12 Biodiversity

12.1 INTRODUCTION

Biological diversity is the variety of all life forms and is usually considered at three levels:

- genetic diversity refers to the variety of genetic information contained in all individual plants, animals and micro-organisms;
- species diversity refers to the variety of living species; and
- ecosystem diversity refers to the variety of habitats, biotic communities and ecological processes.

The nationally agreed criteria for the establishment of a comprehensive, adequate and representative reserve system for forests in Australia (JANIS 1997), jointly developed by the Commonwealth and States, identify the following objectives for biodiversity conservation:

- to maintain ecological processes and the dynamics of forest ecosystems in their landscape context;
- to maintain viable examples of forest ecosystems throughout their natural ranges;
- to maintain viable populations of native forest species throughout their natural ranges; and
- to maintain the genetic diversity of native forest species.

To achieve these objectives, the JANIS document includes a number of biodiversity criteria for establishing a comprehensive, adequate and representative (CAR) reserve system. These are outlined in Table 12.1.

The strategy for conserving biodiversity relies not just on a CAR reserve system, but also on the application of ecologically sustainable forest management across all tenures.

Both the Commonwealth and Western Australia have a number of responsibilities in connection with the conservation of biodiversity. A list of key Commonwealth and State legislation relating to the RFA in Western Australia is given in Appendix 1.

Table 12.1 Summary of the biodiversity criteria

- As a general criterion, 15% of the pre-1750 distribution of each forest ecosystem should be protected in the CAR reserve system.
- Where forest ecosystems are recognised as vulnerable, then at least 60% of their remaining extent should be reserved.
- All remaining occurrences of rare and endangered forest ecosystems should be reserved or protected by other means as far as is practicable.
- Reserved areas should be replicated across the geographic range of the forest ecosystem to decrease the likelihood that chance events such as wildfire or disease will cause the forest ecosystem to decline.
- The reserve system should seek to maximise the area of high quality habitat for all known elements of biodiversity wherever practicable, but with particular reference to:
  - the special needs of rare, vulnerable or endangered species;
  - special groups of organisms, for example species with complex habitat requirements, or migratory or mobile species;
  - areas of high species diversity, natural refugia for flora and fauna, and centres of endemism; and
  - those species whose distributions and habitat requirements are not well correlated with any particular forest ecosystem.
- Reserves should be large enough to sustain the viability, quality and integrity of populations.
- To ensure representativeness, the reserve system should, as far as possible, sample the full range of biological variation within each forest ecosystem.
- In fragmented landscapes, remnants that contribute to sampling the full range of biodiversity are vital parts of a forest reserve system and should be protected.

Source: JANIS (1997)

12.2 METHODS USED IN BIODIVERSITY ASSESSMENT

The Western Australian and Commonwealth governments have agreed that the biodiversity assessment for the South-West Forest Region should be undertaken at the species and ecosystem levels. Because information about genetic variation within species is very limited and costly to obtain, genetic diversity was not assessed, although it is recognised that it does overlap with species and ecosystem diversity and that these are addressed by the national forest reserve criteria.

The biodiversity assessment has therefore been based on an analysis of information about forest ecosystems and communities, flora and fauna species and their habitats. Reports have also been prepared on the responses of species and ecosystems to disturbance. This chapter summarises information gained on the biodiversity of the South-West Forest Region from a range of projects undertaken for the Comprehensive Regional Assessment.

Data review

Biodiversity assessment relies on having adequate information about the distribution of species. In assessing the adequacy of available data, it is important to know whether or not surveys undertaken for species or groups of species have been adequately distributed across the range of environments represented within the region. As part of the CRA process, a data review was undertaken to determine where biodiversity surveys have been undertaken in the South-West Forest Region, which species were targeted and whether survey sites were reasonably distributed to detect most species in most geographic or environmental components. The results of these analyses assisted in highlighting gaps in information and identifying those areas which may require further survey work.

Ecosystem assessment

Mapped forest ecosystems (Bradshaw and Mattiske in prep.) have been derived as the basis for the forest ecosystem biodiversity assessment for the South-West Forest Region. These mapped forest ecosystems were defined following the recommendations of a Panel of Independents Scientists and Experts convened by the Western Australian RFA Steering Committee, and were developed from the forest associations mapping of Bradshaw et al. (1997) and the vegetation complex and ecological vegetation system mapping of Mattiske (in prep.). A full description of the forest ecosystems database, the methodology used in its derivation, and its application in the CRA biodiversity assessment is described in section 12.4 of this chapter.

The first part of the assessment involved mapping the forest ecosystems occurring in the south-west forests and determining the remaining area of each ecosystem. An analysis was also completed to determine the area of each forest ecosystem which occurred in the landscape prior to European settlement. This was used to provide an assessment of current and past distributions of each ecosystem and the level of protection within conservation reserves, so that an assessment against the JANIS reservation targets could be completed.

Target flora and fauna groups

Species which are threatened (endangered or vulnerable to extinction), declining in numbers, patchy in distribution, migratory or mobile, or unique to the region have been reviewed in this assessment. All nationally endangered or vulnerable forest species listed under the Commonwealth *Endangered Species Protection Act 1992* and known to occur in the region were considered a high priority, as were species declared as rare flora under the Western Australian *Wildlife Conservation Act 1950* and those designated as priority flora.

Vulnerability assessment

The degree to which a species is vulnerable to decline or extinction is influenced by a number of factors. These include characteristics or attributes of the species itself such as its habitat requirements, reproductive output and longevity. Other factors such as rarity and whether populations are increasing or decreasing are also important in determining the risk of decline or extinction. This information assists in identifying and prioritising those species which are most in need of management actions to improve the prospects for their long-term survival.

Reservation analysis

Reservation analysis is another component of the Comprehensive Regional Assessment. Essentially it is an analysis to identify the degree to which a species or vegetation community is known to be represented in dedicated and informal reserves (e.g. national parks, stream reserves) within the region. The results of such analyses can be used to assist in the identification of species and communities that require particular attention because of their special conservation needs. Conservation objectives can in some cases be met by increasing representation of populations and communities within reserves and/or minimising the impacts of threatening processes throughout the forested estate. Reservation analyses have been conducted for forest ecosystems and for selected fauna and flora taxa.

Endangered, rare and threatened species

The Western Australian RFA process requires a review of species listed on Schedule 1 of the Commonwealth *Endangered Species Protection Act 1992* and the preparation of recovery plans and threat abatement plans for threatening processes under the Act, to the extent possible within available funds and resources. State-listed species have also been identified and planning mechanisms will be implemented in accordance with State legislation, to the extent possible within available funds and resources.

Conservation statements will be prepared prior to the signing of the RFA for taxa which are listed as endangered or vulnerable on Schedule 1 of the *Endangered Species Protection Act*, as preparation of interim recovery plans will not be possible within the CRA process. Some flora taxa are currently addressed in Western Australian regional rare flora management programs and the development of recovery plans will be considered in the implementation of the RFA.

Response to disturbance

The decline of species can be attributed largely to the impacts of disturbances, both directly on the species and indirectly on essential components of their habitat. For example, predation of native animals by introduced species such as foxes and feral cats has a direct effect on population numbers. Habitat changes resulting from grazing by domestic stock, mining, fire, clearing for agriculture or other disturbances may also indirectly impact populations of native species. Reviews of the response of species and ecosystems to disturbance and the management arrangements currently in place to address these were prepared by consultants for the CRA (Table 12.2). These reports are available separately on request, and will be considered by governments in developing the Regional Forest Agreement for Western Australia. (The reports will also be available on the Internet – see page ii for addresses.)

Table 12.2 Consultants reports prepared for the CRA

Report	Authors
Ecosystem processes	B Lamont, M A Perez-Fernandez and R Mann
Vertebrate fauna (excluding fish)	P Christensen
Fish and aquatic invertebrates	P Horwitz, E J Jasinska, E Fairhurst and J A Davis
Terrestrial invertebrates	J D Majer and B E Heterick
Fungi	N Bougher
Flora	R Safstrom

12.3 DATA REVIEW

Introduction

The Western Australian biodiversity data review and evaluation process involved the identification of datasets relevant to biodiversity and national estate natural value assessments, collation of metadata and the broad scale evaluation of dataset quality. Approximately 250 datasets were identified from a range of sources, of which 37 were considered to be of value to these assessments. A copy of the data review is available on request and will be available on the Internet.

The primary aim of the data review process was to ascertain the adequacy of existing site-based biological data for determining the distribution of flora and fauna species, and relating this to their habitat requirements. Other information on species, communities and response to disturbance was also assessed. Outcomes from the review can also be used to identify data gaps and priority areas for additional survey work.

The first stage of the data review was identifying potentially useful data sets. Only those survey data which met required standards of accuracy, precision and reliability were used, providing a degree of confidence in the analyses of the distribution of species.

The second stage of the review involved assessing the extent to which the site records for flora and fauna were representative of the environmental and geographic variation within the region. This was addressed separately in the flora and fauna assessments.

12.4 FOREST ECOSYSTEMS

Defining and mapping forest ecosystems

The principal sources of information used in the mapping of forest ecosystems are forest associations and vegetation complexes.

Forest associations are based on work originally undertaken by the Forests Department of Western Australia in the 1950s and 1960s using 1:15 840 aerial photography and covered almost all of the forested land in the RFA area. Classification was based on the dominant tree species and crown cover density. “Non forest” areas were classified according to broad structural categories. This basic information has been refined and corrected by a variety of specific mapping projects since that time. These data were summarised and published at a scale of 1:250 000 (resolution two hectares) in 1997 in the form of forest associations. The methodology is described in detail by Bradshaw et al. (1997). The maps cover public land only.

Vegetation complex is a classification based primarily on understorey vegetation. Mapping is based mainly on land form, soils and climatic zones and their relationship to vegetation rather than direct mapping of the vegetation itself. The first mapping of this kind was carried out by Heddle et al. in 1980 for the Darling system (the northern part of the RFA). During 1997 this work was revised and extended to cover the whole of the RFA area including areas now cleared (Mattiske and Havel in prep.). This work is described in detail in the following section.

The JANIS criteria for forest ecosystems require a classification system which:

- discriminates forest from non-forest on the basis of 20% canopy cover;
- discriminates at a resolution requiring a map-standard scale of 1:100 000;
- preferably is defined in terms of floristic composition in combination with substrate and position in the landscape;
- is consistent with the examples given in the JANIS definition of forest ecosystems (i.e. Kirkpatrick and Brown (1991) for Tasmania, Beard (1979a, 1979b) for Western Australia, Young and McDonald (1989) for Queensland and ecological vegetation classes identified in Victoria);
- is recognisable in the field; and
- is able to mapped and able to have their pre-1750 distribution modelled or mapped.

A panel of independent scientific experts recommended that “forest ecosystems for use in the Western Australian RFA be developed by the subdivision (where appropriate) of the forest associations using the ecological vegetation system and other ecological and physical information as bases”.

The development of forest ecosystem categories was undertaken by Bradshaw and Mattiske in 1997. The key elements used in informing the decision on an appropriate subdivision of the associations were the key species in the overstorey (jarrah, karri, wandoo etc.), the height of the overstorey, the canopy cover of the overstorey (forest versus woodland) and the understorey vegetation communities which are primarily determined by a combination of climate, soils and landforms. The weighting attributed to each varied according to their perceived significance.

The outcome of this approach to subdivision is a sub-regionalisation within forest associations on boundaries derived from the grouping of several vegetation complexes.

The main emphasis was the subdivision of the large area of jarrah forest association. The approach described above resulted in a subdivision of the jarrah forest into 11 sub-regions based primarily on a combination of groupings of vegetation complexes and soil substrate. The karri forest was subdivided according to three broad regions of occurrence—the west coast, main karri belt and the south coast (most of which lies outside the RFA area). All complexes and associations were combined as one in the Darling scarp sub-region. Three other areas, representing small parts of a much larger group of ecosystems outside the RFA area were identified as sub-regions but not considered in further analysis. These are described as Swan coastal plain, Dandaragan Plateau, and western wheatbelt. While it is recognised that some associations (e.g. wandoo) occur beyond the RFA boundary, it is in general represented by different groupings of vegetation complex. The RFA boundary is therefore considered appropriate for what has been called western wandoo in this analysis. All other ecosystems (generally non-forest categories) are the same as in the classification of the forest associations. For familiarity, the forest ecosystems have been named according to dominant tree species and geographic location. See Table 12.3 for the list of forest ecosystems. Map 12 shows forest ecosystems on Crown land.

Table 12.3 Present reservation staus of forest ecosystems

Forest ecosystem	Estimated pre-1750 area (ha)	Extant area all lands (ha)	Proportion of pre-1750 reserved				Extant area on public land outside reserves (ha)	Estimated area on private land (ha)
			Gazetted formal	Proposed formal*	Informal	Total reserved		
Bullich and yate	2800	2440	53%	24%	0%	78%	2	261
Darling scarp	29000	9938	4%	0%	1%	6%	1825	6468
Jarrah Blackwood	347200	281805	2%	6%	8%	16%	212474	13016
Jarrah Leeuwin	56400	19552	4%	0%	1%	6%	6984	9237
Jarrah Mt Lindesay	126600	44591	2%	7%	1%	9%	18867	14306
Jarrah north-east	717100	350234	4%	8%	2%	15%	161663	84062
Jarrah north-west	670600	499598	7%	2%	6%	15%	346388	50611
Jarrah Rate’s tingle	1500	1246	63%	2%	0%	65%	96	177
Jarrah red tingle	350	269	30%	32%	0%	62%	13	40
Jarrah sandy	107900	71092	8%	13%	4%	25%	39008	5339
Jarrah south	557300	438912	8%	14%	7%	29%	260475	19052
Jarrah Unicup	81000	29459	6%	12%	0%	18%	2830	12093
Jarrah woodland	106374	67220	11%	8%	32%	50%	3109	10559
Jarrah yellow tingle	11600	9669	14%	1%	14%	29%	5125	1219
Karri main belt	193000	163905	19%	2%	15%	36%	84281	10000
Karri Rate’s tingle	1100	860	67%	0%	0%	67%	0	124
Karri red tingle	7200	5860	38%	32%	0%	70%	89	755
Karri south coast	18500	#						
Karri west coast	14500	6274	27%	2%	0%	30%	458	1500
Karri yellow tingle	15800	13264	14%	1%	14%	28%	7359	1423
Peppermint and coastal heath	80100	70826	67%	5%	0%	72%	2678	10447
Rocky outcrops	26400	12444	16%	7%	20%	43%	1066	0
Sand dunes	10300	10342	95%	2%	0%	97%	307	0
Shrub, herb, and sedgelands	429900	296955	20%	13%	25%	57%	16021	36191
Swamps	15300	8070	33%	2%	6%	42%	208	1415
Western wandoo forest	363200	146598	7%	7%	2%	16%	47854	41404
Western wandoo woodland	163000	72079	8%	7%	2%	17%	23018	20950

Notes: * proposed in Forest Management Plan 1994-2003
not analysed - more than 90% outside RFA region

Estimate of the pre-1750 area of forest ecosystems

Several of the JANIS targets require an estimate of the pre-1750 extent of the forest. An estimation of the pre-1750 extent of forest ecosystems has been done on the basis of the relationship that exists between forest ecosystems and vegetation complexes (on mapped extant areas on Crown land) and extrapolation to cleared areas for which vegetation complexes but not forest ecosystems have been mapped. Because there is no direct correlation between forest ecosystem and vegetation complex it was considered impractical to attempt to map forest ecosystems directly, or to model them in a spatial context.

A statistical extrapolation was undertaken to estimate the area of each ecosystem on private land (regardless of the current state of cover) and on cleared public land. This was then added to the area of existing ecosystems to determine the pre-1750 area. This was done using the following technique:

- Within each sub-region, “vegetation complex” and “forest ecosystem” were intersected in a geographic information system to determine the area of each ecosystem within each vegetation complex (see Table 12.3 for forest ecosystems). This determined the proportion of each vegetation complex by ecosystems for public land on which the original vegetation remains.
- The area of each vegetation complex attributed with a “non-native” ecosystem code was apportioned to a native forest ecosystem using the same proportions as found in the “native forest” attribution derived above. Approximately 45% of the RFA area was attributed in this way.
- The existing and the re-attributed areas were added to arrive at an estimate of the pre-1750 ecosystem area in each sub-region. Where appropriate, ecosystems from each sub-region were added to arrive at the total areas for the RFA area.

- The pre-European karri forest has been mapped directly and is published as *Karri Distribution Before European Settlement* at a scale of 1:350 000 (Bradshaw et al. 1997). For karri the attributed data were adjusted to agree with the mapped areas and differences were re-attributed to appropriate ecosystems. For the whole karri forest, the extrapolation method gave areas that were within 4% of the mapped pre-1750 area. Areas of sand dunes were adjusted in a similar fashion.

The estimated pre-1750 area of each ecosystem is shown in Table 12.3.

12.5 VEGETATION MAPPING

Introduction

Vegetation mapping is an important tool for the development of a comprehensive, adequate and representative (CAR) reserve system and prescriptions and practice for ecologically sustainable forest management (ESFM). While the mapping of forest ecosystems (see section 12.4) will be used in meeting the quantitative JANIS criteria for forest ecosystems and old growth in the CAR reserve system, other methods of vegetation mapping may provide additional information used in reserve design. High resolution vegetation mapping based on floristics, landscape and other ecological factors may also help, for example, to define areas of habitat for species of conservation significance. Mapping at the level of vegetation complexes and ecological vegetation systems for the CRA was undertaken by Mattiske (nee Heddle) and Havel (1997).

In the South-West Forest Region, it is well recognised that there are underlying patterns which determine the distribution of native vegetation cover. Studies by authors such as Havel (1975a and 1975b), Strelein (1988), Wardell-Johnson et al. (1989 and 1995) and Heddle et al. (1980) have highlighted the significance of the underlying soils, landforms and climate in the determining the patterning of vegetation in the region.

A review of past studies and floristic and vegetation classifications has been prepared by Mattiske Consulting Pty Ltd (1997) and Mattiske (nee Heddle) and Havel (1997) have developed a vegetation classification system that integrates all the previous relevant vegetation classification systems and vegetation mapping studies in the region. This methodology is based on the previous regional vegetation mapping by Heddle et al. (1980) in the Darling System (System 6) which includes the northern part of the RFA area and Havel (1968, 1975a and 1975b) on the northern Swan coastal plain and in the northern part of the Darling Range.

In mapping the vegetation of the RFA region, the concept of vegetation complexes developed in the northern Darling Range by Heddle et al. (1980) was expanded to cover the remainder of the RFA region. This approach emphasises the detailed local site vegetation type mapping which integrated details on site characteristics, floristic composition and structural composition achieved at the scale of 1:10 000 in specific areas and provides mapping for the region at a higher resolution than the lower resolution mapping of essentially structural components and dominant species by Beard (1979a, 1979b, 1979c, 1979d, 1981). The vegetation mapping covered both the remaining relatively intact native vegetation and the disturbed and/or cleared areas of vegetation in the South-West Forest Region.

Vegetation complexes

Given the dominance of the forest canopy in the South-West Forest Region by comparatively few species, the concept of a continuum of forest and woodland types based on the composition of the species-rich understorey was considered most applicable for mapping vegetation at the 1:50 000 scale. A key element in defining vegetation complexes is the strong relationship between the physical environmental features in the landscape, the climatic conditions and the vegetation.

The landscape of the south-west does not have major variations in relief compared with other forested areas of Australia. Local variations in water availability and the physical and chemical composition of the soils are key determinants of variations in the vegetation at a given site. Floristic differences due to the soils are largely reflected in the composition of the understorey, and variations due to water availability are largely reflected in the composition and structure of the tree overstorey which is detectable from aerial photos. These variations in species composition are readily detectable in the field by the presence of plant species typical for each soil/landform combinations and it is therefore possible to map the vegetation at a fine scale across the range of sites, from a combination of aerial photography and ground surveys.

The methods for the work were variable as this project enabled the integration of data from a large range of studies in the South-West Forest Region. Essentially the main methods were:

- floristic studies based on all species recorded in specific locations in varying assessment areas from 100 square metres to 10 000 square metres;
- site-vegetation type data based on site characteristics, indicator species or characteristic species from 100 square metres (understorey) and 1600 square metres (overstorey); and
- structural information from an assessment of the height and cover of overstorey species.

The principal sources of information used in the mapping of the vegetation complexes were:

- historical and collated new point source data, from more than 18 000 locations, collected by a range of authors and the consultants over the past 30 years;
- topographical and drainage data from the Department of Land Administration at a scale of 1:50 000;
- soil and landform mapping as collated and prepared by Smolinski et al. (1997) at a scale of 1:50 000 based on previous authors (1970 to 1997), where available;
- previous vegetation complex mapping by Heddle et al. (1980) for the Darling System (the northern section of the RFA area) reviewed and integrated at a scale of 1:50 000; and
- climatic data for the South-West Forest Region by Gentilli (1971, 1972, 1989) and the South-West Western Australia Climate Grids.

The total number of surveyed sites varied substantially between vegetation complexes as a result of the varying degree of clearing within the region and the area occupied by each vegetation complex. Although large areas of the region remain relatively undisturbed, in some places roadside vegetation and other remnants were important in defining vegetation characteristics. Any new survey sites established as part of the CRA data collection process avoided any recently burnt or grazed areas.

Soil and landform maps formed an important layer in the delineation of site selections and mapping types across the region. Aerial photo interpretation, the review of existing site data and the field survey data were then used to map the vegetation complexes.

The nomenclature followed the underlying soil and landform units to allow comparison with underlying determining soil types. Where climatic and regional differences were defined then numbers were also added to the mapping codes. For example, Dwellingup was subdivided into Dwellingup 1, Dwellingup 2, Dwellingup 3 and Dwellingup 4 or D1, D2, D3 and D4 on the basis of underlying differences in the dominance of overstorey species, the height of the overstorey, the cover of the overstorey and the composition of the understorey. This subdivision allowed for the recognition of the regional patterns of vegetation on the laterite gravel uplands from the western side of the Darling Range in the higher rainfall areas to the vegetation on the laterite gravel uplands on the eastern side of the Darling Range in the lower rainfall regions.

A total of 312 vegetation complexes was defined and mapped for the South-West Forest Region. In view of the degree of clearing in some sections of the survey area, the level of information collated for the respective complexes varied significantly within the project area. A full description of each of the vegetation complexes will be provided in a separate project report, which will be available on request.

Ecological vegetation systems

Mattiske and Havel have also developed a simplified vegetation classification system that integrates the vegetation complexes at a regional scale. For example, jarrah-marri forests with key indicator species for sandy soils found in per humid areas were grouped, as were all swamps in semi-arid climatic areas. This methodology differs from the mapping of forest associations by Bradshaw et al. (1997) through the reliance on underlying relationships between floristic composition and physical determinants such as soils, landforms and climate, rather than dominant species and structural vegetation mapped from aerial photographs.

The 306 vegetation complexes were grouped according to similarities in structure and floristic composition. This work resulted in an approximately four-fold reduction in the total number of vegetation mapping units. This latter work was based on a hierarchical system so that similar vegetation complexes were grouped into one ecological vegetation system. The number of vegetation complexes grouped into the ecological vegetation systems varied depending on the degree of similarity within and between the groups. This grouping was tested using statistical tests through the PATN package (Belbin 1987a, 1987b, 1989).

The nomenclature followed a new system developed by the authors as part of this project which enabled a grouping of vegetation categories with similar vegetation which reflected climatic and soil and landform patterns in the South-West Forest Region. The name adopted expressed in the simplest of terms the groupings at this system level.

This approach allowed a grouping at a higher level and allowed similar vegetation on similar soil and landform units within similar climatic zones to be defined. This process of grouping was similar to the ecological vegetation classes adopted in the East Gippsland project area (Woodgate et al. 1994). The key feature of the ecological vegetation systems is that it is a hierarchical system which links the similar vegetation complexes together for presentation at the broader scale of mapping (1:500 000).

12.6 FLORA SPECIES ASSESSMENT

Introduction

Assessment of the South-West Forest Region flora has involved analysing the distribution and viability of individual plant species and their populations in the region. The purpose of this assessment is to help address the JANIS criteria relating to protection of species (see section 12.1).

The assessment process involved the compilation and validation of flora data from a range of sources, the development of the new database (WABiota) and the analysis and display of various themes.

Data acquisition

Data were obtained from a variety of existing sources internal and external to CALM (see Tables 12.4 and 12.5). Records from these databases were incorporated into a new database for the CRA flora assessments called WABiota.

Table 12.4 CALM data sources for the flora species assessment

Source	Vouchered?	Records
WA Herbarium – WAHerb original records	Yes	36137
WA Herbarium – vouchered specimens from vegetation mapping	Yes	3954
WA Herbarium – voucher specimens from RFA flora surveys	Yes	9392
Floristic survey of the Tingle Mosaic (Wardell-Johnson et al. 1989, Wardell-Johnson et al. 1995)	Some	15056
Havel site-vegetation type bulletins (Havel 1975a, Havel 1975b)	Some	5126
CALM Threatened Flora Database	Some	2949
Banksia Atlas (Taylor and Hopper 1988)	No	2896
Total		**70384**

Table 12.5 Other data sources for the flora species assessment

Source	Records
Alcoa of Australia Ltd	19784
Worsley Alumina Pty Ltd	9864
Scott River National Park survey for BHP (Mattiske Consulting 1996)	637
Griffin Coal	1985
Water and Rivers Commission and Water Corporation	9862
John Forrest National Park and Red Hill Survey (Mattiske and Burbidge 1991)	745
Mt Westdale – Dobaberry Swamp (Trudgen 1984)	813
Per Christensen PhD data (Christensen 1980)	4662
RFA Vegetation mapping – Mattiske Consulting (Mattiske Consulting 1997a)	27334
Shire of Mundaring (Mattiske Consulting 1997b)	2016
Total	**82828**

Systematic flora surveys have occurred sporadically throughout the region, primarily for the purpose of vegetation mapping in certain localities. Gaps in the data and the relative intensity of sampling across the region were well known. Three major surveys in the RFA region were undertaken to address these gaps.

Flora surveys

Field collecting was undertaken with the aim of sampling every taxon of vascular plant present at 150 survey sites throughout the region, stratified by landscape unit and fire history. Voucher specimens of each species were collected in addition to information on phenology, degree of flowering, presence of seed capsules, survival of plants from year to year and, importantly, age since last fire.

There were 13 410 voucher specimens collected and 11 009 of these were databased for incorporation into WABiota. The remaining 2401 voucher specimens were cryptogams (mosses and lichens) which will be identified at a later date.

Vegetation mapping surveys

Voucher specimens for about 4000 vascular plant species collected during the fieldwork for the *Mapping of Vegetation Complexes in the South-West Forest Region of Western Australia* project (see section 12.5) were lodged at the Herbarium. These data were incorporated into WAHerb and ultimately WABiota. Additional vascular plant species data (unvouchered) were provided from a range of sources, including a number of mining companies and other agencies.

Survey of threatened taxa

Surveys of threatened flora focused on taxa listed as declared rare flora (DRF) under Western Australia's *Wildlife Conservation Act 1950* or designated as priority species (P1, P2, P3, P4). Populations of DRF within the RFA region were field inspected to confirm their location and record current population details and other relevant information. Opportunistic surveys were also conducted for listed priority flora known to occur in areas containing DRF and specifically for priority flora under consideration for recommendation to be listed as DRF.

Altogether, 191 DRF populations from within the RFA region were surveyed during two periods in the springs of 1996 and 1997. Another 19 priority flora populations were also surveyed. The resultant data were entered in the CALM Threatened Flora Database.

Priority flora data entry

Data entry for priority flora previously collected, but not captured digitally, was undertaken as part of the endangered species assessment project. A total of 1476 priority flora data records from field survey sheets was added to the CALM Threatened Flora Database.

Development of WABiota

WABiota is essentially a warehouse of flora data obtained from a variety of sources internal and external to CALM. It was designed to contain not only individual site and specimen flora and fauna records but also taxonomic information and a variety of species-level attributes.

The database is structured to enable the updating of any given portion of the database from a recognised source such as WAHerb or the Threatened Flora Database. The nomenclature for the majority of taxa has been taken from WACensus, an authoritative database of names acceptable to the WA Herbarium, the relevant data custodian.

Data captured

A total of 153 212 vouchered and non-vouchered flora records (3244 taxa) were warehoused in WABiota from a range of sources internal and external to CALM.

Validation of WABiota records

The initial data validation involved removal of records which were:

- outside the RFA region;
- obviously misidentified; or
- exotic species.

Records with non-current names were also excluded.

A method for prioritising the validation of geocodes was developed using climatic attributes and BIOCLIM (McMahon et al. 1995) to identify potential outliers as targets for validation. This approach was required because the large number of points within WABiota meant a detailed analysis was not possible.

Using BIOCLIM, for each point in WABiota, 35 climatic parameters were evaluated and summary statistics calculated. A test was then applied to determine the extent to which the climatic parameters for each of the individual points were within the environmental envelope described by the points as a whole. Points for which a given climatic attribute was more than two standard deviations outside the mean of that parameter were then checked manually and WABiota was updated to reflect the validated coordinates. Records from other data sources were not validated any further as this was beyond the scope of the project.

A total of 5086 records was validated in this manner. Of these, 1752 existing geocodes were validated as being correct and 3334 records required a new geocode to be calculated. The data were then used to update the main WAHerb database records.

Attribution of taxa for conservation significance

Of the 3244 native flora taxa found within the RFA region, 72 are declared rare flora under Western Australia's *Wildlife Conservation Act* and 390 are designated as priority flora. These include 52 taxa also listed under Schedule 1 of the Commonwealth *Endangered Species Protection Act (ESP Act).* The declared rare flora are generally recommended for inclusion in Schedule 1 of the *ESP Act*, but this schedule has not been updated since 1994, and there is a disparity between the two lists. The schedule of declared rare flora is updated annually. Western Australian codes used to attribute conservation significance for all taxa are shown in Table 12.6.

Table 12.6 Categories of flora listed under Western Australia's Wildlife Conservation Act 1950 and those designated as priority flora by CALM

Category	Definition
Declared Rare Flora – extinct taxa	Taxa which have not been collected or otherwise verified over the past 50 years despite thorough searching, or of which all known wild populations have been destroyed more recently.
Declared Rare Flora – extant taxa	Taxa which have been adequately searched for and are deemed to be in the wild either rare, in danger of extinction or otherwise in need of special protection.
Priority One – poorly known taxa	Taxa which are known from one or a few (generally <5) populations which are under threat.
Priority Two – poorly known taxa	Taxa which are known from one or a few (generally <5) populations, at least some of which are not believed to be under immediate threat (i.e. not currently endangered).
Priority Three – poorly known taxa	Taxa which are known from several populations, at least some of which are not believed to be under immediate threat (i.e. not currently endangered).
Priority Four – rare taxa	Taxa which are considered to have been adequately surveyed and which, while being rare (in Australia), are not currently threatened by any identifiable factors.

Other taxa were attributed as candidates for JANIS reserve selection target groups. This included 350 taxa identified as narrow endemics (restricted to a range of less than 150 kilometres), 134 taxa with disjunct populations found within the study area and 85 taxa which were considered as primitive or relictual. A total of 726 taxa reach their distributional limits within the region, but the lack of systematic flora surveys across the entire region makes it difficult to determine the importance of these records for the analysis and protection of biodiversity, and they were used only to inform the analyses.

Species prediction modelling

It is recognised that large portions of the RFA region are under-sampled within existing databases while comparatively large numbers of records exist for some particular areas which have been the subject of intensive research. These sampling biases in the region can be overcome to some extent by predicting the distribution of species using computer-based models.

The SpModel software package (Ferrier and Watson 1996) was used to generate predicted distributions for each species within WABiota. Only vascular non-weed flora with current nomenclature were modelled. SpModel required a minimum of 10 point locations for any given species. This reduced the candidates for modelling from more than 3000 species to more than 2000 species.

SpModel has the capability to model using Generalised Linear Model (GLM) or generalised Additive Model (GAM). GLM was adopted in the South-West Forest Region species modelling as an acceptable compromise between processing time and confidence in the model in recognition that:

- the data to be modelled were primarily presence-only data due to the large proportion of opportunistic records;
- many of the historical records require caution regarding geocodes; and
- the increased requirement of processing time by GAM over GLM would have substantially extended the processing of the large number of taxa.

The spatial predictor variables for SpModel can include continuous surfaces such as climatic attributes or categorical variables such as geology or vegetation. A range of predictor variables was assessed for their potential use within the modelling process. A suitable subset of climatic parameters was chosen that incorporated temperature, precipitation and radiation levels at both annual and seasonal levels, aspect, slope, geology (regolith and Precambrian), forest ecosystems and ecological vegetation systems. The ecological vegetation system grid is a higher level classification of the vegetation complex database compiled as part of the "Mapping of Vegetation Complexes in the South-West Forest Region of Western Australia" project (see section 12.5).

Grids of these parameters were generated on a longitude/latitude base at a resolution of nine seconds of arc. This scale was determined by the resolution of the Digital Elevation Model (DEM).

Outputs from species prediction modelling

Distribution models were generated for 2202 current, native species occurring within the RFA region. Records were aggregated at the species level for processing by SpModel. Distribution maps were printed for each species and assessed for suitability.

The most common predictors for distribution were climatic surfaces, followed by slope and geology. The most common climatic surfaces employed by the model were those incorporating some aspect of seasonality in temperature and precipitation. Very occasionally forest ecosystems were used by the model.

Each model output was statistically analysed to assess whether the prediction was realistic. Unacceptable prediction maps, usually those over-predicting possible species distribution by about 25%, were omitted.

Botanical experts were asked to validate the prediction maps for families or genera with which they were familiar. These botanists included Neville Marchant (*Agonis*, *Calothamnus*, *Chamelauceum*, *Darwinea*, *Drosera*), Bruce Maslin (*Acacia*), Andrew Brown (*Orchidaceae*), Terry MacFarlane (*Amphipogon*, *Austrostipa*, *Stipa*, *Lomandra*), Ray Cranfield (various taxa) and Mike Hislop (various taxa).

Models were also compared against independently compiled distribution maps in Churchill (1961).

After assessment, 263 models were rejected because the model did not reflect true or likely distribution, leaving a total 1929 acceptable models.

Species richness modelling

Models accepted as valid were used to generate a species richness prediction map. A one kilometre grid was selected as suitable on the basis of the nine seconds (270 metres) unit for base data used to generate the predicted distributions and the minimum level of accuracy required by the integration and planning phases of the RFA process, noting that there is a large number of existing CALM reserves less than 100 hectares in area.

The number of species within one by one kilometre grids were counted across the entire RFA region. Counts for all taxa and for endemic taxa were generated and maps at 1:500 000 were generated for endemic taxa and for all taxa.

Several areas of high species richness were predicted, including the Leeuwin-Naturalist ridge, the Blackwood River plateau, the south coast and to a lesser extent the Darling scarp east of Perth (Map 5).

The species richness prediction maps were checked in a number of ways including sampling of raw data from WABiota and consultation with the experienced botanists including Neville Marchant, Greg Keighery, Libby Mattiske and Roger Hearn. All of these botanists agreed with the general species richness patterns. They also agreed that the very high species richness around the Blackwood River plateau is of scientific note, however, and warrants further investigation.

Species vulnerability assessment

A review of the reservation status of declared rare flora (DRF) and priority flora from the Threatened Flora Database has been undertaken (Table 12.7).

The purpose of the vulnerability assessment was to identify plant species of conservation significance that are likely to be at higher risk of decline or extinction. The assessment of risk considered the proportion of the geographic range of each species within the south-west forests, the narrowness of habitat requirements, current estimated population sizes, and susceptibility to threatening processes or natural catastrophic events. Species which have low overall number of records in the region, few records from elsewhere in Australia, narrow habitat requirements and most of their records from outside the reserve system are regarded as most likely to be of concern.

Reservation analysis for declared rare flora and priority flora

The CALM Threatened Flora Database was analysed using the most recent survey data for each population to provide a summary of the reservation status of each DRF or priority flora taxon with part or all of its known distribution within the RFA region.

Data were analysed for total populations, plus sub-populations occurring on land vested in the National Parks and Nature Conservation Authority (NPNCA—primarily national parks and nature reserves), the Lands and Forest Commission (LFC—primarily State forest), local authorities (Shire—primarily road reserves) and private property (Private). These four categories were chosen as being the main land tenures containing rare flora in the RFA area. Other populations occur on other tenures of Crown land, such as main roads, water reserves and unvested Crown reserves. Data were extracted as the number of (sub)populations and plants present in each category.

Sub-populations are defined where a population is split over different land tenures, or is separated by a distance that results in separate management being undertaken, but is still essentially the same population for the species. Population size estimates are provided for those taxa where the most recent survey records the number of individual plants.

It must be noted that for priority flora taxa in the Southern Forest Region (only), no data were entered for distributions outside the RFA region. This must be taken into consideration in any evaluation of the reservation status of these taxa.

Tables 12.8 to 12.12 provide information on the reservation status of DRF and priority flora found within the South-West Forest Region.

Map 15 shows the known locations of declared rare flora in the South-West Forest Region.

Endangered, rare and threatened vascular flora

The current list of declared rare flora and taxa listed on Schedule 1 of the *Endangered Species Protection Act* were reviewed to determine those taxa which had specific management actions documented for their protection. They include:

- critically endangered taxon (*Caladenia winfieldii*) with a published interim recovery plan;
- critically endangered taxa with interim recovery plans in preparation;
- taxa recommended for reclassification as critically endangered by the Threatened Species Scientific Committee, and hence will have interim recovery plans prepared; and
- taxa currently addressed in regional rare flora management programs.

A further species, *Leptomeria dielsiana*, was also omitted as it is known only from a herbarium specimen, and hence no information is available on which to prepare a conservation statement.

Altogether, 36 taxa (Table 12.7) which are listed as endangered or vulnerable on Schedule 1 of the *Endangered Species Protection Act*, require the preparation of interim recovery plans. As preparation of interim recovery plans was not possible within the CRA process, conservation statements will be prepared prior to the signing of the RFA. These taxa are currently addressed in regional rare flora management programs and the preparation of interim recovery plans will be addressed in the implementation of the RFA.

Table 12.7 ESP listed flora, without interim recovery plans, for which conservation statements will be prepared prior to the signing of the RFA and the development of interim recovery plans will be addressed in the implementation of the RFA

Acacia anomala	*Dryandra nivea* subsp. *uliginosa*
Acacia aphylla	*Grevillea flexuosa*
Anthocercis gracilis	*Kennedia glabrata*
Asterolasia grandiflora	*Kennedia macrophylla*
Asterolasia nivea	*Lambertia orbifolia*
Banksia verticillata	*Laxmannia jamesii*
Brachysema modestum ms	*Lechenaultia laricina*
Caladenia christineae ms	*Lechenaultia pulvinaris*
Caladenia dorrienii	*Meziella trifida*
Caladenia excelsa ms	*Microtis globula*
Caladenia harringtoniae ms	*Pimelea rara*
Chamelaucium roycei ms	*Pleurophascum occidebtale*
Corybas limpidus	*Pultenaea pauciflora*
Darwinia acerosa	*Restio chaunocoleus*
Darwinia apiculata	*Spirogardnera rubescens*
Darwinia ferricola ms	*Tetraria australiensis*
Drosera fimbriata	*Thelymitra stellata*
Dryandra mimica	*Verticordia fimbrilepis* subsp. *australis*

Responses to disturbance

Reviews of the responses to disturbance of vascular flora and fungi were undertaken by Safstrom and Lemson (1997) and Bougher (1997) for the CRA. These reviews gathered information, through literature searches and consultation with experts, on the responses to disturbance of individual species. These reports are available separately on request, and will be considered by governments in developing the Regional Forest Agreement for Western Australia. (They will also be available on the Internet – see page ii for addresses.)

The RFA region contains 462 taxa of conservation significance. The review was restricted to declared rare flora under Western Australia's *Wildlife Conservation Act* and those designated as priority 4 species. Of these species, information was readily available for 49 taxa, comprising 43 DRF and six priority 4 taxa. Other priority taxa are classified as poorly known and did not have sufficient data available to provide reliable information.

Attention in the review was given to human induced disturbances which alter ecosystem processes, such as fuel reduction burning or soil disturbance in roading operations, rather than natural periodic or stochastic disturbances, such as lightning induced fire or severe drought, which have been part of the evolutionary history of the south-west vegetation. The study recognised that:

- single disturbance events have different impacts from either repeated disturbances and combinations of disturbances;
- combinations of human induced and natural disturbances can have severe impacts; and
- some combinations of disturbances have cumulative self-reinforcing impacts, such as repeated fire encouraging weed invasion which in turn increases fuel load and thus encourages more frequent burning.

A disturbance can be evaluated in relation to the following factors:

- the extent of its occurrence in the South-West Forest Region;
- any other potentially threatening processes associated with it;
- the strength of association between threatening processes;
- the significance of the threats posed;
- attributes of flora that might predispose them to negative impacts from the threat (e.g. due to their ecology, life history or life form);
- attributes of flora that might provide potential resilience to potential impacts from a disturbance;
- taxa likely to suffer negative impacts due to the threat; and
- management, including policies and processes, to reduce impacts of the threat.

Western Australia's *Wildlife Conservation Act* affords special protection to DRF, requiring Ministerial permission to collect these taxa and controlling impacts from timber harvesting, burning, road building and other activities. Some taxa are in need of active management and the review by Safstrom and Lemson (1997) provides a summary of threatening processes to inform management actions.

Table 12.8 The occurrence of declared rare flora within and outside the Western Australian RFA area and within major land vestings

Species name (ESP status)	RFA	Total Pops	Total Plants	NPNCA Pops	NPNCA Size	LFC Pops	LFC Size	Shire Pops	Shire Size	Private Pops	Private Size
Acacia anomala (V)	Y	13	10965	3	167	5	10556	9	55	13	187
Acacia aphylla (V)	N	7	2394	0	0	0	0	1	23	11	679
	Y	8	3023	4	822	5	99	0	0	1	102
Anigozanthos humilis subsp.	N	8	714	2	150	0	0	7	124	1	50
chrysanthus (V)	Y	3	3443	2	3019	0	0	3	27	3	397
Anthocercis gracilis (E)	N	1	1300	0	0	0	0	0	0	1	1300
	Y	7	2905	2	0	4	470	0	0	3	2026
Aponogeton hexatepalus (V)	N	24	23022	1	2000	4	430	10	1697	19	6084
	Y	1	4500	0	0	1	4500	0	0	0	0
Asterolasia grandiflora (V)	N	2	1659	5	1508	0	0	1	20	1	131
	Y	6	6633	3	5582	0	0	4	1001	6	50
Asterolasia nivea (V)	Y	7	1286	4	488	1	692	0	0	1	7
Banksia goodii	N	20	2256	12	900	0	0	9	191	6	1165
	Y	7	184	0	0	4	117	5	66	1	1
Banksia verticillata (V)	N	27	3778	24	1322	0	0	0	0	0	0
	Y	3	11801	3	11200	0	0	0	0	0	0
Brachysema modestum	Y	2	1100	0	0	2	1100	0	0	0	0
Caladenia bryceana subsp.	N	4	151	7	109	0	0	0	0	4	42
bryceana (V)	Y	1		1	0	0	0		0	0	0
Caladenia busselliana (E)	Y	2	63	0	0	0	0	2	0	0	0
Caladenia christineae (V)	N	1	0	0	0	0	0	0	0	1	0
	Y	10	184	0	0	4	4	0	0	1	0
Caladenia dorrienii (V)	N	3	0	1	0	0	0	0	0	2	0
	Y	6	142	0	0	6	102	1	0	1	40
Caladenia excelsa (V)	Y	14	96	6	16	0	0	1	1	4	38
Caladenia harringtoniae (V)	N	2	30	0	0	1	30	1	0	0	0
	Y	28	359	4	26	20	285	4	0	1	43
Caladenia huegelii (V)	N	28	381	2	8	0	0	9	47	17	263
	Y	11	56	7	46	0	0	2	10	1	0
Caladenia viridescens (E)	N	3	24	0	0	0	0	4	24	0	0
	Y	1	30	0	0	0	0	0	0	0	0
Caladenia winfieldii	Y	1	0	0	0	1	0	0	0	0	0
Centrolepis caespitosa (X)	N	3	7	1	7	0	0	1	0	1	0
	Y	1	200	0	0	0	0	0	0	0	0
Chamelaucium roycei (V)	N	11	2274	1	111	0	0	4	1351	2	3
	Y	4	116	0	0	0	0	2	22	1	20
Corybas limpidus (V)	N	3	5100	1	0	0	0	1	0	0	0
	Y	1	35	1	35	0	0	0	0	0	0
Darwinia acerosa (V)	N	4	1588	0	0	0	0	2	57	2	1530
	Y	4	15300	0	0	0	0	0	0	7	15300
Darwinia apiculata (E)	Y	2	2350	2	210	0	0	0	0	0	0
Darwinia ferricola (E)	Y	3	12675	1	1100	0	0	3	100	7	11475
Diuris drummondii (V)	N	1	75	0	0	0	0	0	0	0	0
	Y	10	335	6	230	2	5	2	21	1	20
Diuris micrantha (E)	N	4	540	1	20	0	0	1	20	1	0
	Y	2	100	0	0	0	0	1	50	0	0
Drakaea confluens (V)	N	2	3	2	3	0	0	0	0	0	0
	Y	4	30	1	3	0	0	0	0	2	27
Drakaea elastica (V)	N	23	1143	8	584	0	0	6	40	18	483
	Y	2	0	0	0	0	0	0	0	1	0
Drakaea micrantha (V)	N	6	8	1	0	0	0	0	0	2	3
	Y	10	170	0	0	11	130	0	0	1	40
Dryandra mimica (E)	N	2	26	0	0	0	0	0	0	4	26

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Species name (ESP status)	RFA	Total Pops	Total Plants	NPNCA Pops	NPNCA Size	LFC Pops	LFC Size	Shire Pops	Shire Size	Private Pops	Private Size
	Y	1	100	0	0	1	100	0	0	0	0
Dryandra nivea subsp. *uliginosa*	N	6	599	1	0	1	100	4	159	0	0
	Y	7	325	1	0	1	100	2	110	1	100
Eucalyptus goniantha subsp. *goniantha*	N	24	7272	6	136	0	0	9	145	12	3591
	Y	1	50	1	50	0	0	0	0	0	0
Eucalyptus graniticola (E)	Y	1	1	0	0	1	1	0	0	0	0
Grevillea flexuosa (E)	Y	4	2619	12	754	0	0	4	193	19	1642
Hydrocotyle lemnoides (V)	N	1	11015	0	0	0	0	0	0	2	1000
	Y	6	44100	4	39100	1	5000	0	0	1	0
Kennedia glabrata (V)	N	3	25	4	25	0	0	0	0	0	0
	Y	5	281	4	279	3	2	0	0	0	0
Kennedia macrophylla (V)	Y	4	103	1	15	0	0	3	75	2	13
Lambertia orbifolia (E)	Y	7	7797	2	233	0	0	2	77	10	7487
Laxmannia jamesii (V)	N	11	235	5	3	0	0	2	122	1	0
	Y	7	233	2	50	4	150	0	0	0	0
Lechenaultia laricina (V)	N	3	58	0	0	0	0	2	9	2	40
	Y	5	1458	6	1359	1	3	1	96	0	0
Lechenaultia pulvinaris (V)	N	19	483	11	37	0	0	2	5	8	366
	Y	5	2855	3	1713	17	1142	0	0	0	0
Meziella trifida (E)	Y	1		0	0	1	0	1	0	0	0
Microtis globula (V)	N	3	1100	4	950	0	0	0	0	1	150
	Y	3		3		0	0	0	0	0	0
Pimelea rara (E)	Y	12	123	0	0	20	123	0	0	0	0
Pultenaea pauciflora (E)	N	3	100	0	0	1	19	1	52	0	0
	Y	16	10927	8	4318	18	6609	0	0	0	0
Restio chaunocoleus	N	2	11000	2	8700	0	0	2	2300	2	0
	Y	1	500	0	0	0	0	1	250	1	250
Rulingia sp. Trigwell Bridge	Y	1	4	0	0	0	0	0	0	1	4
Schoenus natans (X)	N	7	19403	2	600	1	10000	2	7100	0	0
	Y	2		0	0	2		0	0	0	0
Sphenotoma drummondii	N	11	595	10	594	0	0	0	0	0	0
	Y	1		1		0	0	0	0	0	0
Spirogardnera rubescens (V)	N	5	201	2	7	0	0	6	194	0	0
	Y	3	71	0	0	0	0	2	8	2	43
Tetraria australiensis (X)	N	5	2400	3	1200	0	0	0	0	3	1200
	Y	2	300	0	0	0	0	1	100	0	0
Thelymitra dedmaniarum (E)	Y	23	1204	20	607	11	488	5	18	3	91
Thelymitra stellata (V)	N	14	47	8	27	0	0	2	5	1	0
	Y	12	33	1	7	0	0	10	26	0	0
Verticordia fimbrilepis. subsp *australis* (E)	N	2	0	0	0	0	0	1	0	1	0
	Y	1	1000	0	0	1	1000	0	0	0	0
Verticordia fimbrilepis. subsp *fimbrilepis*	N	8	92	0	0	0	0	9	92	0	0
	Y	1		0	0	0	0	0	0	0	0
Verticordia plumosa var. ananeotes (E)	Y	2	260	0	0	0	0	2	260	0	0

Notes: 1 Population numbers within the different vestings are for subpopulations and may thus sum to more than the total number of populations.

2 Number of plants is that recorded at the last survey, and may be none where specific plant counts were not undertaken (e.g. herbarium collections).

Table 12.9 The occurrence of Priority 1 flora within and outside the Western Australian RFA area and within major land vestings

Species name (ESP status)	RFA	Total Pops	Total Plants	NPNCA Pops	NPNCA Size	LFC Pops	LFC Size	Shire Pops	Shire Size	Private Pops	Private Size
Acacia brachypoda	N	4	733	0	0	0	0	0	0	4	1400
	Y	1	215	1	215	0	0	0	0	0	0
Acacia chapmanii subsp. *australis*	Y	1	100	1	100	0	0	0	0	0	0
Acacia lasiocarpa var. bracteolata	Y	1	1000	0	0	0	0	0	0	0	0
Acacia lateriticola glabrous	N	1		0	0	0	0	1		0	0
variant (BR Maslin 6765)	Y	1		1		0	0	0	0	0	0
Adenanthos cygnorum subsp. *chamaephyton*	Y	11	780	2	900	1	100	6	370	1	0
Andersonia macronema	Y	3	1000	0	0	3	1000	0	0	0	0
Andersonia sp. Collis Rd (G Wardell-Johnson GWJ5A)	Y	1	300	0	0	1	300	0	0	0	0
Andersonia sp. Ironstone	N	1		0	0	0	0	1	0	0	0
(BJ Keighery & N Gibson 227)	Y	3	1000	0	0	2	1000	1	0	1	0
Andersonia sp. Mitchell River (BG Hammersley 925)	Y	7	1530	0	0	7	1230	1	300	0	0
Asteridea gracilis	N	3		0	0	0	0	1	0	0	0
	Y	2		0	0	1	0	1	0	0	0
Baeckea sp. Chittering (RJ Cranfield 1983)	Y	2	400	0	0	0	0	0	0	2	400
Baeckea sp. Darling Range (RJ Cranfield 1673)	Y	3	8	0	0	0	0	1	8	0	0
Boronia exilis	Y	1	100	0	0	0	0	1	100	0	0
Boronia humifusa	Y	2		0	0	0	0	2		0	0
Caladenia caesarea subsp. *transiens*	Y	2	65	0	0	0	0	0	0	0	0
Caladenia evanescens	Y	1		0	0	0	0	1		0	0
Caladenia longicauda	N	5	81	1	0	0	0	3	80	0	0
subsp. *clivicola*	Y	2		0	0	1	0	1	0	0	0
Caladenia uliginosa subsp. *patulens*	Y	2	2	0	0	0	0	2	2	0	0
Calothamnus sp. Whicher	N	6	200	0	0	1	100	5	100	0	0
(BJ Keighery & N Gibson 230)	Y	2	150	0	0	1	50	1	100	1	0
Calytrix simplex subsp. *simplex*	Y	1		0	0	1		0	0	0	0
Carex tereticaulis	N	1		0	0	0	0	1		0	0
	Y	2		0	0	0	0	1	0	0	0
Chordifex jacksonii	N	1		1		0	0	0	0	0	0
	Y	10	150	1	0	5	150	2	0	0	0
Conospermum caeruleum subsp. *contortum*	Y	1		0	0	0	0	0	0	0	0
Cryptandra arbutiflora var. *pygmaea*	Y	1	220	0	0	2	220	0	0	0	0
Daviesia elongata subsp. *elongata*	Y	5	914	0	0	4	912	0	0	0	0
Dryandra squarrosa subsp.	N	5	393	0	0	2	0	3	300	4	23
argillacea	Y	5	1450	0	0	3	1300	0	0	2	100
Eriochilus scaber subsp. *orbifolia*	Y	2		3		0	0	0	0	0	0
Eryngium sp. Lake Muir (E Wittwer 2293)	Y	1		0	0	0	0	0	0	0	0
Eucalyptus lane-poolei var. Whicher (SD Hopper 6316)	Y	1		0	0	1		0	0	0	0
Eucalyptus loxophleba x	N	10	8	2	1	0	0	6	4	1	2
wandoo	Y	1	3	0	0	0	0	1	2	0	0
Genus sp. Shannon (PG Wilson 1237B)	Y	1		1		0	0	0	0	0	0
Goodenia arthrotricha	N	2	100	1	100	0	0	0	0	1	0
	Y	2		0	0	0	0	1	0	1	0
Grevillea althoferorum	N	1	100	0	0	0	0	1	100	0	0
	Y	1	30	1	30	0	0	0	0	0	0
Grevillea corrugata	Y	1		0	0	0	0	1		0	0

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Species name (ESP status)	RFA	Total Pops	Total Plants	NPNCA Pops	NPNCA Size	LFC Pops	LFC Size	Shire Pops	Shire Size	Private Pops	Private Size
Grevillea manglesii subsp. *dissectifolia*	Y	1		0	0	0	0	0	0	0	0
Grevillea rara	Y	5	1271	0	0	2	1001	2	120	0	
Grevillea sp. Scott River (GJ Keighery 4070)	Y	5	1150	0	0	0	0	4	150	0	0
Hakea sp. Williamson)	N	4	217	0	0	2	130	3	87	0	0
(BJ Keighery & N Gibson 226	Y	3	1100	0	0	2	1000	1	100	0	0
Jacksonia sp. Collie (CJ Koch 177)	Y	1		0	0	1		0	0	0	0
Johnsonia inconspicua	Y	5		0	0	3	0	1	0	0	0
Leucopogon florulentus	N	6		1	0	0	0	3	0	0	0
	Y	1		0	0	0	0	0	0	0	0
Microcorys longifolia	N	3	21	0	0	0	0	1	0	0	0
	Y	1		0	0	0	0	1		0	0
Nemcia alternifolia	Y	1	3	0	0	0	0	1	3	0	0
Nemcia cyanophylla	Y	1		0	0	0	0	1		0	0
Nemcia sparsa	Y	1		0	0	0	0	0		0	1
Philydrella pygmaea subsp. *minima*	Y	1		1		0	0	0	0	0	0
Pterostylis turfosa	N	4	200	4	200	0	0	0	0	0	0
	Y	13	320	9	220	4	100	0	0	0	0
Spyridium riparium	Y	5	1603	0	0	2	203	3	1400	0	0
Stenanthemum intropubens	Y	1		0	0	0	0	0		0	1
Stenanthemum nanum	Y	2		0	0	2		0	0	0	0
Stylidium marradongense	Y	1		0	0	2		0	0	0	0
Synaphea decumbens	Y	1		0	0	1		0	0	0	0
Synaphea incurva	N	1		0	0	0	0	0	0	0	0
	Y	2		0	0	2		0	0	0	0
Synaphea intricata	Y	9		0	0	9		0	0	0	0
Synaphea macrophylla	Y	1		0	0	0	0	0		0	1
Synaphea nexosa	Y	1		0	0	0	0	1		0	0
Synaphea odocoileops	N	2	20	0	0	0	0	1	0	0	0
	Y	1		0	0	1		0	0	0	0
Synaphea otiostigma	Y	2		0	0	1	0	0	0	0	0
Synaphea panhesya	N	1		0	0	0	0	1		0	0
	Y	1		0	0	0	0	0	0	0	0
Thomasia laxiflora	Y	4		0	0	4		0	0	0	0
Tripterococcus sp. Cannington	N	9	610	0	0	0	0	2	10	5	598
(AS George 16201)	Y	1	5	0	0	1	5	0	0	0	0
Verticordia endlicheriana var. *angustifolia*	Y	5	13000	0	0	4	12000	1	1000	0	0
Verticordia plumosa var.	N	4	501	0	0	0	0	4	501	0	0
pleiobotrya	Y	1		1		0	0	0	0	0	0
Verticordia plumosa var.	N	6	2156	1	1016	0	0	9	763	0	0
vassensis	Y	4	2476	0	0	0	0	7	1476	0	0

Notes: 1 Population numbers within the different vestings are for subpopulations and may thus sum to more than the total number of populations.

2 Number of plants is that recorded at the last survey, and may be none where specific plant counts were not undertaken (e.g. herbarium collections).

Table 12.10 The occurrence of Priority 2 flora within and outside the Western Australian RFA area and within major land vestings

Species name (ESP status)	RFA	Total Pops	Total Plants	NPNCA Pops	NPNCA Size	LFC Pops	LFC Size	Shire Pops	Shire Size	Private Pops	Private Size
Acacia browniana var. *glaucescens*	Y	6		0	0	1	0	0	0	0	0
Acacia campylophylla	N	8	85	0	0	3	75	1	10	1	0
	Y	2		0	0	1	0	0	0	0	0
Acacia cuneifolia	N	2	20	1	20	0	0	0	0	1	0
	Y	11	2108	11	1069	4	988	0	0	2	51
Acacia gemina	N	4		3	0	1	0	0	0	0	0
	Y	5		0	0	5		0	0	0	0
Acacia mooreana	N	1		0	0	0	0	0	0	1	
	Y	28	29	1	0	19	29	0	0	3	0
Acacia oncinophylla subsp.	N	1	5	1	5	0	0	0	0	0	0
patulifolia	Y	5	38	0	0	0	0	3	16	0	0
Acacia subracemosa	Y	9	1	4	0	1	1	1	0	0	0
Actinotus sp. Walpole (JR Wheeler 3786)	Y	8		4	0	4	0	0	0	0	0
Actinotus whicherae	Y	3	300	0	0	3	300	0	0	0	0
Alexgeorgea ganopoda	Y	9	33100	4	20500	5	12500	0	0	0	0
Amperea micrantha	N	1		1		0	0	0	0	0	0
	Y	1		1		0	0	0	0	0	0
Amperea protensa	N	5	4	3	2	0	0	1	2	0	0
	Y	12	20	9	10	2	10	0	0	1	0
Andersonia annelsii	Y	1	1000	0	0	1	1000	0	0	0	0
Andersonia auriculata	N	3		2	0	0	0	1	0	0	0
	Y	8	723	3	100	0	0	4	111	1	12
Anthocercis sylvicola	Y	4	2400	4	2400	0	0	0	0	0	0
Astartea sp. Mt Johnston (AR Annels 5645)	Y	2		0	0	2		0	0	0	0
Astroloma foliosum	N	1		0	0	0	0	1		0	0
	Y	8	10	0	0	0	0	4	5	1	0
Billardiera sp. Walpole	N	2	100	1	0	0	0	2	100	0	0
(AR Annels 277)	Y	6	550	2	0	3	550	0	0	0	0
Boronia capitata subsp.	N	4		1	0	2	0	0	0	0	0
gracilis	Y	2		0	0	2		0	0	0	0
Borya longiscapa	N	1	2000	0	0	1	2000	0	0	0	0
	Y	11	10800	0	0	11	10600	0	1	200	0
Bossiaea modesta	Y	2		0	0	2		0	0	0	0
Caladenia abbreviata	N	1		0	0	0	0	0	0	0	0
	Y	3	50	3	50	0	0	0	0	0	0
Caladenia rubrichila	Y	1	50	0	0	0	0	0	0	1	50
Caladenia subdita	Y	1		0	0	0	0	0	0	0	0
Calothamnus sp. Mt Lindesay (BG Hammersley 439)	Y	2	2500	0	0	2	2500	0	0	0	0
Calothamnus sp. Scott River (RD Royce 84)	Y	6	301	0	0	3	0	4	101	1	100
Chamaexeros longicaulis	Y	3	2000	4	2000	0	0	3	0	1	0
Chamelaucium forrestii subsp. *forrestii*	Y	5		3	0	2	0	0	0	0	0
Conospermum	N	1	10	1	10	0	0	0	0	0	0
quadripetalum	Y	2		0	0	1	0	1	0	0	0
Cryptandra congesta	Y	3	1600	0	0	3	1600	0	0	0	0
Diplolaena andrewsii	Y	2	135	2	15	0	0	1	0	1	120
Diuris heberlei	Y	1	500	1	500	0	0	0	0	0	0
Drosera binata	Y	2	1500	0	0	0	0	2	500	0	0
Dryandra aurantia	Y	4	1735	4	1735	0	0	0	0	0	0
Dryandra sessilis var.	N	1		1		0	0	0	0	0	0
cordata	Y	1		1		0	0	0	0	0	0
Eremaea blackwelliana	N	1		1		0	0	0	0	0	0
	Y	3	2150	3	1350	0	0	0	0	4	800

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Species name (ESP status)	RFA	Total Pops	Total Plants	NPNCA Pops	NPNCA Size	LFC Pops	LFC Size	Shire Pops	Shire Size	Private Pops	Private Size
Eryngium pinnatifidum subsp. *palustre*	N	9		1	0	0	0	1	0	3	0
	Y	1		1		0	0	0	0	0	0
Eucalyptus virginae	Y	3	2010	0	0	2	1998	0	2	12	0
Euphrasia scabra	Y	1		0	0	0	0	0	0	0	0
Goodenia katabudjar	Y	2	100	0	0	2	100	0	0	0	0
Grevillea brachystylis subsp. *australis*	Y	2	230	1	100	0	0	1	130	0	0
Grevillea brachystylis subsp. *brachystylis*	N	2		0	0	0	0	0	0	0	0
	Y	3	100	0	0	0	0	1	0	0	0
Grevillea candolleana	Y	7	261	2	0	0	0	3	105	1	50
Grevillea fuscolutea	Y	3	2380	0	0	3	2300	0	1	80	0
Grevillea manglesii subsp. *ornithopoda*	N	1	5	0	0	0	0	1	5	0	0
	Y	1		1		0	0	0	0	0	0
Grevillea prominens	Y	1		0	0	1		0	0	0	0
Grevillea scabra	N	1	203	3	203	0	0	0	0	0	0
	Y	5	715	2	15	2	700	1	0	0	0
Hakea sp.Walyunga (L Penn s.n.)	Y	1		1		0	0	0	0	0	0
Hakea tuberculata	N	1		0	0	0	0	1	0	1	0
	Y	5		1	0	0	0	4	0	0	0
Hemiandra australis	Y	3	1020	3	1020	0	0	0	0	0	0
Hydatella dioica	N	1		0	0	0	0	0	0	0	0
	Y	1	1000	1	1000	0	0	0	0	0	0
Hydrocotyle hamelinensis	N	1		1		0	0	0	0	0	0
	Y	1		1		0	0	0	0	0	0
Lasiopetalum cardiophyllum	N	1		1		0	0	0	0	0	0
	Y	13	6585	0	0	9	6585	1	0	2	0
Lasiopetalum cordifolium subsp. *acuminatum*	Y	3		1	0	2	0	0	0	0	0
Laxmannia sp. Little Lindesay (BG Hammersley 1615)	Y	2	220	0	0	2	220	0	0	0	0
Leptinella drummondii	Y	5	50	1	0	3	50	0	0	0	0
Leptocarpus ceramophilus	Y	6		3	0	0	0	0	0	0	0
Leptomeria furtiva	Y	2		1	0	0	0	0	0	0	0
Leucopogon glaucifolius	N	8	100	3	100	0	0	3	0	0	0
	Y	1		1	0	0	0	0	0	0	
Leucopogon polystachyus	N	4		0	0	0	0	2	0	0	0
	Y	22	1176	9	0	12	1136	0	0	1	20
Leucopogon tamariscinus	N	13	231	8	207	0	0	3	24	1	0
	Y	2		1	0	0	0	1	0	0	0
Lysinema elegans	N	16	8453	10	6286	1	0	9	536	27	794
	Y	1	46	0	0	0	0	0	0	0	0
Lysinema lasianthum	N	10	507	5	127	0	0	3	80	0	0
	Y	3	8	0	0	0	0	0	0	0	0
Melaleuca incana subsp. Gingilup (Gibson & M Lyons 593)	Y	1		1		0	0	0	0	0	0
Melaleuca micromera	N	2	3	0	0	0	0	1	1	0	0
	Y	1	10	0	0	0	0	0	0	0	0
Millotia tenuifolia var. *laevis*	Y	1		0	0	0	0	1		0	0
Mitreola minima	N	2		1	0	0	0	0	0	1	0
	Y	5		1	0	1	0	0	0	0	0
Nemcia axillaris	N	17	246	7	59	0	0	5	152	1	5
	Y	1		0	0	0	0	0	0	0	0
Nemcia epacridoides	Y	10	10853	3	10000	2	200	7	350	7	303
Parsonsia diaphanophleba	N	2	6	0	0	0	0	1	6	0	0
	Y	1	4000	1	4000	0	0	0	0	0	0
Phyllota gracilis	N	4	320	1	300	0	0	1	0	1	0
	Y	3		0	0	3		0	0	0	0
Pithocarpa corymbulosa	N	1		0	0	0	0	1		0	0
	Y	4		2	0	0	0	2	0	0	0
Restio cracens	Y	10	476	0	0	12	476	0	0	0	0
Restio isomorphus	Y	3	2000	0	0	0	0	2	0	1	2000

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Species name (ESP status)	RFA	Total Pops	Total Plants	NPNCA Pops	NPNCA Size	LFC Pops	LFC Size	Shire Pops	Shire Size	Private Pops	Private Size
Rorippa dictyosperma	N	1		1		0	0	0	0	0	0
	Y	2		2		0	0	0	0	0	0
Schizaea rupestris	N	1	10	1	10	0	0	0	0	0	0
	Y	3		1	0	1	0	0	0	0	0
Schoenus capillifolius	N	2	200	0	0	0	0	0	0	3	200
	Y	2	100	1	100	0	0	0	0	0	0
Schoenus loliaceus	N	1		0	0	1		0	0	0	0
	Y	1		1		0	0	0	0	0	0
Sollya drummondii	N	8	175	0	0	1	0	3	119	0	0
	Y	10	48	0	0	4	4	1	6	2	23
Stylidium rigidifolium	N	1		1		0	0	0	0	0	0
	Y	2		0	0	1	0	0	0	0	0
Stylidium semaphorum	Y	1		1		0	0	0	0	0	0
Stylidium sp. Boulder Rock (AH Burbidge 2536)	Y	2		0	0	1	0	0	0	0	0
Tetratheca similis	N	1		1		0	0	0	0	0	0
	Y	5	25	0	0	0	0	2	25	0	0
Tetratheca sp. Granite (S Patrick SP1224)	Y	1	500	0	0	0	0	0	0	0	0
Trichocline sp. Treeton	N	1		1		0	0	0	0	0	0
(BJ Keighery & N Gibson 564)	Y	2		1	0	1	0	0	0	0	0
Trymalium urceolare	N	1	50	0	0	0	0	1	50	0	0
	Y	6	12	1	10	1	0	0	0	0	0
Verticordia apecta	Y	1	30	0	0	0	0	0	0	0	0
Verticordia bifimbriata	N	5	101	2	1	2	50	1	50	0	0
	Y	2	0	1	0	0	0	1	0	0	0
Verticordia citrella	Y	1		1		0	0	0	0	0	0
Verticordia densiflora var.	N	4	321	1	200	0	0	3	103	0	0
pedunculata	Y	2	10	0	0	0	0	1	10	0	0
Verticordia serrata var. *Udumung* (D Hunter & B Yarran 941006)	Y	1		1		0	0	0	0	0	0
Wurmbea sp. Cranbrook (AR Annels 3819)	Y	1		0	0	0	0	0	0	0	0

Notes: 1 Population numbers within the different vestings are for subpopulations and may thus sum to more than the total number of populations.
2 Number of plants is that recorded at the last survey, and may be none where specific plant counts were not undertaken (e.g. herbarium collections).

Table 12.11 The occurrence of Priority 3 flora within and outside the Western Australian RFA area and within major land vestings

Species name (ESP status)	RFA	Total Pops	Total Plants	NPNCA Pops	NPNCA Size	LFC Pops	LFC Size	Shire Pops	Shire Size	Private Pops	Private Size
Acacia anarthros	N	9	262	0	0	0	0	5	42	0	0
	Y	6	1782	2	741	0	0	1	3	0	0
Acacia drummondii	N	4		0	0	0	0	0	0	0	0
subsp. *affinis*	Y	9		1	0	2	0	0	0	0	0
Acacia horridula	N	3	1236	7	186	0	0	3	1050	0	0
	Y	5	60	2	10	1	0	0	0	2	50
Acacia inops	Y	6		0	0	4	0	2	0	0	0
Acacia oncinophylla	N	1		0	0	0	0	0	0	0	0
subsp. oncinophylla	Y	5	25	1	0	0	0	0	0	1	0
Acacia semitrullata	N	10	982	2	580	2	0	2	400	5	0
	Y	14		0	0	9	0	2	0	3	0
Allocasuarina	N	4	100	2	100	0	0	2	0	0	0
ramosissima	Y	1		0	0	0	0	1		0	0
Andersonia amabile	N	1		0	0	0	0	1		0	0
	Y	8		4	0	4	0	0	0	0	0
Aotus cordifolia	N	1		0	0	0	0	1		0	0
	Y	4	20	0	0	1	0	1	0	1	20
Banksia micrantha	N	9	100	4	0	0	0	2	0	0	0
	Y	1		0	0	0	0	0	0	1	
Blennospora sp. Ruabon	N	7		4	0	0	0	1	0	1	0
(BJ Keighery & N Gibson 20)	Y	1		0	0	0	0	0	0	0	0
Boronia virgata	N	4	360	2	260	0	0	1	100	0	0
	Y	12	1440	8	290	7	650	2	500	0	0
Bossiaea disticha	Y	9		6	0	0	0	2	0	0	0
Calothamnus pallidifolius	Y	16	1226	0	0	15	1226	0	0	0	0
Calytrix pulchella	N	2		0	0	0	0	0	0	0	0
	Y	1		0	0	1		0	0	0	0
Chamelaucium floriferum subsp. *floriferum*	Y	6	1000	6	1000	0	0	0	0	0	0
Chordifex gracilior	N	2		0	0	0	0	0	0	1	0
	Y	8	745	3	230	3	515	2	0	0	0
Chorizema carinatum	N	5		2	0	0	0	3	0	0	0
	Y	1		0	0	1		0	0	0	0
Chorizema reticulatum	N	8		1	0	0	0	6	0	0	0
	Y	8	183	1	30	1	0	3	30	0	0
Conospermum	N	1		0	0	0	0	1		0	0
paniculatum	Y	6		0	0	4	0	0	0	0	0
Cyathochaeta stipoides	Y	10		7	0	3	0	0	0	0	0
Darwinia pimelioides	Y	8	375	6	325	0	0	1	0	2	50
Dryandra echinata	N	13	503	3	100	0	0	6	361	5	42
	Y	1		0	0	0	0	0	0	0	0
Dryandra praemorsa var.	N	1		0	0	0	0	0	0	0	0
praemorsa	Y	2		0	0	1	0	0	0	0	0
Dryandra praemorsa var. *splendens*	Y	1		0	0	0	0	1		0	0
Dryandra subpinnatifida var. *imberbis*	Y	1		0	0	1		0	0		0
Eleocharis sp. Kenwick	N	5	1000	1	0	0	0	2	1000	1	0
(GJ Keighery 5179)	Y	3	150	1	0	0	0	0	0	0	0
Eucalyptus brevistylis	Y	7		8	0	2	0	0	0	0	0
Gahnia sclerioides	Y	2		2		0	0	0	0	0	0
Galium migrans	N	8		5	0	0	0	0	0	0	0
	Y	1		1		0	0	0	0	0	0
Gastrolobium brownii	N	4	20	2	0	0	0	1	20	1	0
	Y	8	1074	3	24	5	1050	0	0	0	0
Gonocarpus simplex	Y	14	28750	9	15550	7	13200	0	0	0	0
Gonocarpus trichostachyus	Y	1	200	0	0	1	200	0	0	0	0
Grevillea papillosa	Y	14	1615	9	1190	1	0	4	425	0	0

cont/...

Species name (ESP status)	RFA	Total Pops	Total Plants	NPNCA Pops	NPNCA Size	LFC Pops	LFC Size	Shire Pops	Shire Size	Private Pops	Private Size
Grevillea uncinulata subsp. *florida*	N	2		0	0	0	0	0	0	1	0
	Y	5	526	0	0	0	0	4	118	0	0
Hakea myrtoides	N	2	20	0	0	0	0	0	0	1	0
	Y	17	4493	4	205	0	0	3	15	11	650
Halgania corymbosa	Y	5	30	0	0	1	0	2	0	2	30
Helipterum pyrethrum	N	11	2300	1	0	0	0	3	0	6	1300
	Y	1	300	1	300	0	0	0	0	0	0
Isopogon drummondii	N	29	5126	1	30	0	0	22	1597	20	2816
	Y	2	1484	0	0	0	0	2	1307	0	0
Isopogon formosus subsp. *dasylepis*	N	3		0	0	0	0	0	0	0	0
	Y	7		0	0	0	0	3	0	0	0
Jacksonia sparsa	N	4		1	0	0	0	2	0	0	0
	Y	4		0	0	4	0	0	0	0	0
Jansonia formosa	Y	13	214	7	200	3	0	4	14	1	0
Lambertia multiflora var. *darlingensis*	N	3		0	0	0	0	0	0	1	0
	Y	4		0	0	0	0	1	0	1	0
Lambertia rariflora subsp. *lutea*	Y	7	254	2	0	5	254	0	0	0	0
Lasiopetalum glabratum	Y	14	40	1	0	8	0	2	40	0	0
Lepyrodia heleocharoides	Y	7		0	0	3	0	3	0	0	0
Leucopogon gilbertii	N	1		0	0	0	0	0	0	0	0
	Y	29	2031	2	20	22	1511	2	0	0	0
Lomandra ordii	Y	8	3220	9	2220	3	1000	0	0	1	0
Loxocarya magna	N	1		0	0	0	0	0	0	0	0
	Y	8	40	3	30	1	0	0	0	3	0
Meeboldina crassipes	N	1		0	0	0	0	0	0	0	0
	Y	5		5	0	1	0	0	0	0	0
Meeboldina thysanantha	Y	6		1	0	3	0	0	0	1	0
Melaleuca diosmifolia	N	12	7	5	2	0	0	2	0	1	0
	Y	1	100	1	100	0	0	0	0	0	0
Monotoca leucantha	N	8	2000	4	900	0	0	1	0	2	1100
	Y	1		0	0	0	0	0	0	1	
Myriocephalus appendiculatus	N	5		2	0	0	0	1	0	1	0
	Y	1	50	1	50	0	0	0	0	0	0
Myriophyllum echinatum	N	8	300	4	0	0	0	2		0	0
	Y	1		0	0	0	0	0	0	0	0
Nemcia acuta	N	2	1000	1	1000	0	0	0	0	1	0
	Y	8	152	4	152	0	0	2	0	2	0
Petrophile plumosa	N	4	5250	3	4050	0	0	0	0	2	0
	Y	1	50	1	50	0	0	0	0	0	0
Platysace ramosissima	N	3		1	0	0	0	0	0	0	0
	Y	1		1		0	0	0	0	0	0
Pultenaea pinifolia	Y	5	1200	0	0	4	1200	1	0	0	0
Pultenaea radiata	Y	16	22700	0	0	13	22700	1	0	1	0
Schoenus benthamii	N	2		0	0	0	0	0	0	2	
	Y	1		0	0	0	0	0	0	0	0
Sphenotoma parviflorum	N	1		1		0	0	0	0	0	0
	Y	10	1720	3	1500	7	220	0	0	0	0
Sporadanthus rivularis	Y	14		4	0	9	0	2	0	0	0
Stenanthemum coronatum	N	2	20	0	0	1	0	0	0	0	0
	Y	7	135	1	0	2	30	2	0	0	0
Stenanthemum pumilum	N	2		2		0	0	0	0	0	0
	Y	1		0	0	0	0	0	0	0	0
Stirlingia divaricatissima	Y	5	1100	4	1100	3	0	0	0	0	0
Stylidium barleei	Y	9	300	0	0	7	300	0	0	0	0
Stylidium leeuwinense	Y	8		4	0	1	0	1	0	0	0
	N	4		0	0	0	0	1	0	1	0
Stylidium longitubum	Y	3		2	0	0	0	0	0	0	0
Stylidium mimeticum	N	8		2	0	0	0	2	0	1	0
	Y	10		3	0	0	0	4	0	1	0

cont/...

Species name (ESP status)	RFA	Total Pops	Total Plants	NPNCA Pops	NPNCA Size	LFC Pops	LFC Size	Shire Pops	Shire Size	Private Pops	Private Size
Synaphea acutiloba	N	3		0	0	0	0	2	0	0	0
	Y	14		2	0	1	0	4	0	8	0
Synaphea cuneata	Y	1	9	0	0	0	0	1	9	0	0
Synaphea damopsis	Y	2		0	0	1	0	1	0	0	0
Synaphea hians	N	1		0	0	0	0	0	0	0	0
	Y	2		0	0	0	0	0	0	0	0
Synaphea pinnata	N	2	650	1	650	0	0	0	0	0	0
	Y	14	869	3	0	0	0	9	287	20	582
Synaphea preissii	N	5		2	0	0	0	0	0	0	0
	Y	1		1		0	0	0	0	0	0
Synaphea whicherensis	Y	9		0	0	9	0	0	0	0	0
Tetratheca pilifera	Y	6	11	0	0	0	0	2	10	1	0
Thelymitra jacksonii	Y	8	38	3	30	5	8	0	0	0	0
Thysanotus anceps	N	3		2	0	0	0	1	0	0	0
	Y	5	306	2	300	0	0	2	6	0	0
Verticordia huegelii var.	N	1		0	0	0	0	0	0	1	
decumbens	Y	6	50	0	0	4	50	0	0	0	0
Verticordia serrata var.	N	1		0	0	0	0	1		0	0
linearis	Y	3		3		0	0	0	0	0	0

Notes: 1 Population numbers within the different vestings are for subpopulations and may thus sum to more than the total number of populations.
2 Number of plants is that recorded at the last survey, and may be none where specific plant counts were not undertaken (e.g. herbarium collections).

Table 12.12 The occurrence of Priority 4 flora within and outside the Western Australian RFA area and within major land vestings

Species name (ESP status)	RFA	Total Pops	Total Plants	NPNCA Pops	NPNCA Size	LFC Pops	LFC Size	Shire Pops	Shire Size	Private Pops	Private Size
Acacia clydonophora	N	11	7030	7	1020	0	0	2	10	3	6000
	Y	1	79	0	0	0	0	0	0	1	79
Acacia flagelliformis	N	6	36	1	36	1	0	2	0	1	0
	Y	8	100	0	0	2	0	3	0	1	0
Acacia tayloriana	Y	22	749	0	0	21	668	1	81	0	0
Anthotium junciforme	N	15	814	3	0	0	0	3	343	3	52
	Y	1		1		0	0	0	0	0	0
Asplenium aethiopicum	N	8	20	12	0	0	0	4	20	0	0
	Y	18	264	12	200	13	64	0	0	0	0
Astroloma sp. Nannup (RD Royce 3978)	Y	28	415	0	0	25	232	6	168	2	15
Boronia tenuis	N	4	211	0	0	0	0	3	0	5	211
	Y	13	3372	3	0	4	146	0	0	4	113
Caladenia integra (V)	N	9	2187	5	437	0	0	4	1000	1	750
	Y	3	352	0	0	1	300	0	0	0	0
Caladenia interjacens	N	1	3	1	3	0	0	0	0	0	0
	Y	5		8		0	0	0	0	0	0
Caladenia plicata	N	14	87	8	61	1	10	1	1	1	10
	Y	12	51	1	0	7	31	0	0	1	0
Calothamnus graniticus subsp.	N	5	104	0	0	0	0	1	0	2	4
leptophyllus	Y	9	101565	0	0	4	500	0	0	2	100000
Calothamnus rupestris	N	3	30	1	30	0	0	1	0	0	0
	Y	3	5	1	0	2	5	0	0	0	0
Calytrix sylvana	N	8	22609	1	20	0	0	1	150	1	0
	Y	10	1041	3	355	2	200	2	0	2	486
Chamelaucium	N	1	79	1	27	0	0	1	26	1	26
erythrochlorum (V)	Y	7	7177	0	0	8	6177	1	1000	1	0
Conospermum undulatum	N	14	6829	0	0	0	0	11	1071	32	3640
	Y	1	2585	0	0	0	0	2	2035	0	0
Conostephium minus	N	21	221	5	0	4	0	1	0	9	174
	Y	1		1		0	0	0	0	0	0
Darwinia thymoides subsp. St Ronans (JJ Alford & GJ Keighery 64)	Y	1	25	1	25	0	0	0	0	0	0
Daviesia microphylla	N	7	16	3	11	0	0	4	5	0	0
	Y	33	1663	41	1263	1	400	0	0	0	0
Drosera marchantii subsp.	N	9	330	0	0	0	0	1	0	4	300
marchantii	Y	5	38	0	0	1	0	0	0	0	0
Drosera occidentalis	N	13	23320	0	0	0	0	7	2257	5	20810
	Y	14	26081	6	15759	5	322	2	10000	1	0
Dryandra polycephala	N	4		2	0	0	0	0	0	0	0
	Y	11	29218	1	3000	4	25000	1	66	2	132
Eucalyptus aspersa	N	6	332	0	0	1	15	3	38	5	279
	Y	25	1119	5	718	16	310	1	0	0	0
Eucalyptus exilis	N	16	57	14	0	0	0	2	8	7	49
	Y	2	85	1	40	1	45	0	0	0	0
Eucalyptus latens	N	17	218	6	106	7	0	3	11	1	80
	Y	6	1594	0	0	4	1400	0	0	0	0
Grevillea cirsiifolia (V)	N	3		0	0	0	0	0	0	0	0
	Y	36	7329	6	207	32	6767	2	251	0	0
Grevillea drummondii	N	4	51	2	0	0	0	2	50	3	0
	Y	19	3276	1	50	17	2528	1	150	2	0
Grevillea pimeleoides	Y	4	80	3	50	0	0	0	0	0	0
Microtis media subsp.	N	1		1		0	0	0	0	0	0
quadrata	Y	1	20	0	0	0	0	0	0	1	20
Microtis pulchella	N	2		2		0	0	0	0	0	0
	Y	2	100	1	0	0	0	1	100	0	0
Reedia spathacea	Y	15	500	7	100	6	400	1	0	0	0
Rinzia crassifolia	N	3		0	0	0	0	0	0	0	0

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Species name (ESP status)	RFA	Total Pops	Total Plants	NPNCA Pops	NPNCA Size	LFC Pops	LFC Size	Shire Pops	Shire Size	Private Pops	Private Size
	Y	2		0	0	0	0	1	0	0	0
Senecio leucoglossus	Y	10	21	1	10	5	0	1	1	2	0
Stylidium scabridum	N	5	77	2	35	0	0	1	20	2	12
	Y	6	719	0	0	8	719	0	0	0	0
Templetonia drummondii	Y	7	3	2	0	0	0	2	3	2	0
Thysanotus glaucus	N	8		4	0	0	0	2	0	0	0
	Y	3		0	0	1	0	2	0	0	0
Tripterococcus brachylobus	N	1		1		0	0	0	0	0	0
	Y	2		1	0	1	0	0	0	0	0
Tyrbastes glaucescens	Y	30	1030	10	1030	13	0	1	0	4	0
Verreauxia verreauxii (V)	N	1	10	0	0	0	0	0	0	1	10
	Y	27	12584	2	53	42	12531	0	0	0	0
Verticordia lindleyi subsp.	N	25	13072	7	10375	0	0	7	70	11	2347
lindleyi	Y	1		0	0	0	0	1		0	0
Verticordia lindleyi subsp.	N	13	4532	1	0	0	0	10	758	1	15
purpurea	Y	3	0	1	0	0	0	1	0	0	0
Verticordia multiflora subsp.	N	8	1150	2	0	0	0	4	1150	0	0
multiflora	Y	1		1		0	0	0	0	0	0
Villarsia submersa	N	13	4145	3	4000	0	0	3	6	5	85
	Y	8	8350	2	3050	2	5300	0	0	2	0

Notes: 1 Population numbers within the different vestings are for subpopulations and may thus sum to more than the total number of populations.
2 Number of plants is that recorded at the last survey, and may be none where specific plant counts were not undertaken (e.g. herbarium collections).

12.7 FAUNA SPECIES ASSESSMENT

Introduction

The South-West Forest Region consists of a comparatively uniform forested landscape quite unlike the deeply incised and varied landscapes of eastern Australia. As a consequence of this uniformity, the forests of the south-west are depauperate in faunal diversity when compared to eastern forests. Species generally tend to occur broadly across the landscape. However this apparent homogeneity does not necessarily apply at the local level, where the distribution of fauna is affected by factors such as the diversity of understorey flora, soil moisture, rainfall, variations in relief and the presence of fire as a regular feature in the landscape.

The geological history of this landscape has greatly influenced the development of the fauna, supporting endemic species unique to the south-west such as the sunset frog (*Spicospina flammocaerulea*) and allowing the persistence of elements of terrestrial and aquatic Gondwanic invertebrates such as the mygalomorph spiders in small refugia where favourable environmental conditions have been maintained. Even fire, unquestionably one of the most defining elements of the south-west forests, has occurred as a mosaic across the landscape, producing a biota well-adapted to fire but also conversely, enabling the persistence of such relictual species in small, protected refugia in the landscape such as within the tingle forests. The south-west forests also represent refugia for a number of once widespread critical weight-range vertebrate species that have contracted south-westwards into the forest environment. For example, the numbat and chuditch were once widespread species in the arid and semi-arid regions of Australia and following their decline, Perup and similar areas represent important refugia in historical times for critical weight range species.

The hydrological systems the South-West Forest Region are complex. The region is characterised by short coastal rivers with greatly fluctuating flow rates and water levels, and a large number of permanent or ephemeral water bodies, including lakes and flats. The presence of palaeodrainage features forming swamps, and relict landscape features such as granite monadnocks where seasonal but important pools form, are examples of particular but important aquatic habitats in the south-west. Cave root-mat communities and tumulus springs are examples of sensitive microhabitats in the region.

The aquatic vertebrate fauna of the south-west is depauperate in comparison with eastern Australia, with 10 naturally-occurring native species of fish. There is a high level of endemism, with eight of the 10 species being endemic. At least one species is known to be migratory. The number of aquatic invertebrate species in the region is unknown and adequate distributional information exists for only a few of these. Many of the known aquatic invertebrates are highly endemic, some being entirely restricted to a particular wetland, tumulus spring or cave root-mass community (Horwitz et al. 1997).

Data acquisition

Data acquisition for the assessment of fauna species biodiversity was directed towards those data which met reasonable standards of accuracy, precision and reliability and could be captured within the assessment timeframe. Metadata statements were compiled for all potential data sources as part of the biodiversity data review.

The biodiversity data review indicated that the capture of unpublished and published information on highly restricted primitive, relictual and endemic invertebrate and amphibian species in the RFA region would provide key data for the biodiversity assessment. This work was undertaken for the Comprehensive Regional Assessment.

It was also recognised that analysis of fauna data in the South-West Forest Region would be severely restricted by the absence of an amalgamated fauna database and the absence of systematic widespread survey across the RFA region. No extensive terrestrial fauna studies of the entire region have been undertaken. A limited number of studies of varying intensity has been completed over sub-units of the region, primarily in association with land-use changes such as dam construction, forest management and mining, or studies of particular taxa. One of the limitations to extensive faunal surveys in the region is that there are significant areas, notably in the south, where access is seasonally restricted by climatic events.

Several regional surveys for various groups have been undertaken, but to date no coordinated effort has been made to survey systematically the aquatic habitats and associated fauna of the region. Surveys of aquatic invertebrates in the south-west forests have been conducted by the Water and Rivers Commission and various research institutions, but much of the region has not been adequately sampled.

Gaps also exist in fish information for the South-West Forest Region as a result of the limited systemic survey data (although this is better than is available for many taxonomic groups) and the limited knowledge of life history, population characteristics and disturbance processes affecting species.

The taxonomy, distribution and ecology of aquatic invertebrates occurring in the south-west is generally poorly understood. Few species were able to be assessed because of the absence of sufficient data. This indicates a need for additional capture of available data and for further taxonomic and survey work on aquatic invertebrates.

Development of fauna database

A major component of the fauna assessment was the compilation of such data as could be gathered within a reasonable timeframe and its amalgamation into a relational fauna database.

The assessment of vertebrate and invertebrate fauna for the south-west forests used data and expertise from a range of sources, including the Western Australian Museum, CALM, other government agencies, industry, research institutions and consultants.

The database constructed for the CRA was the first large scale fauna database ever compiled for a wide range of taxonomic groups in Western Australia. Due to the time constraints for the process, bird data capture targeted 27 significant bird species including listed species (under Schedule 1 of the Commonwealth *Endangered Species Protection Act* or the Western Australian *Wildlife Conservation Act*) or species potentially sensitive to disturbances, such as fire or the removal of hollow trees. The other terrestrial vertebrate groups were considered in their entirety, based largely on museum records. Only a small proportion of the known terrestrial invertebrate taxa was captured. A database was compiled from Western Australian Museum records on freshwater crustacea. A database on fish of the south-west was drawn from Morgan et al. (1996) which yielded 886 records for the area between Busselton and Walpole. This work included survey work on fish taxa and data from past surveys conducted in the area. No other fish data were able to be used in the assessment.

The amalgamation of captured records yielded 63 710 vertebrate records across 286 selected taxa and 12 981 invertebrate records across 610 selected taxa. These records comprise a large number of validated historical records across the period 1830 to 1997, but very little data from formal systematic regional surveys. The data capture of relict and endemic invertebrate and amphibian taxa yielded 380 additional records.

A number of other data sources exist for the study region but these data could not be captured for the CRA due to problems with access, scale, validation or reliability.

While the compilation of this database is a significant achievement, its limitations are recognised. In brief, these are:
- the large number of incidental records and consequent strong bias in the data that is dependent on land use, access and observer bias;
- time constraints on data capture which introduced a bias towards easily captured records and effectively excluded a number of non-digital datasets that could not be captured within the time frame; and
- an absence of presence/absence records outside mining company records which places a strong reliance on incidental observation and limits the usefulness of modelling.

The primary sources of data used in the study were:
- pre-disturbance fauna surveys conducted by the mining companies Alcoa of Australia and Worsley Alumina;
- vertebrate fauna databases compiled by CALM;
- a regional study of south-western fishes conducted by Murdoch University in association with the Water and Rivers Commission;
- Glenn Storr Bird Database, captured by the Western Australian Museum;
- CSIRO cockatoo study for the south-west region;
- Birds Australia (RAOU) database for Western Australia;
- selected vertebrate and invertebrate records from the Western Australian Museum;
- dam sites fauna studies conducted by Water and Rivers Commission; and
- miscellaneous other studies provided by university researchers.

The data review and development of the integrated fauna database for the CRA indicate a need for comprehensive and systematic fauna sampling across the assessment region.

Validation of data records

The database was validated and audited using ARCVIEW and the Data Audit Management Toolkit (DAM) software supplied by Environment Australia (Bennet et al. 1997). Geocoding errors were removed during this process and the database restricted to records within the RFA boundary. Taxonomic anomalies and inconsistencies were resolved or removed. Vagrant or anomalous records, defined as species records outside known or accepted distribution ranges, were also removed or resolved.

Auditing revealed the lack of meaningful presence/absence data derived from systematic survey for anywhere in the region outside areas of interest to aluminium companies and a longer-term museum study through the extreme south of the assessment area. Presence-only data biases analysis towards sampling sites. For example, the aluminium company areas appear as species-rich areas, where in fact this is actually an artefact of the intensity of sampling in this area and the comparative lack of sampling elsewhere. Effectively, this means that subsequent fauna modelling and distribution mapping which rely heavily on incidental sightings are limited by the lack of validation to demonstrate that species do or do not occur where they have not been recorded.

Species attribution

Following data validation, the database was attributed for values that would allow species to be prioritised for modelling and inclusion in further analyses taking into account JANIS and national estate criteria. Species were considered on the basis of the following characteristics:
- known core distribution (e.g. core distribution in forested areas);
- relictual characteristics (e.g. species shows primitive characteristics);
- conservation status (e.g. State or federally-listed species or known restricted occurrence);
- distribution (e.g. degree of disjunction or continuity across species range);
- phylogenetic distinctiveness (e.g. unique taxa at species, genus or family level); and
- endemism (degree to which species was restricted to the RFA area).

Species were given a numerical ranking on each of the above characteristics. All species demonstrating high values for the above traits (i.e. forest distribution, highly relictual, high conservation status etc.) were mapped. It is important to recognise that the list of taxa available for consideration was incomplete and particularly poor for invertebrates, the group with the most restricted relict and endemic taxa to the south-west. Further work to identify JANIS target taxa would assist in developing biodiversity strategies for the region.

Taxa of conservation significance

Attribution of vertebrate taxa and selected terrestrial taxa allowed a ranking of species for analysis to highlight the species considered by experts to be of high conservation significance with reference to JANIS target groups and national estate values. This ranked list was validated by experts working with the relevant taxonomic group. Species were ranked by vulnerability (highest to lowest) as follows:

1. Major population declines and/or range reductions impacting on conservation status.
2. Species with naturally restricted ranges, specific habitat requirements or general population/range reductions.
3. Species with somewhat restricted ranges or species with broad ranges but only occupying limited number of habitats.
4. Widespread species but endemic forest species dependent on a general but widespread resource e.g. tree hollows.
5. Widespread species not dependent on, but using some forest resources.

The vertebrate fauna listed under State or Commonwealth legislation, or identified by the experts as of conservation priority according to these criteria, included 20 mammal species, 28 bird species, 19 frog species, 22 reptile species, 21 mollusc species, five spider species and eight aquatic invertebrate species. These species are listed in Table 12.13.

Table 12.13 Ranking of fauna taxa for the CRA biodiversity assessment

Scientific name	Common name	Code[1]	Priority[2]
Mammals			
Dasyurus geoffroii	Chuditch	3	1
Macropus eugenii	Tammar wallaby	2	1
Setonix brachyurus	Quokka	2	1
Myrmecobius fasciatus	Numbat	3	1
Bettongia penicillata	Brush-tailed bettong	3	1
Pseudocheirus occidentalis	Western ringtail possum	3	1
Antechinus flavipes	Mardo		2
Phascogale calura	Red-tailed phascogale	3	2
Phascogale tapoatafa	Brush-tailed phascogale		2
Sminthopsis gilberti	Gilbert’s dunnart		2
Sminthopsis griseoventer	Grey-bellied dunnart		2
Macropus irma	Western brush wallaby		2
Isoodon obesulus	Quenda	2	2
Hydromys chrysogaster	Water rat		2
Falsistrellus mackenziei	Western false pipistrelle		2
Nyctophilus gouldi	Gould’s long-eared bat		2
Cercatetus concinnus	Western pygmy possum		3
Rattus fuscipes	Bush rat		3
Trichosurus vulpecula	Brushtail possum		3
Tarsipes rostratus	Honey possum		3
Birds			
Cacatua pastinator pastinator	Western corella	3	1
Calyptorhynchus banksii naso	Red-tailed black-cockatoo		1
Calyptorhynchus baudinii	Long-billed black-cockatoo	2	1
Calyptorhynchus latirostris	Short-billed black-cockatoo	2	1
Ninox connivens	Barking owl		1
Calyptorhynchus baudinii/latirostris	White-tailed black-cockatoo	2	1
Climacteris rufa	Rufous treecreeper		2
Coturnix ypsilophora	Brown quail		2
Falcunculus frontatus leucogaster	Crested shrike-tit		2
Leiopoa ocellata	Malleefowl	3	2
Lophoictinia isura	Square-tailed kite		2
Stagonopleura oculata	Red-eared firetail		2
Stipiturus malachurus westernensis	Southern emu-wren		2
Eopsaltria georgiana	White-breasted robin		3
Malurus elegans	Red-winged fairy-wren		3
Phaps elegans	Brush bronzewing		3
Polytelis anthopeplus westralis	Regent parrot		3
Turnix varia varia	Painted button-quail		3
Tyto novaehollandiae	Masked owl		3
Ninox novaeseelandiae	Southern boobook		4
Pardalotus striatus	Striated pardalote		4

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Scientific name	Common name	Code[1]	Priority[2]
Platycercus icterotis	Western rosella		4
Platycercus spurius	Red-capped parrot		4
Barnardius zonarius	Australian ringneck		5
Falco peregrinus	Peregrine falcon	2	5
Neophema elegans	Elegant parrot		5
Tyto alba	Barn owl		5
Dacelo novaeguineae	Laughing kookaburra		
Frogs			
Geocrinia alba	White-bellied frog	3	2
Geocrinia lutea	Nornalup frog	2	2
Geocrinia vitellina	Yellow-bellied frog	3	2
Heleioporus barycragus	Western marsh frog		2
Spicospina flammocaerulea	Sunset frog		2
Crinia subinsignifera	Squelching frog		3
Geocrinia rosea	Roseate frog		3
Heleioporus inornatus	Plain frog		3
Heleioporus psammophilus	Sand frog		3
Metacrinia nichollsi	Nicholl's frog		3
Myobatrachus gouldii	Turtle frog		3
Litoria adelaidensis	Slender tree frog		4
Litoria moorei	Motorbike frog		4
Crinia georgiana	Quacking frog		4
Crinia glauerti	Galuert's froglet		4
Crinia pseudinsignifera	Bleating froglet		4
Geocrinia leai	Lea's frog		4
Limnodynastes dorsalis	Banjo frog		4
Pseudophryne guentheri	Guenther's toadlet		4
Reptiles			
Morelia spilota imbricata	Carpet python	2	1
Egernia luctuosa	Skink		1
Ctenotus delli	Skink		2
Egernia pulchra	Skink		2
Elapognathus minor	Short-nosed snake		2
Rhinoplocephalus bicolor	Square-nosed snake		2
Ctenophorus ornatus	Dragon		3
Egernia kingii	Skink		3
Glaphyromorphus gracilipes	Skink		3
Lerista microtis	Skink		3
Ramphotyphlops pinguis	Blind snake		3
Suta nigriceps	Snake		3
Acritoscincus trilineatum	Skink		4
Aprasia puchella	Worm lizard		4
Ctenotus labillardieri	Skink		4
Diplodactylus polyophthalmus	Skink		4
Hemiergis initialis	Skink		4
Hemiergis peronii tridactyla	Skink		4
Lerista distinguenda	Skink		4
Oedura reticulata	Gecko		4
Suta gouldii	Snake		4
Underwoodisaurus milii	Barking gecko		4
Snails (molluscs)			
Bothriembryon indutus	Land snail		2
Bothriembryon sp. nov. "Boddington"	Land snail		2
Bothriembryon fuscus	Land snail		2
Bothriembryon revectus	Land snail		2
Bothriembryon sp. nov. "Augusta"	Land snail		2
Bothriembryon sp. nov. "Denmark B"	Land snail		2
Bothriembryon sp. nov. "Nannup"	Land snail		2
Bothriembryon sp. nov. "Pt D'Entrecasteaux"	Land snail		2
Bothriembryon leeuwinensis	Land snail		3
Bothriembryon sayi	Land snail		3
Bothriembryon serpentinus	Land snail		3
Bothriembryon sp. nov. "Manjimup"	Land snail		3
Bothriembryon sp. nov. "SW Caves"	Land snail		3
Bothriembryon brazieri	Land snail		4
Bothriembryon jacksoni cf.	Land snail		4

cont/...

Scientific name	Common name	Code[1]	Priority[2]
Bothriembryon naturalistarum	Land snail		4
Bothriembryon bulla	Land snail		5
Bothriembryon jacksoni	Land snail		5
Bothriembryon kendricki	Land snail		5
Bothriembryon kingii	Land snail		5
Westralunio carteri	River and lake mussel	2	Not ranked
Spiders (Arachnids)			
Aganippe rhapiduca	Spider		Not ranked
Ambicodamus marae	Spider		Not ranked
Cercophonius sulcatus	Spider		Not ranked
Urodactus planimanus	Spider		Not ranked
Cormocephalus hartmeyeri	Spider		Not ranked
Acarines (water-mites)			
Pseudohydraphantes doegi	Doeg's water-mite	2	Not ranked
Acercella sp.	Poorginup Swamp water-mite	2	Not ranked
Copepods			
Fibulacamptus bisetosus		2	Not ranked
Calamoecia elongata		2	Not ranked
Cladocerans (water-fleas)			
Daphnia occidentalis		2	Not ranked
Ostracods (seed shrimps)			
Limnocythere porphyretica		2	Not ranked
Decapods (shrimps and crayfish)			
Cherax tenuimanus Engaewa sp.	Margaret River marron	2	Not ranked
(WAM 182-94)		2	Not ranked

Notes: 1 The following codes apply:

Code 1 Commonwealth *Endangered Species Protection Act 1992*
Code 2 State-declared species in Western Australia
Code 3 Listed on State and Commonwealth lists

2 See priority listings on page 148

Point distribution maps were produced electronically on ARCVIEW for all species ranked above five in the database and for the captured relict and endemic invertebrates and amphibians. National estate values are addressed in the National Estate report, to be available separately. The point distribution maps were used to conduct additional validation work. Historical records were included in the database in recognition of the significance of decline that has occurred in many mammal and bird species in Western Australia.

None of the 10 native freshwater fish species recorded from the South-West Forest Region is listed under endangered species legislation at State or federal level. Four species however, are on the list of threatened Australian fish complied by the Australian Society for Fish Biology. A report by Horwitz et al. (1997) also identifies a further five species as of conservation significance.

A total of 21 of the aquatic invertebrate species known from the south-west was identified as being restricted, vulnerable, rare or threatened in Western Australia. It is recognised that additional research and survey work is likely to add further taxa to this list.

Horwitz et al. (1997) have identified a range of aquatic species which they consider falls within JANIS target groups, although these species are not listed under State or Commonwealth legislation. These species are listed in Table 12.14.

Table 12.14 Aquatic fauna species occurring in the South-West Forest Region and listed in the Australian Society of Fish Biology's list of threatened fish or identified by Horwitz et al. (1997) as species of conservation significance

Species name	Common name	Conservation status
Fish		
Lepidogalaxias salamandroides	Salamander fish	Restricted, well conserved
Galaxiella nigrostriata	Black-striped minnow	Restricted, well conserved
Nannatherina balstoni	Balston's pygmy perch	Restricted, well conserved
Galaxiella munda	Western mud minnow	Restricted
Edelia vittata	Western pygmy perch	
Galaxias occidentalis	Western minnow	
Bostockia porosa	Nightfish	
Tandanus bostocki	Freshwater cobbler	
Geotria australis	Pouched lamprey	
Molluscs (mussels and snails)		
Austroassiminea letha	Cape Leeuwin freshwater snail	Restricted, primitve
Crustacea (general)		
Kapcypridoopsus asymmetra		Restricted
Protorcangonyx frontinalis		Restricted
Totgammarus eximius		Restricted
Insecta (general)		
Kosrheithrus boorarus		Restricted
Oligochaeta (general)		
Astacopsidrilus novus		Restricted
Amphipods		
Uroctena whadjukia		Restricted
Uroctena yellandi		Restricted
Acarines (water-mites)		
Larri laffa		Restricted, relict
Notoaturinae gen. nov.		Restricted, relict
Tartarothyas sp. nov.		Restricted, relict
Tillia davisae		Restricted, interstitial
Penemideopsis pusilla		Restricted, interstitial
Copepods		
Boeckella geniculata		Restricted
Cladocerans (water-fleas)		
Biapertura imitatoria		Restricted
Calanoida		
Hemiboeckella powellensis		Restricted
Ostracods (seed shrimps)		
Ilyodromus candonites		Restricted
Decapods (shrimps and crayfish)		
Cherax glaber		Restricted
Engaewa subcoerulea		Restricted
Engaewa reducta		Restricted
Engaewa sp. nov. 1		Restricted
Engaewa sp. nov. 2		Restricted
Odonatans (damselflies and dragonflies)		
Petalura hesperia	W. Petalura dragonfly	Restricted
Plecoptera (stoneflies)		
Dinotoperla sp.		Undescribed, restricted

Note: The conservation status classifications are defined as:
Well conserved = species well represented in reserves
Restricted = species known from a single location or a geographically confined area
Primitive/relict = see National Estate Report

The aquatic communities of the south-west contain most of the features suggested by Hopper et al. (1996) as being important for the endurance of relict and primitive species, and recent work shows the high levels of occurrence of such taxa in aquatic environments in the region (Horwitz et al. 1997). Cave root-mats, tumulus springs and wetlands all possess communities sensitive to microchanges in their environment and indirect disturbances, such as lowering of water-flows. Horwitz et al. (1997) have highlighted aquatic communities that in their view require protection. These are:

- tumulus springs (organic mound springs)—Perth to Gingin*;
- aquatic root-mat communities—Leeuwin-Naturaliste ridge*;
- *Baumea* wetlands—Lake Muir system, southern jarrah forest; and
- relictual peat community—Lake Surprise.

(* entered on CALM's Threatened Ecological Communities database and assessed as critically endangered)

The importance of monadnocks is recognised in providing surface pools and wetlands around their bases as habitat for a poorly understood but potentially important group of macroinvertebrates. Horwitz et al. (1997) have suggested that headwater aquatic environments in the region in good condition are potential refuges for Gondwanic relicts.

Species habitat modelling

Species modelling was attempted for all terrestrial vertebrate fauna groups. Only records with a geocoding accuracy of nine seconds were included for mammals and birds. A geocoding accuracy of one minute was accepted for amphibians and reptiles because of the insufficient number of records with higher resolutions.

Modelling was based on presence only data because of the high number of incidental records. Modelled outputs were examined by a panel of experts in the relevant taxa group. Of the 100 modelled distributions attempted, 24 vertebrate taxa yielded acceptable models, of which eight were for species ranked highly for conservation significance.

Although these models were regarded as acceptable, the predicted distributions were modelled at such a low probability of occurrence that the results must be interpreted with caution. Consequently, the point distribution data are considered more appropriate than the modelled distributions for use in subsequent analyses.

Species richness modelling

It was concluded that the available data for fauna were inadequate for species richness modelling, both in terms of point distribution and modelled outputs.

Species vulnerability

Indices of vulnerability in terms of broad conservation status, prepared in consultation with experts in the various taxonomic groups, were used in attribution and ranking species for analysis. This attribution is discussed under 'Taxa of conservation significance' above.

Responses to disturbance

Christensen (1997) has prepared a report for the CRA which reviews the current state of knowledge on the impacts of disturbance on vertebrate terrestrial species in the South-West Forest Region. Majer and Heterick (1997) and Horwitz et al. (1997) have prepared similar reports dealing with terrestrial invertebrates and fish and aquatic invertebrates respectively. Disturbances considered include fire, timber harvesting, mining and quarrying, agricultural clearing, dams, pest control, grazing, disease, recreation, predation and competition by introduced species, dams, groundwater extraction and waste disposal.

These reports are the initial stage in the identification of potentially threatening processes. They are available on request, and will be considered by Governments in developing the Regional Forest Agreement for Western Australia.

Endangered, rare and threatened fauna

The current list of nine species listed on Schedule 1 and 2 of the Commonwealth *Endangered Species Protection Act 1992* was reviewed to determine whether recovery plans or were in place or in preparation, or whether specific conservation management actions being implemented for their protection. The status of recovery plans for these species is shown in Table 12.15.

Table 12.15 Status of recovery plans for fauna species listed under the Endangered Species Protection Act

Species	Scientific name	Recovery plan prepared?
White-bellied frog	*Geocrinia alba*	Yes
Malleefowl	*Leipoa ocellata*	No
Woylie	*Bettongia penicillata*	Yes
Chuditch	*Dasyurus geoffroii*	Yes
Numbat	*Myrmecobius fasciatus*	Yes
Western ringtail possum	*Pseudocheirus peregrinus*	In preparation
Orange-bellied frog	*Geocrinia vitellina*	Yes
Long-billed corella	*Cacatua pastinator pastinator*	No
Crested shriketit	*Falcunculus frontatus leucogaster*	No

Formal recovery plans have only been written for the six species listed in Table 12.15. The preparation of interim recovery plans will be addressed in the implementation of the RFA.

There are currently 18 listed vertebrate species relevant to the RFA which are declared as rare or threatened under the Western Australian *Wildlife Conservation Act 1950*. Eleven invertebrate species that occur in or near the RFA region are also declared as rare or threatened under the Act. CALM takes these species into account in the course of management activities.

12.8 SOILS AND LANDFORMS

Introduction

An understanding of geomorphology, soils and landforms is relevant to several aspects of the Comprehensive Regional Assessment. Maps of soils and landforms are an important foundation layer for the assessment of biodiversity and an aid to vegetation mapping, particularly in forest types where floristic differences are not reflected in the structure of the vegetation and are thus not capable of being mapped from aerial photographs. Maps of soils and landforms have been used as a basis for vegetation mapping in the south-west region (Heddle 1979; Wardell-Johnson et al. 1995).

Previous soils and landform maps

According to Mattiske (1997) the earliest mapping of geomorphological units began in the 1920s and 1930s (Clarke 1926, Jutson 1934). The main relevant development began in the agricultural areas (Mulcahy et al. 1961), and then in the forested areas (Mulcahy et al. 1972, Finkl 1976). It was at this stage that the linkages between geomorphology and plant ecology were developed through mapping of vegetation over a range of geomorphic units. The geomorphological mapping was extended by McArthur et al. (1977) to the Murray catchment and by Churchward and McArthur (1980) to the entire forested region north of the Blackwood River.

McArthur and Clifton (1975) extended the geomorphological mapping to the south coast near Pemberton, dealing not only with geomorphology, but also with vegetation and land use. Their work was subsequently expanded by Churchward et al. (1988) to cover the bulk of the south coast from Northcliffe to Mt Manypeaks.

Parallel to the work of the CSIRO Division of Land Resources by Mulcahy, McArthur and Churchward, a Land Resources Series was begun by Agriculture Western Australia which helped in filling in some of the gaps in geomorphological mapping. Initially the latter mapping did not include areas of State forest. The areas mapped were the Darling Range, east of Perth (King and Wells 1990) and the Northam region (Lantzke and Fulton 1992). In the southern region, Tille and Lantzke surveyed the Busselton-Margaret River-Augusta area in 1990. The last study of Churchward in Manjimup (1992) formed part of this series. There have been minor differences in the approach from the CSIRO and Agriculture Western Australia researchers, nevertheless both approaches have provided valuable linkages between geomorphology and vegetation.

Methods

Soil and landform mapping project for the CRA

A project was undertaken for the CRA to complete soil and landform mapping in all unmapped areas and to provide a single seamless map for the entire RFA region. Resources were provided to Agriculture WA to accelerate the current mapping program in areas within the RFA region boundary. All existing soil and landform maps were collated and standard descriptions prepared. Boundaries between all of the new and previous survey map sheets were rationalised and edge mapped to derive a single map for the region.

Results

A comprehensive digital map of soils and landforms has been completed for the entire RFA region. There are more than 200 landform and soil units in 27 groups within the region.

12.9 MAPPING OF REMNANT VEGETATION COVER ON PRIVATE LAND

The aim of the project was to provide a map of the extant forest and woodland vegetation derived from Landsat Thematic Mapper satellite data captured in 1990 and 1995 covering the South-West Forest Region of Western Australia. The output will be used in the integration phase of the Western Australian RFA to provide base data for identification of forest and woodland on private lands for the calculation of reservation targets.

The first phase of the project was contracted and completed by CSIRO Mathematics and Information Sciences using a method developed by the Western Australian Department of Land Administration and Agricultural Western Australia for a Commonwealth funded project, “Monitoring Agricultural Land Cover Change”. In brief, the method involves image rectification and calibration to pseudo-reflectances. A statistical analysis is used to define spectral indicators of woody vegetation. A final map is produced to highlight the woody versus non-woody extents and thus a strategic picture of the spatial extent of remnant vegetation.

Subsequent analysis removed plantations and public land from the database to derive remnant native vegetation on private land. Patches of vegetation less than 25 hectares in area were also removed from the dataset to simplify the analysis.

No field validation or direct forest ecosystem attribution of this information has been possible. While it is expected that the technique will provide good estimates of tree cover it is unable to detect the condition of the understorey within these stands. The data will therefore include significant areas which consist of native tree cover over exotic pasture. Extensive field work would be required to determine the extent of this condition, particularly given the variable nature of past management of these private lands.

Attribution of the remnant vegetation native vegetation to a forest ecosystem was done using the statistical relationship that exists for forest ecosystems (mapped on public land only) and vegetation complexes and extrapolating to the remnant native vegetation on private land (for which vegetation complex mapping has been done). The method is similar to that used to estimate pre-1750 area of forest ecosystems described in more detail elsewhere in this report. The exception to this method was that used for karri forest which had previously been mapped directly on all lands.

The estimated area of remnant native vegetation on private property in the South-West Forest Region is 350 649 hectares (see Table 12.3 and Map 13).

12.10 HISTORICAL FIRE FREQUENCY

Introduction

Fire is an important agent of disturbance in the South-West Forest Region. To gain an improved understanding of the fire regimes that the biota of the region has been subjected to, this project sought to reconstruct fire frequency over the past 200 years by analysing grasstree stems.

Methods

Grasstree stems (*Xanthorrhoea* spp.) were cleaned to reveal coloured annual growth rings and bands of darkly pigmented leafbases that are observed where fires are known to have occurred in recent times. From the frequency of these dark bands in former times, an implied fire history can be reconstructed as far back as 1750. It has been shown that the technique can reconstruct fire history accurately for sites where the recent fire history is known, for example on farms, where living members of the family can verify fire history from the 1920s to the present (Ward in press).

A stratified random survey design was proposed, involving 36 sites throughout the jarrah forest. These sites were to cover different landforms, rainfall zones and vegetation types. At each site the aim was to sample at least two grasstrees, but more if possible, so giving a sample size of at least 72 grasstrees. Both tall and short grasstrees were to be sampled at each site to test the hypothesis that fires may pass under tall grasstrees without igniting them, so giving an underestimate of fire frequency.

Some chemical analysis was proposed to determine the nature of the dark pigment and its possible genesis, and also to determine if there was a link between fires and subsequent changes in nutrient and trace element levels in the stem of the grasstrees.

Results

The search for sample sites was constrained by the rarity of tall grasstrees in good condition. Eventually 50 sites were found and 150 grasstrees were cleaned and recorded, giving a data matrix of 1548 decades of record. The height of these grasstrees ranged from 0.6 to 4.3 metres, and the aim of at least one tall and one short grasstree at each site was achieved. Annual rainfall at the study sites ranged from 680mm to 1390mm. About half the sites were in the southern jarrah understorey community, and half in the northern type. It proved impossible to achieve a balanced number of sites on ridges, midslopes and valleys, since grasstree occurrence is strongly biased toward valleys.

A multiple regression was used as an initial test of the effect of annual rainfall on fire frequency over the past two centuries. This was intended only as a test of hypothesis and not as a prediction tool. This is a preliminary analysis and more sophisticated analyses may be possible, but will take more time than was available for this preliminary report.

Fires tended to be more frequent at study sites in the lower rainfall zones, and taller grasstrees (at the time of the fire) tend to give a lower estimate of fire frequency. No simple relationship with understorey community or landform was found.

Fires/decade = 23.8 minus 0.0014 rainfall (mm) minus 0.685 height (m) minus 0.0103 decade

N = 1548, F – 398, $p<0.001$, R-squared = 43.5%

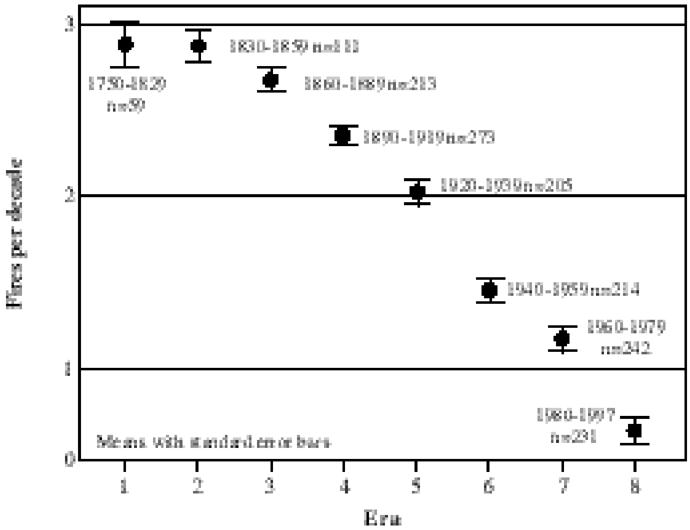
The data were grouped into eight historical eras, shown below with brief reasons for the selection of that era:

1. 1750-1829—pre-European era, fires from lightning and Noongar burning
2. 1830-1859—early settlement, with traditional Noongar burning still common
3. 1860-1889—decline in Noongar population
4. 1890-1919—uncontrolled logging with severe wildfires
5. 1920-1939—attempted fire exclusion by Forests Department, but severe wildfires
6. 1940-1959—World War II and post-war period
7. 1960-1979—introduction of controlled burning after Dwellingup fire
8. 1980-1997—recent

Figure 12.1 shows the pattern of fire frequency as far back in time as 1750, as interpreted from the black marks on stems of grasstrees. In the pre-European era, there appears to have been about 3 fires per decade. This same frequency of fire appears to have continued in the era of early settlement by Europeans. In the period 1860-1889, a drop in fire frequency is apparent, with an average of about 2.7 fires per decade.

The pattern of declining fire frequency appears to continue right through to the present era. In the period 1890-1919 average fire frequency appears to have been about 2.4 fires per decade; in 1920-1939 average fire frequency appears to have been about 2 fires per decade, in 1940-1959 average fire frequency appears to have been about 1.4 fires per decade; in 1960-1979 average fire frequency appears to have been about 1.2 fires per decade; and in 1980-1997 average fire frequency appears to have been about 0.6 fires per decade.

Figure 12.1 Fire frequency at 50 sites in the jarrah forest as interpreted from black marks on the stems of grasstrees



Although the standard errors shown in Figure 12.1 are small, there is considerable variation of the individual observations about the mean. Table 12.17 aids in understanding the variation in apparent fire frequency, and its implications for the fire regime of that era.

Table 12.16 Comparison of implied Aboriginal and recent fire regimes in jarrah forest

Frequency (fires per decade)	% of fires from 1750-1829	% of fires from 1980-1997
<1	0	49.4
1	5.1	45.8
2	15.3	4.8
3	64.4	0
4+	15.3	0

From Table 12.17, it appears that in the pre-European era approximately 80% of the study sites in jarrah forest was burnt at a frequency of 3 to 4 fires per decade (i.e. 2 to 4-year intervals between fires), with the remaining 20% burnt less frequently (i.e. 4 to 20-year intervals between fires). On average, fire frequency appears higher on sites in the low rainfall eastern jarrah forest, with only 2 to 3-year intervals between fires. Study sites in the high rainfall zone closer to the Darling scarp had a modal fire interval of 3 to 4 years. A wet site in the sunklands west of Nannup showed 6 to 10-year intervals between fires.

Very preliminary chemical analyses of leafbases of grasstrees has been completed. The current data on the dark pigment of the leafbases supports the hypothesis that the dark pigment is formed by fires killing green grasstree leaves. Thus, the dark pigment appears to be a reliable marker for fire. The chemical analysis also shows a rise in the calcium and zinc content of leafbases directly above the dark bands.

Discussion

In the recent era the fire regime appears to be quite different to that in pre-European times. Ninety five percent of study sites in jarrah forest was burnt with a frequency of less than 2 fires per decade. Only 5% of the study sites in jarrah forest appears to have been burnt at a frequency of 2 or more fires per decade, in contrast to the 1750-1829 era where the corresponding figure was 95% of sites in the jarrah forest. The estimate for the current era may be a slight underestimate because of fires not always igniting the thatch of tall grasstrees.

While the results of this study suggest a higher fire frequency in the jarrah forests under the pre-European Aboriginal fire regime than occurs today, the tendency of grasstrees to be located in valleys and the resulting sampling bias means that some caution is necessary in extrapolating these results across the landscape. Research into traditional Aboriginal burning practices and routes of movement may also assist in the interpretation of these data.

12.11 CONTEMPORARY FIRE REGIMES

Introduction

Fire management in Western Australian forests has been controversial. This project is about only one aspect, albeit an important one, of fire management—the changes in fire regimes that have taken place since settlement by Europeans in 1829. Changes over the past 40 years are given particular emphasis, as this is the period for which most data were available.

Methods

The project concerned the compilation and analysis of qualitative information and quantitative data concerning areas of prescribed and unplanned fires for the duration of the Forests Department (earlier) and CALM records (later). The methods used depended upon the nature of the information available. Background information essential to the understanding of the quantitative data was obtained from a detailed review of departmental and sectional annual reports, books, journal articles and unpublished sources. Quantitative analyses were carried out on figures gleaned from annual reports, or on those supplied by CALM, using the SYSTAT for WINDOWS package (SPSS 1996). Computer programs examined hypotheses using time-since-fire data from the Forest Management Information System (FMIS).

Results

General

A feature of the data for the south-western forests was that every data set showed considerable variation as a result of various policy changes, natural events or history of the area. Nothing was constant; equilibria did not exist. Apart from the expected variations in areas burnt, there was variation over time in the areas of State forest and Timber Reserves, the “Protected Area” and areas of fire exclusion; there was variation in fire cause and number of fires per year; there was variation in areas logged and in silvicultural systems. Categories of variables were not always considered uniformly—such as tenure categories for numbers of fires. Even the names or definitions of variables seemed to shift over time. Terms for areas where fire was actively used as a management tool include “Protected Area” and “area under fire control” while fires lit for management purposes may be “controlled burning” or “prescribed burning”. These name changes could be trivial but may well reflect changes made in attitude, policy, practice or area to which the data applied. These variations affected the quality of the analyses.

Fire regimes

Patterns of burnt ground may be observed *in situ* or on maps. They are generated by fire edges burning with different intensities, an important point ecologically. Burn patterns that we can see are the manifestation of stand-age or time-since-fire distributions for the entire landscape. In turn, time-since-fire distributions translate into fire-interval distributions (Johnson and Gutsell 1994). Fire-interval distributions and fire-intensity distributions may be seen as two major components of the fire regime, the others involving seasonality of fire occurrence and fire type (Gill 1975). Burn patterns, time-since-fire patterns and fire-interval distributions can be depicted as three levels of organization in relation to fire regimes, all of which are important in considerations of the effects of fires on biodiversity (Gill 1997).

Burning patterns

Where and when fires occur each year, and their sizes and intensities, determines the fire regime. In the 1930s there appear to have been large proportions of the forest estate burnt each year while other areas, particularly prime timber areas, were protected from fire. In the 1940s the area protected probably increased while the area burnt as often as possible probably declined. From the early 1950s until about 1969 the proportionate area of the forestry estate burnt by prescription increased, thereby shortening the average fire interval. After 1969 the area prescribed burnt progressively declined.

Today, prescribed burning levels—as a proportion of area managed—are similar to those existing around 1950, if the "Protected Area" is used as a base, and similar to those of about 1960, if the area of the forestry estate as a whole is used. The peak for the proportion of the forestry estate being burnt was in the late 1960s when it is likely that the effects of the 1960-61 Dwellingup fires were still strongly affecting burning policy and practice. At that time, aerial ignitions of prescribed fires were taking over from those ignited by hand.

The rise and subsequent decline in the proportions of the forestry estate being burnt was probably due to many factors including changes in policy, sources of ignition, cost, intensity of management and the rise of awareness of the environment by the public at large. In the past 40 or 50 years, management fires have burnt a much greater proportion of the forest estate per year than unplanned (or "wild" fires) have done. A qualified exception to this is the year of the economically disastrous Dwellingup fires, 1960-61.

Changes in burning policy in the early 1950s were directed towards better management of unplanned fires. Even so, in the early years of this policy, unplanned fires damaged the timber resource and, on one occasion, destroyed the township of Dwellingup. Maximum fire intensities for unplanned fires were, on average, much higher than those for prescribed fires. Interestingly, Forests Department records show that unplanned fires created burning patterns in which an average of about 56% of the area was burnt at low intensity.

Unplanned fires have a wide variety of sizes but it is the very few large fires that burn most of the cumulative area. The numbers of these fires attended by Departmental staff declined on average from 1937-38 to 1979-80 but have risen subsequently, apparently due to an increase in the number of deliberately-lit fires in pine plantations.

One might expect that unplanned fires would be distributed at random. While this may have the greatest chance of being true for fires ignited by lightning, it may not be so as far as deliberately lit fires are concerned. The many fires started by mill locomotives in the 1940s and 1950s would have been relatively predictable in location. The literature suggests that prescribed fires have been regular rather than at random intervals but, because an average of about 70% of the area designated for prescribed burning is actually burnt, there is opportunity for variability within a burning block. An appearance of randomness may arise when the forestry estate is examined as a whole because of the considerable variation in environments, vegetation types and logging patterns—and thus burning patterns—to be found within it. Some of the variety in burning patterns among Forests Districts was demonstrated.

Patterns of burning may be expressed mathematically, but not in a spatially explicit way, as "hazard" functions (Johnson and Gutsell 1994). Hazard functions describe the probability of a point in the landscape burning. They are the mathematical base for the derivation of stand-age and fire-interval functions. Usually hazard functions are derived mathematically once the stand-age functions for landscapes have been estimated from maps. This practice can create problems because a number of random models can produce similar stand-age functions which may be hard to distinguish when using field data (McCarthy et al. in review). However, with the successive yearly maps of fire data available for recent seasons from spatially-explicit FMIS, hazard functions can be estimated directly. This report proposes what hazard functions may be appropriate on the basis of *a priori* argument and we found some support for these in the spatially explicit research on fire histories of the Collie District conducted by S Lang (pers. comm.) in parallel with this study.

Lang found that hazard functions have changed with time implying a change from more random to more regular fires. Data for fires from the late 1930s to the late 1980s indicated that a threshold may be reached in the extent of prescribed burning in so far as it influences the extent of unplanned fires but Lang (pers. comm.) and the authors emphasise that this result should not be accepted uncritically.

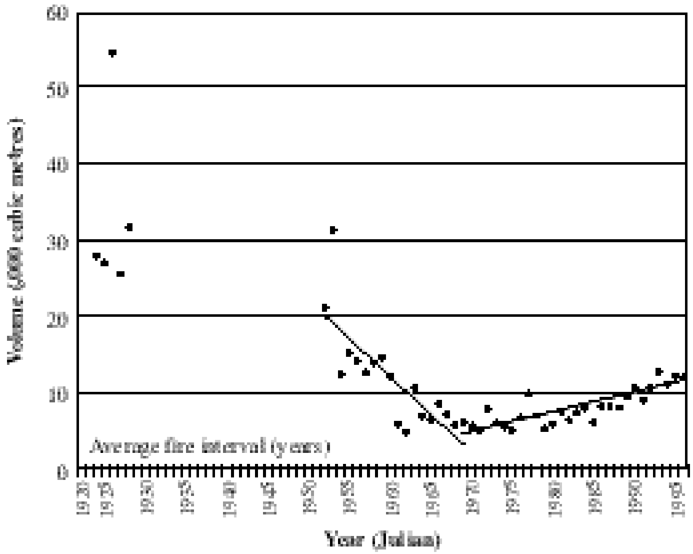
Times since fire

Times-since-fire can be reflected in the forested landscape as regrowth, soon after high intensity fire, and "old growth", long after high intensity fire. Similar expressions of change can be seen in the forest understorey even after low intensity fire. Indeed, ecological changes in understorey are often expressed in terms of the time since the last fire. As times since fire increase, it may be expected that the areas involved would decrease smoothly but the patterns we observed were somewhat irregular. All forest districts showed considerable variation in areas having different times since fire.

Intervals between fires

Intervals between fires are ecologically important for the survival of the biota. With inappropriate intervals, some Australian species have gone locally extinct (Gill and Bradstock 1995). Intervals between fires in south-western Australia have changed in concert with changes in policy. They declined from the early 1950s to the late 1960s then increased linearly with time subsequently. Figure 12.2 indicates this but any interpretation of the graph, quantitatively, needs to be made in conjunction with the details of its construction as outlined in the full report.

Figure 12.2 Changes in fire interval interpreted from Forests Department and CALM records



Early data are sparse and should not be regarded as being continuous with that from the early 1950s. The interval scale needs to be considered in the light of information given in the full report. Data, albeit incomplete, span the period 1921-22 to 1995-96.

Recommendations

1. Accurate mapping of internal as well as external perimeters of unplanned and prescribed fires should be undertaken. Given the cost entailed, it would be worth investigating new methods of data capture and recording. There has been no determination of the extent of overlap of repeated prescribed fires, an important point in relation to the quantitative determination of fire intervals at a point. The hypothesis that prescribed fires burn at random within a block should be tested. For unplanned fires, the hypothesis that the fire perimeter includes unburnt areas, the proportion of which changes with fire size, should be examined.
2. Fire maps, available from 1937, should be incorporated into a spatially-explicit data base. Commercially available packages could be compared and contrasted formally with the in-house FMIS package. Protocols have been established for the capture of the data from micromaps (S Lang pers. comm.). Times of fires, fire-category and association, if any, with logging should be stated. A computer file linked to the data base should be established and added to each year in order to detail pertinent aspects of each season's fires, and any associated silvicultural operation, in order to avoid possible future difficulties of retrospective interpretation of mapped categories. Having accurate maps should avoid the problem of knowing which administrative category was the basis of the observations made.

3. Spatially-explicit analyses of fire maps should be undertaken in order to determine past fire regimes throughout the forest estate.
4. Fuel measurements in long-unburnt plots should be taken to extend the range of current measurements and models.

12.12 SURVIVAL OF HOLLOW-BEARING JARRAH AND MARRI TREES

Introduction

There are 42 species in Western Australia's forests that use hollows in standing trees; 21 are birds, 16 are mammals and five are reptiles (Abbott pers. comm.). Twenty-four of these species are considered totally dependent on tree hollows for breeding. Logging of the jarrah forest since the 1860s has preferentially removed the larger trees that are most likely to provide hollows suited to the larger of these animal species. To lessen this impact, CALM marks and retains habitat trees when logging jarrah forest. The current tree-marking prescription specifies the retention of an average of four habitat trees per hectare on all forest logged under shelterwood and thinning prescriptions, and the retention of an additional six to eight potential habitat trees on areas logged to gap (CALM 1995). The specification of the type of trees to retain is based on the research of Inions (1985), Faunt (1992) and Whitford (unpublished data).

To manage for the ongoing availability and the timely recruitment of replacement habitat trees, it is necessary to know the probable fate of these habitat trees over time.

This retrospective study examined how long habitat type trees remain standing after logging, and how the probability of habitat tree fall (i.e. tree fall due to natural causes) is related to tree and site characteristics. Results from a preliminary analysis of the data are described in this report.

Methods

CALM's current habitat tree specification, (Appendix 5, Silviculture Specifications, CALM 1995a) specifies retained habitat trees be mature to senescent, greater than 70 cm in diameter and be from intermediate senescence classes (selected from an eight class pictorial scale). As trees of this size are less common across the forest than smaller trees, it was assumed that the mechanisms responsible for tree fall would operate similarly on smaller trees, and trees down to 50 centimetres in diameter were included in the study. This enabled the efficient collection of data from a large number of trees.

Tree fall after logging was surveyed on and around hardwood permanent increment plots (HPIPs) at 79 sites distributed throughout the South-West Forest Region. Trees on HPIPs, which were subject to the standard practices at the time of logging (between 1920 and 1992), have been measured since 1943. A range of logging practices has been applied over this period, with 18 of the sites never having been logged. On these unlogged sites the period of observation was taken as being from 1920 to the present and the fall date of logs on these sites, and on the transects around the HPIPs, was determined by assessing the degree of log decay. The period of observation of the sites ranged from five to 77 years with a mean period of observation of 46 years. A total of 2526 trees was assessed.

Results

Figure 12.3 shows the diameter distribution of trees observed in this study and Table 12.18 shows the source and status of these jarrah and marri trees.

Figure 12.3 Diameter distribution of all assessed trees and logs
n=2526

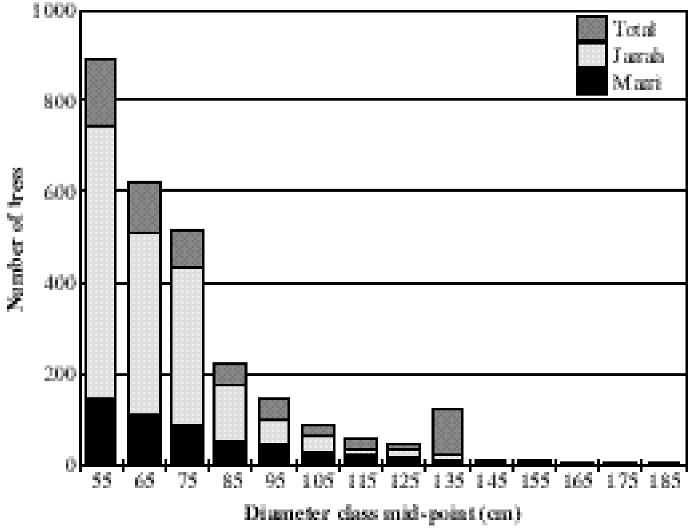


Table 12.17 Source, species and status of 2526 trees observed on 79 sites

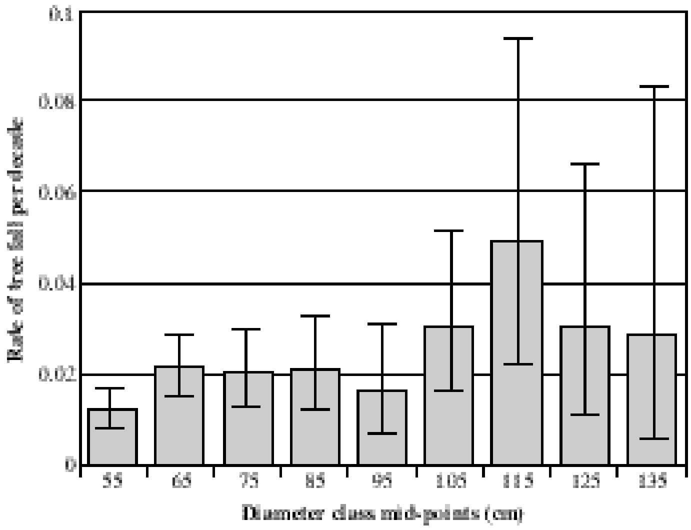
Source	Jarrah standing	Jarrah fallen	Marri standing	Marri fallen	All trees totals
HPIPs	612	17	150	6	785
Transects around HPIPs	1232	145	338	26	1741
Totals	**1844**	**162**	**488**	**32**	**2526**

Over the study period of approximately 46 years very few (7.7%) of the 2526 trees fell. It was expected that the lower decay resistance of marri compared with that of jarrah (Da Costa 1979) would result in marri trees falling more frequently than jarrah. This was not observed. There was no significant difference between the percentage of marri trees that fell (6.2%) and the percentage of jarrah trees that fell (8%).

Rate of tree fall

The rate of tree fall was calculated as the proportion of the observed trees falling per decade. Figure 12.4 shows the rate of tree fall in each diameter class. The rate of tree fall generally increases as the diameter of the trees increase, from 1.2% per decade for trees of 50 to 60 centimetres, to 3.1% per decade for trees of 120 to 130 centimetres.

Figure 12.4 Rate of tree fall per decade by diameter class
Error bars are 95% confidence intervals



The mean rate of tree fall for all sites was 2% per decade (see Table 12.19). Considering only those trees with diameters of 70 centimetres or greater, the mean rate of tree fall was 2.4% per decade.

Table 12.18 The rate of tree fall per decade for 61 logged sites and 18 sites that had never been logged observed over a mean period of 46 years

	All sites %	Logged sites %	Unlogged sites %
Trees >= 50 cm	2.0	1.7	2.6
Trees >= 70 cm	2.4	2.1	3.1

Comparing logged and unlogged stands

The rate of tree fall on sites that had never been logged (2.6% per decade, n = 18 sites) was greater than the rate of tree fall on logged sites (1.7% per decade n = 61 sites). This result most likely occurs because there are more large trees on unlogged sites and large trees are more likely to fall than small trees.
This will be examined further in the final report.

Causes of tree fall

Hollow butt and fire

The major cause of tree fall was hollowing out of the base of the tree (hollow butt), and the subsequent failure of the tree at this point. The mean amount of hollow butt of the fallen trees was 62% while the mean amount of hollow butt of standing trees was 7%. Fire was assessed as a major cause of tree fall in 63% of cases.

Wind, termites, and rot

The effects of wind alone, or wind in association with causes other than fire, was assessed as a major cause of tree fall for 37% of fallen trees. These trees were either blown over with their root plate intact, or the stem was broken, frequently in association with termite damage or rot (74% of these wind blown cases).

Termite infestation was assessed as a major cause of tree fall in only 16% of cases. It was predominantly a contributing cause weakening the bole or roots, or aiding the development of hollow butt, and thus leading to wind damage. Similarly, significant weakening of the stem or roots by rot was rarely identified as a major cause of tree fall. Logging activities were a direct cause of the loss of four of the 2526 trees.

Table 12.19 Major causes of tree fall assessed on 194 fallen trees observed on 79 sites in the jarrah forest

Causes tree of fall	% of cases
Fire and wind	39
Fire and termites	4
Fire and rot	1
Fire alone	19
Wind alone	10
Wind and rot	16
Wind and termites	11
Termites alone	1

Management implications

The rates of fall of jarrah and marri trees greater than 70 centimetres in diameter (2.4% per decade) are an order of magnitude below those observed by Lindenmayer et al. (1990) in ash-type forest (36% per decade). Based on this estimate, 96 of the 400 habitat trees retained after logging of 100 hectares of jarrah forest will fall in a 100-year period. This low rate of loss of habitat trees is unlikely to have a major impact on hollow availability as many of the smaller trees retained on logged areas will grow into hollow-bearing size and condition over this period.