</td>
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<tr>
<td>CLIMATIC ZONE</td>
<td>PERARID TO ARID</td>
<td>SEMIARID TO SUBHUMID</td>
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<tr>
<td>---------------</td>
<td>----------------</td>
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</tr>
<tr>
<td>LANDFORM TYPE</td>
<td>Steep valley slopes and escarpments</td>
<td>Steep valley slopes and escarpments</td>
</tr>
<tr>
<td>VEGETATION COMPLEX</td>
<td>Bi, He2, Dk3, Fa3, NWg2</td>
<td>Ce, DSn, DMg, NWg1</td>
</tr>
<tr>
<td>VEGETATION SYSTEM</td>
<td>Dso, WS2, Ds2</td>
<td>Rs3, Rs4, Ms4</td>
</tr>
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<td>SOILS</td>
<td>Skeletal rocky soils and shallow earths</td>
<td>Skeletal rocky soils and shallow earths</td>
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<td>STRUCTURAL FORMATIONS</td>
<td>Herbland, shrublands and woodlands</td>
<td>Herbland, shrublands and woodlands</td>
</tr>
<tr>
<td>OVERSTOREY COMPONENTS</td>
<td><em>Eucalyptus wandoo</em> subsp. <em>wandoo</em>  <em>Eucalyptus loxophleba</em> subsp. <em>loxophleba</em>  <em>Allocasuarina huegeliana</em>  <em>Acacia acuminata</em></td>
<td><em>Eucalyptus wandoo</em> subsp. <em>wandoo</em>  <em>Corymbia calophylla</em>  <em>Eucalyptus laeiae</em>  <em>Allocasuarina huegeliana</em></td>
</tr>
<tr>
<td>SECOND STOREY COMPONENTS</td>
<td>Largely absent</td>
<td>Largely absent</td>
</tr>
<tr>
<td>UNDERSTOREY SPECIES</td>
<td><em>Dianella revoluta</em>  <em>Borya sphaerocephala</em>  <em>Cheilanthes austrotenifolia</em>  <em>Hakea lissocarpa</em>  <em>Styopandra glauca</em></td>
<td><em>Hakea undulata</em>  <em>Grevillea bipinnatifida</em>  <em>Borya sphaerocephala</em>  <em>Cheilanthes tenuifolia</em>  <em>Hakea trifurcata</em>  <em>Darwinia citriodora</em></td>
</tr>
<tr>
<td>CLIMATIC ZONE</td>
<td>PERARID TO ARID</td>
<td>SEMIARID TO SUBHUMID</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------</td>
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</tr>
<tr>
<td>LANDFORM TYPE</td>
<td>Lateritized plateau uplands</td>
<td>Lateritized plateau uplands</td>
</tr>
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<td>VEGETATION COMPLEX</td>
<td>Y6, Y5, Bo1, Dk1, Fa1</td>
<td>D3, D4, D2, MH, DM1, BE3, FH1</td>
</tr>
<tr>
<td>SOILS</td>
<td>Deep yellow duplex soils with lateritic gravels</td>
<td>Deep yellow duplex soils with lateritic gravels</td>
</tr>
<tr>
<td>STRUCTURAL FORMATIONS</td>
<td>Woodland</td>
<td>Woodland to open forest</td>
</tr>
<tr>
<td>OVERSTOREY COMPONENTS</td>
<td>Eucalyptus accedens Eucalyptus wandoo Corymbia calophylla Eucalyptus marginata subsp. thalassica</td>
<td>Eucalyptus marginata subsp. marginata (north) Eucalyptus marginata subsp. marginata (south) Corymbia calophylla some Eucalyptus accedens</td>
</tr>
<tr>
<td>SECOND STOREY COMPONENTS</td>
<td>Weakly developed Persoonia longifolia, tall Dryandra sessilis</td>
<td>Persoonia longifolia Banksia grandis Allocasuarina fraseriana</td>
</tr>
<tr>
<td>UNDERSTOREY SPECIES</td>
<td>Hakea lissocarpa Styphelia tenuiflora Gastrolobium calycinum Petropolete serruriae</td>
<td>Hakea lissocarpha Adenantheros barbiger Leucopogon propinquus Styphelia tenuiflora</td>
</tr>
<tr>
<td>CLIMATIC ZONE</td>
<td>PERARID TO ARID</td>
<td>SEMIARID TO SUBHUMID</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>LANDFORM TYPE</td>
<td>Sandy deposit or colluvium</td>
<td>Sandy deposit or colluvium</td>
</tr>
<tr>
<td>VEGETATION COMPLEX</td>
<td>G, parts of Cu, K, Mb, Mh</td>
<td>CF, Bo1s, QUs</td>
</tr>
<tr>
<td>VEGETATION SYSTEM</td>
<td>Ig0, An0, Ac2</td>
<td>Ac4, Ac3</td>
</tr>
<tr>
<td>SOILS</td>
<td>Deep sands</td>
<td>Deep sands</td>
</tr>
<tr>
<td>STRUCTURAL FORMATIONS</td>
<td>Woodland to heath</td>
<td>Woodland</td>
</tr>
<tr>
<td>OVERSTOREY COMPONENTS</td>
<td>Banksia attenuata Banksia menziesii Eucalyptus todiata Eucalyptus marginata subsp. thalassica Banksia prionotes</td>
<td>Banksia attenuata Allocasuarina fraseriana Nuytsia floribunda Eucalyptus marginata subsp. marginata Banksia ilicifolia</td>
</tr>
<tr>
<td>SECOND STOREY COMPONENTS</td>
<td>Banksias may form a lower storey to Eucalyptus</td>
<td>Eucalyptus may form higher storey above other genera</td>
</tr>
<tr>
<td>UNDERSTOREY SPECIES</td>
<td>Stirlingia latifolia Petrophile linearis Conospermum stoechadis Hakea ruscifolia Daviesia decurrens</td>
<td>Stirlingia latifolia Allocasuarina humilis Bossiaea eriocarpa Patersonia occidentalis Calytrix flavescens</td>
</tr>
</tbody>
</table>
**APPENDIX 5.1 (Continued)**

<table>
<thead>
<tr>
<th>CLIMATIC ZONE</th>
<th>PERARID TO ARID</th>
<th>SEMIARID TO SUBHUMID</th>
<th>HUMID</th>
<th>PERHUMID TO HYPERHUMID</th>
</tr>
</thead>
<tbody>
<tr>
<td>LANDFORM TYPE</td>
<td>Seasonally wet depression</td>
<td>Seasonally wet depression</td>
<td>Seasonally wet depression</td>
<td>Seasonally wet depression</td>
</tr>
<tr>
<td>VEGETATION COMPLEX</td>
<td>Wn, Br, Co, Yn, Dk5, Fa4, Fa5</td>
<td>S, QUw, KUt, CM, Bu, MO, Wg, FH4, FH5, GD1, GD4, st</td>
<td>Nu, QN, SC, KP, YR, UC1, UC4, f, t, CA</td>
<td>BW, BWp, Wp, KO, A, CT, HA, Q, Bw</td>
</tr>
<tr>
<td>VEGETATION SYSTEM</td>
<td>Cw0, Cv2, Cv1</td>
<td>Sw3, Gw3, Gw4, Yv4, Zv4</td>
<td>Gw6, Gw5, Sw5, Sw6, Sv6</td>
<td>Gw9, Bw8, Sw7</td>
</tr>
<tr>
<td>SOILS</td>
<td>Varying from humusoid sands to solonetzic soils</td>
<td>Humus and iron podzols solonetzic soils</td>
<td>From humusoid sands to yellow duplex soils and clays</td>
<td>Humus podzols, iron podzols and peats</td>
</tr>
<tr>
<td>STRUCTURAL FORMATIONS</td>
<td>Herblands, sedgelands, shrublands and woodlands</td>
<td>Sedgelands, shrublands and woodlands</td>
<td>Sedgelands, shrublands and woodlands</td>
<td>Sedgelands, shrublands and woodlands</td>
</tr>
</tbody>
</table>
| OVERSTOREY COMPONENTS | *Casuarina obesa*  
*Melaleuca preissiana*  
*Actinostrobus pyramidalis*  
*Banksia litoralis*  
*Eucalyptus rudis subsp. rudis* | *Melaleuca preissiana*  
*Banksia litoralis*  
*Actinostrobus pyramidalis*  
*Eucalyptus rudis subsp. rudis*  
*Melaleuca cicutlaris*  
*Eucalyptus occidentalis* | *Melaleuca preissiana*  
*Banksia litoralis*  
*Eucalyptus occidentalis*  
*Melaleuca cicutlaris*  
*Banksia ilicifolia* | *Eucalyptus megacarpa*  
*Eucalyptus patens*  
*Banksia litoralis*  
*Melaleuca preissiana* |
| SECOND STOREY COMPONENTS | No true second storey | No true second storey | No true second storey | No true second storey |
| UNDERSTOREY SPECIES | *Halorscia pergranulata*  
*Halorscia indica subsp. bidens*  
*Melaleuca teretifolia*  
*Melaleuca hamulosa*  
*Samolus juncea* | *Hakea varia*  
*Hakea ceratophylla*  
*Astartea fascicularis*  
*Meeboldina scariosa*  
*Hypocalymma angustifolium*  
*Melaleuca vininea* | *Hakea varia*  
*Astartea fascicularis*  
*Meeboldina scariosa*  
*Beaufortia sparsa*  
*Hypocalymma angustifolium*  
*Melaleuca vininea* | *Anarthria scabra*  
*Evandra aristata*  
*Homaloapermum firmum*  
*Agonis linearifolia*  
*Beaufortia sparsa*  
*Viminaria juncea* |