Forest Ecosystem Classification and Mapping for the Eden Comprehensive Regional Assessment

A report undertaken for the NSW CRA/RFA Steering Committee

FOREST ECOSYSTEM CLASSIFICATION AND MAPPING FOR THE EDEN COMPREHENSIVE REGIONAL ASSESSMENT

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Report Status

This report has been prepared as a working paper for the NSW CRA/RFA Steering Committee under the direction of the Environment and Heritage Technical Committee. It is recognised that it may contain errors that require correction but it is released to be consistent with the principle that information related to the comprehensive regional assessment process in New South Wales will be made publicly available.

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This project has been jointly funded by the New South Wales and Commonwealth Governments. The work undertaken within this project has been managed by the joint NSW / Commonwealth CRA/RFA Steering Committee which includes representatives from the NSW and Commonwealth Governments and stakeholder groups.

The project has been overseen and the methodology has been developed through the Environment and Heritage Technical Committee which includes representatives from the NSW and Commonwealth Governments and stakeholder groups.

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1. EXECUTIVE SUMMARY

This report has been prepared for the joint Commonwealth/State Steering Committee which oversees the comprehensive regional assessments (CRAs) of forests in New South Wales.

The CRAs provide the scientific basis on which the State and Commonwealth governments will sign regional forest agreements (RFAs) for the major forests of New South Wales. These agreements will determine the future of the State's forests, providing a balance between conservation and ecologically sustainable use of forest resources.

This report was undertaken to develop a classification and map of forest ecosystems for the Eden region, consistent with specifications of the Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee (JANIS 1997). Forest ecosystems are the primary surrogates for biodiversity used in CRAs.

The scope of this work, as approved by the Environment and Heritage Technical Committee, was to 'refine the [Interim Forest Assessment] map, incorporating the best available past and proposed aerial photo-interpreted mapping, additional audited survey plot data and improved terrain, substrate and climate variables.'

To achieve this end, forest ecosystem classification in Eden followed an approach recommended by the Forest Ecosystem Working Group (1997) which had previously been applied in the Interim Forest Assessment Process (RACAC 1996, Keith et al. 1995). The approach entailed: hierarchical multivariate classification of floristic data; definition of ecosystem units from the hierarchy based on their floristic, structural and environmental integrity; and mapping using environmental relationships and remote sensing (Aerial Photography Interpretation) as a basis for spatial interpolation. Modification of the map used in the Interim Forest Assessment (IFA) was also required to accommodate new data and to extend the analysis over an additional 140 000 hectares in the north-west of the region (Numeralla-Wadbilliga).

Seventy-six forest ecosystems were classified and mapped in the Eden region, including 47 forests dominated by eucalypts, six rainforests or scrub forests with rainforest affinities, 12 shrublands and heathlands, and three swamps. Four ecosystems were estuarine wetlands associated with the high tide mark and a further four ecosystems were restricted to estuaries below low tide mark (sea grass meadows) and consequently were excluded from the CRA. Comprehensive descriptions of each ecosystem are presented in this report.

Ecosystems were mapped using a hybrid decision tree model/expert system that was developed and proofed iteratively. The model related the occurrence of ecosystems to spatial patterns in mapped environmental variables (parent material, terrain and climate) and in the structure and composition of the tallest vegetation stratum as interpreted from aerial photographs. The resulting map of pre-1750 ecosystems was cut using a 1994 Landsat coverage of extant native vegetation cover to derive extant distributions of forest ecosystems. An assessment of map accuracy using independent sample data indicated 92% accuracy within spatial neighbourhoods of 95 hectares. The forest ecosystem map is available under licence from the NSW National Parks and Wildlife Service.

1. INTRODUCTION

1.1 COMPREHENSIVE REGIONAL ASSESSMENT

As part of the Regional Forest Agreement (RFA) process, a Comprehensive Regional Assessment (CRA) was carried out to evaluate the economic, social, cultural, environmental and heritage values of the Eden region. The CRA provided scientific information needed to develop a comprehensive, adequate and representative (CAR) forest reserve system, the establishment of which is an agreed outcome of RFAs and a commitment of the National Forest Policy Statement (Commonwealth of Australia 1992). Studies carried out under the CRA are intended to refine the results of preliminary studies carried out as part of an Interim Forest Assessment Process (IFA). Regional Forest Agreements will also establish a regime of Ecologically Sustainable Forest Management for all forest tenures in New South Wales, as well as a framework for agreed social and economic outcomes on forest use.

Components of CRAs involving environmental and heritage values including biodiversity are overseen in New South Wales by the Environment and Heritage Technical Committee. The conservation status of biodiversity will be assessed against conservation criteria at several agreed levels including ecosystems, species, wilderness and old growth (JANIS 1997).

The conservation criteria followed in New South Wales CRAs were defined in general terms by JANIS (1997). These criteria recognise biodiversity as a highly complex system of living things incorporating variation at the genetic, species and ecosystem levels (Commonwealth of Australia 1995). Given the logistic difficulty of surveying and assessing representation of all elements of biodiversity, maps of species assemblages are widely recognised in conservation biology as potential 'surrogates' or 'coarse filters' for biodiversity (Austin and Margules 1986, Noss 1987).

JANIS (1997) identified 'Forest Ecosystems' as the primary surrogate for biodiversity in CRAs. Forest Ecosystems were therefore used as a basis for the assessments of biodiversity. For the development of a CAR reserve system in CRAs, JANIS (1997) established the following guidelines for representation of Forest Ecosystems in reserves:

- 15% of the pre-1750 distribution of each Forest Ecosystem, with flexibility considerations applied;
- 60% of remaining extent of vulnerable Forest Ecosystems; and
- all remaining occurrences of rare and endangered Forest Ecosystems reserved or protected by other means as far as practicable.

JANIS (1997) defined Forest Ecosystems and offered advice for application of Forest Ecosystem mapping as a surrogate for biodiversity in CRAs as follows:

A Forest Ecosystem is 'an indigenous ecosystem with an overstorey of trees that are greater than 20% canopy cover. These ecosystems should normally be discriminated at a resolution requiring a map-standard scale of 1:100 000. Preferably these units should be defined in terms of floristic composition in combination with substrate and position within the landscape.'

The aim of this project was to prepare a classification and map of forest ecosystems for the Eden CRA region.

1.2 APPROACH

The scope of this project, as approved by the Environment and Heritage Technical Committee, was to 'refine the [Interim Forest Assessment] map, incorporating the best available past and proposed aerial photo-interpreted mapping, additional audited survey plot data and improved terrain, substrate and climate variables.'

To achieve this end, forest ecosystem classification in Eden followed an approach recommended by the Forest Ecosystem Working Group (1997) which had previously been applied in the Interim Forest Assessment Process (RACAC 1996, Keith et al. 1995). The approach entailed: hierarchical multivariate classification of floristic data; definition of ecosystem units from the hierarchy based on their floristic, structural and environmental integrity; and mapping using environmental relationships and remote sensing (Aerial Photography Interpretation) as a basis for spatial interpolation. The use of floristics, substrate and topographic position (as in JANIS 1996) to guide definition of ecosystem units from the hierarchy was to constrain an otherwise arbitrary choice of the number of units in the ecosystem classification to a scale of detail intended by the JANIS (1996) criteria. Modification of the IFA map was also required to accommodate new data and to extend the analysis and mapping over an additional 140 000 hectares in the north-west of the region (Numeralla-Wadbilliga).

1.3 STUDY AREA

The study area for the Eden Comprehensive Regional Assessment is the Eden Native Forest Management Area situated between latitudes 36° 20'S and 37° 30'S and longitudes 149° 00'E and 150° 05'E. The region is bounded by the coast in the east, the Monaro Tableland in the west along a line from Nimmitabel to Bombala, the New South Wales-Victorian state border in the south and a line stretching west from Bermagui in the north.

The region covers approximately 800 000 hectares including areas of natural vegetation, dedicated primarily to timber production and conservation, and areas of cleared land used mainly for agriculture and plantation forestry. The climate, physiography and geology of the region is described by Keith and Sanders (1990).

2. METHODS

2.1 VEGETATION SAMPLING

2.1.1 Data Evaluation

All available vegetation data were reviewed and evaluated for use in the Eden Comprehensive Regional Assessment (Table 2.1). These data originated from numerous surveys of local management areas (for example, Gilmour 1983, Binns and Kavanagh 1990a) and from a regional survey carried out in several phases between 1987 and 1997 (Keith and Sanders 1990, Keith et al. 1995).

A total of 3168 samples were evaluated, from which 1590 were selected for analysis and either modelling or validation. All 3168 samples were located on the Australian Map Grid with a precision of at least 100 m. The following criteria were used to select samples of suitable quality for analysis:

(I) Area of plot within the range 0.04 - 0.1 hectares;

(II) Complete list of vascular plant species within the plot;

(III) Species cover-abundance preferably estimated on six-point Braun-Blanquet scale;

(IV) Assignable to a forest ecosystem with a high level of certainty.

The limits suggested in Criterion I were supported by trial data analyses in which the outcome of cluster analysis was not sensitive to variation in sample size between 0.04 and 0.1 hectares. All samples met Criterion I except those of Gilmour (1983) for which the dimensions of plots were not recorded. However, it is likely that most of these samples fell within the 0.04 - 0.1 hectares range (Gilmour, pers. comm.). All samples met Criterion II, although it is likely that a few inconspicuous species may have been overlooked in some samples, particularly geophytes which may be absent above ground during certain seasons or years. A large number of additional samples were not considered for analysis because they included tree species only. Tree species make up approximately 5% of the known vascular flora of the Eden region.

Approximately half of the samples had species cover-abundance data on the six-point Braun-Blanquet scale (Poore 1955) and a further 173 samples had species frequency scores based on nested quadrats (Outhred 1985). Criterion III excluded from analysis 943 samples that had species presence/absence data only (Breckwoldt 1979, SFNSW unpublished) and 309 samples that had qualitative species abundance classes (for example, Gilmour 1983). In some surveys (for example, Fanning and Mills 1990a), species were assigned multiple abundance estimates for respective strata, but no overall estimate for the plot. Criterion IV excluded from analysis a further 326 samples that could not be assigned with acceptable certainty to vegetation classes defined by floristic analyses carried out previously on 1066 samples (Keith et al. 1995).

The certainty of sample assignments was determined by consensus among four alternative multivariate methods (see below). The regional coverage of vegetation data was largely unaffected by the exclusion of samples that were unsuitable for analysis. Their exclusion was therefore unlikely to have a major impact on sample stratification.

TABLE 2.1: VEGETATION DATA SETS EVALUATED

Reference	Location surveyed	No. samples	Species recorded	Plot size (ha)	Abundance measure
Binns & Kavanagh 1990a	Nalbaugh State Forest	62	All vascular	0.1	Braun-Blanquet
Binns & Kavanagh 1990b	Nullica State Forest	91	All vascular	0.1	Braun-Blanquet
Breckwoldt 1979	Bermagui Nature Reserve, Bournda Nature Reserve, Goura Nature Reserve, Mimosa Rocks National Park, Wallaga Lake National Park	385	All vascular	0.1	Presence/absence
Clarke 1988	Coastal dunes	84	All vascular	0.04	Braun-Blanquet
Dodson et al 1988	Tantawangalo catchment	30	All vascular	0.1	% Cover
Fanning & Clark 1991	Jingera, Nullica State Forest	66	All vascular	0.1	Braun-Blanquet
Fanning & Fatchen 1990	Wog Wog Creek	113	All vascular	0.1	Braun-Blanquet
Fanning & Mills 1989	South Rockton, Bondi State Forest	71	All vascular	0.1	Frequency index
Fanning & Mills 1990	Myanba Creek	107	All vascular	0.1	Intuitive index
Fanning & Mills 1991	Stockyard Creek	66	All vascular	0.1	Intuitive index
Gilmour 1983	Nadgee Nature Reserve	65	All vascular	undefined	Intuitive index
Keith et al 1987-1997	Eden region	1147	All vascular	0.04	Braun-Blanquet
Outhred 1986	Wadbilliga National Park	173	All vascular	0.1	Frequency score
State Forests (NSW)	Coolangubra Escarpment Forest Reserve	22	All vascular	0.1	Braun-Blanquet
State Forests (NSW)	Illawambra Forest Reserve	21	All vascular	0.1	Braun-Blanquet
State Forests (NSW)	Mt Poole Forest Reserve	24	All vascular	0.1	Braun-Blanquet
State Forests (NSW)	Waalimma Forest Reserve	22	All vascular	0.1	Braun-Blanquet
State Forests (NSW)	Yambulla Forest Reserve	6	All vascular	0.1	Braun-Blanquet
State Forests (NSW)	Yambulla catchments	558	All vascular	0.1	Presence/absence
Williams 1997	Bermagui Nature Reserve, Biamanga National Park, Goura Nature Reserve, Wallaga Lake National Park	73	All vascular	0.1	Braun-Blanquet

2.1.2 Sample Stratification

Sampling in the regional survey was stratified using classes defined by combinations of elevation, parent material and terrain (Keith et al. 1995). Further sampling carried out during 1997 sought to increase the evenness of samples according to a stratification scheme based on parent material, mean annual rainfall and mean annual temperature, as adopted for the Comprehensive Regional Assessment (Table 2.2). Additional samples were allocated to coincide with locations sampled for vertebrate fauna and to target areas of uncertainty identified during vegetation mapping for the Interim Forest Assessment. These latter areas included Timbillica-Wallagaraugh in the south and the additional area at Numeralla-Wadbilliga in the north west.

TABLE 2.2: SAMPLE STRATIFICATION SCHEME

Lithology class	Rainfall class (mm)	Temperature class (°C)
1 Coastal beach deposits	1 <600	1 <5
2 Alluvium (fluvial and continental)	2 601-900	2 5-8
3 Basic igneous	3 901-1200	3 8.1-12.0
4 Granitic	4 1201-1500	4 12.1-14.0
5 Leucogranitic	5 >1500	5 14.1-16.0
6 Acid volcanic dominant		6 >16.0
7 Basic volcanic dominant		
8 Limestone		
9 Sedimentary (high quartz)		
10 Sedimentary (low quartz)		

2.1.3 Data Variables

The primary vegetation data consisted of lists of species, with respective cover-abundance values, recorded within sample plots of a standard size range (0.04 - 0.1 hectares). Cover-abundance values conformed to a six-point Braun-Blanquet scale (1-<5% and uncommon, 2- <5 and common, 3- 5-20%, 4- 20-50%, 5- 50-75%, 6- 75-100%; Poore 1955). Additional data recorded from each plot included: (i) estimates of the height and cover of each vegetation stratum; (ii) measurements of slope, aspect and horizon azimuths; (iii) parent material; and (iv) qualitative notes on soil moisture, texture and depth, and disturbance history.

Taxonomic nomenclature was standardised according to Harden (1990-1993) and more recent revisions accepted by the National Herbarium of NSW. Standardisation was necessary to eliminate artefacts due to taxonomic changes over the time spanned by collection of the different data sets (1979-1997). Thus, cases in which a single taxon may have been recorded under more than one name in different surveys were removed by assigning the correct name.

2.2 VEGETATION DATA ANALYSIS

2.2.1 Classification Analyses

Data analysis was carried out initially on a core set of 1066 samples (Keith et al. 1995) using the PATN analysis package (Belbin 1994). The core data analyses were conducted during the IFA using methods similar to those used previously by Keith and Sanders (1990). Compositional dissimilarity among samples was calculated using the symmetric version of the Kulzcynski coefficient applied to unstandardised cover-abundance data (Faith et al. 1987). An unweighted pair-group arithmetic averaging (UPGMA) clustering strategy was applied to the resulting association matrix (Belbin and McDonald 1993) to derive a hierarchical classification. Homogeneity analysis (Bedward et al. 1992) was used to identify a level in the hierarchy (dendrogram) from which lineages were to be interpreted for the definition of floristic groups. This technique measures the extent to which group splitting yields improvements in overall homogeneity of all groups based on inter-sample dissimilarities. Thirty-three dendrogram lineages were so identified for further interpretation. These lineages were interpreted at successively lower levels in the hierarchy by assessing differences between sister groups (Keith and Sanders 1990) with respect to diagnostic species, vegetation structure and physical attributes (elevation, aspect, parent material, distribution). Interpretation using these attributes is consistent with JANIS' (1997) criteria for forest ecosystem definition, viz. 'units should be defined in terms of floristic composition in combination with substrate and position in the landscape.' Units were recognised provisionally as forest ecosystems when further splitting failed to yield substantial resolution in variation in any of these factors. The number of units in the forest ecosystem classification was therefore limited by the identification of prominent differences in species composition, vegetation structure and physical habitat.

A nearest neighbour check was carried out to identify samples that may have been misclassified during the clustering procedure, an artefact that may sometimes occur in hierarchical clustering strategies (Belbin 1994). Samples with fewer than two of their five nearest neighbours within the provisional unit to which they were allocated were identified for further evaluation. Alternative allocations of these samples were considered by examining the group affinities of nearest neighbours and respective values of structural and environmental variables.

To modify and refine the classification with new data available since the IFA analysis, further analyses were conducted during the CRA on an expanded data set to assign new samples to existing classification units and, where new variation was apparent, define additional units. Four analyses were carried out to establish relationships to the classification defined by analysis of the core data. These included further cluster and nearest neighbour analyses as described previously, group centroid analyses and indicator species allocation analyses. Group centroid analyses were carried out using ALOC (Belbin 1992, 1994) to determine the five nearest group centroids to each new sample. Indicator species allocation analyses allocated new samples to classification units using the dendrogram as a decision rule structure for the presence or absence of species (Bedward and Keith 1997). The method delivers an indeterminate result for samples with no informative species or where different species suggest conflicting information on group membership.

Where cluster analysis agglomerated new samples into discrete dendrogram lineages, these were assessed against sister lineages and new forest ecosystems were recognised as described previously. The remainder of new samples were assigned to classification units using rules to assess consensus among the four alternative allocation analyses (Table 2.3).

TABLE 2.3: CONSENSUS RULES FOR SAMPLE ASSIGNMENT

A new sample was assigned to an existing classification unit (Group x) if any of the following conditions were met:	
1	Three or more of its five nearest neighbours belong to Group x;
2	Allocated to Group x by cluster analysis AND at least one of five nearest neighbours belongs to Group x AND closest centroid is Group x;
3	Allocated to Group x by cluster analysis AND at least one of five nearest neighbours in Group x AND indicator species analysis suggests exclusive membership of Group x;
4	Allocated to Group x by cluster analysis AND at least two of five nearest neighbour belong to Group x AND second closest centroid is Group x;
5	Allocated to Group x by cluster analysis AND at least two of five nearest neighbours belong to Group x AND indicator species analysis suggests membership of Group x and no more than three other groups.

As part of data evaluation (see Section 2.1), samples that failed to meet any of the consensus rules (Table 2.3) were excluded from further analyses. The conservative data evaluation rules were intended to avoid the introduction of methodological artefacts into the results.

In Outhred's (1985) survey of Wadbilliga National Park species abundance was estimated using a frequency index that was analytically incompatible with Braun-Blanquet cover-abundance estimates. Exclusion of these data would have resulted in an inadequate coverage of samples in this part of the region. To assign samples from Wadbilliga National Park to appropriate ecosystems, it was necessary to carry out supplementary analyses in which all data were reduced to presence/absence format. Lineage assessment and consensus rules were then applied as described previously.

2.3 DESCRIPTIVE TECHNIQUES

Each forest ecosystem was described using summaries of the sample data to produce profiles of species composition, vegetation structure and physical habitat.

Diagnostic species of each ecosystem were defined by the extent to which their occurrence at local and regional scales discriminated the target ecosystem from residual vegetation (pooled samples of all other ecosystems) as shown in Table 2.4. Median cover-abundance represented local abundance, while mean frequency represented regional abundance.

TABLE 2.4: DEFINITIONS OF DIAGNOSTIC SPECIES

		Residual Ecosystems		
		Frequency ≥0.5 AND C/A ≥2	Frequency <0.5 OR C/A <2	Frequency =0
	Frequency ≥0.5 AND C/A ≥2	Constant	Positive diagnostic	Positive diagnostic
Target Eco-system	Frequency <0.5 OR C/A <2	Negative diagnostic	Uninform-ative	Positive diagnostic
	Frequency =0	Negative diagnostic	Uninform-ative	-

Three categories of species were defined: positive diagnostic species (those more likely to occur within the target ecosystem than in all others); negative diagnostic species (those unlikely to occur within the target ecosystem but generally abundant elsewhere) and constant species (those common or dominant in the target ecosystem, but also likely to be common in others). All tree species recorded were listed in the descriptions of each ecosystem for context, irrespective of whether they met any of the three diagnostic criteria.

The vegetation structure of each ecosystem was characterised by calculating the frequency of occurrence, mean height and percentage cover of each of four vertical life-form strata. The four strata were trees, small trees/tall shrubs, shrubs and herbs/graminoids.

The physical habitat of each ecosystem was characterised by calculating summary statistics for terrain variables and parent material from the sample data. These summaries included: the frequency of occurrence on eight classes of parent material (coastal sands, Tertiary alluvium, Genoa sandstone, Devonian sediments, Ordovician sediments, Devonian rhyolite, Devonian granitoids and basalt); frequency of occurrence in five aspect classes (flat, north, west, east and south); mean and range of slope; and mean and range of altitude.

2.4 SPATIAL DATA

A set of spatial data layers compiled for the Eden CRA were rasterised to 25 m square grid cells for use in vegetation modelling. Terrain variables were derived from a 25 m grid digital elevation model supplied by the NSW Land Information Centre (Table 2.5).

Climatic surfaces (Table 2.5) were derived using ESOCLIM (Hutchinson 1989). The sparse distribution of weather stations within the region, and consequent scarcity of weather data, precluded quantitative evaluation of the climatic surfaces. Modelled temperature surfaces were very closely related to altitude and patterns due to local frost hollows were likely to be under-represented. Similarly, rainfall surfaces possibly underestimated regional orographic effects, although intuitively expected patterns were evident.

Spatial data for parent material supplied by the Bureau of Resource Sciences was based on a revision of earlier maps by Beams and Hough (1984) and Department of Mines (1968) and recent field observations. The classification was modified to distinguish coastal sands from other Holocene alluvium, Lochiel Basalt from associated Devonian lithologies and Genoa Sandstone beds from other Devonian sediments (Department of Mines 1968). The final classification included 106 lithological units within the Eden region. Related units were lumped according to dominant lithology into 28 classes and these were lumped further into 7 major formations to provide three hierarchical spatial coverages of parent material (Table 2.5).

TABLE 2.5: SPATIAL DATA LAYERS USED IN MODELLING

GIS COVERAGE	DESCRIPTION
Altitude	Elevation above sea level (metres)
Slope	Inclination from horizontal (degrees)
Aspect	Deviation from grid north perpendicular to slope (degrees)
Sine Aspect Index	Continuous index (0-100) calculated as 100 times sine of half aspect value in degrees (flat sites allocated missing values)
Ordinal Aspect Index	Categorical index of aspect (0: flat, 1: 301-30°, 2: 211-300°, 3: 31-120°, 4: 121-210°)
Solar Radiation Index	Continuous index representing topographic exposure to solar radiation calculated from slope, aspect, horizon azimuth and latitude. Varies below 100 for sheltered sites and above 100 for exposed sites
Wetness Index	Continuous index representing the volume of water draining to a given point in the landscape (after Moore et al. 1993)

Local Topographic Position (S)	Continuous index (0-100) representing proportional distance between local ridge (100) and local gully (0) (after Skidmore 1990)
Neighbourhood Topographic Position (250)	Difference between altitude of a central cell and mean altitude of cells within a 5 x 5 neighbourhood
Neighbourhood Topographic Position (500)	Difference between the altitude of a central cell and mean altitude of cells within a 7 x 7 neighbourhood
Neighbourhood Topographic Position (1000)	Difference between the altitude of a central cell and mean altitude of cells within a 10 x 10 neighbourhood
Neighbourhood Topographic Roughness (250)	Standard deviation of altitude within a neighbourhood of 5 x 5 cells
Neighbourhood Topographic Roughness (500)	Standard deviation of altitude within a neighbourhood of 7 x 7 cells
Neighbourhood Topographic Roughness (1000)	Standard deviation of altitude within a neighbourhood of 10 x 10 cells
Annual Rainfall	Mean total yearly rainfall (mm)
Rainfall of Wettest Month	Maximum mean monthly rainfall (mm)
Rainfall of Driest Month	Minimum mean monthly rainfall (mm)
Minimum Temperature of Coldest Month	Mean minimum monthly temperature (°C)
Maximum Temperature of Hottest Month	Mean maximum monthly temperature (°C)
7-class Parent Material	Major geological formations
28-class Parent Material	Dominant lithologies
106-class Parent Material	Lithological classes
Vegetation Structure	Major vegetation formations (excluding temperate rainforest) determined from aerial photos
Temperate Rainforest	Rainforest determined from aerial photos
Forest Types	Types and mosaics interpreted from aerial photos according to Baur (1989)
Extant Native Vegetation Cover	Presence of extant native vegetation determined from Landsat TM
Distance from Coast	Shortest distance from coast (metres)
Easting	Australian map grid
Northing	Australian map grid

A Geographical Information System (GIS) coverage differentiating native vegetation from cleared land and plantations of exotic species was prepared by manual interpretation of a Landsat TM image taken in 1989 and a map of existing plantations. This coverage was used as training data for a spectral classification of a Landsat TM image taken in 1994. It was assumed that negligible land clearance has occurred between 1994 and 1997.

A GIS coverage differentiating major structural types of native vegetation was prepared by manual interpretation of 1:25,000 scale black and white aerial photographs flown in 1963 (Table 2.5). For small parts of the area where these were unavailable photographs flown in 1979 and 1990 were used. Mapped occurrences of various structural types were checked using the sample data and observations gathered during field traverse. A separate coverage of rainforest was prepared from colour aerial photographs flown in 1994 as part of the Eden CRA old growth mapping study.

Forest Type maps (Baur 1989) prepared by State Forests of NSW were also included in the spatial data set for modelling.

Attribute values were extracted from each spatial data layer for all samples to be used in spatial modelling and validation. Samples were located in the field to a resolution of 100 m. They were assigned to a 25 m x 25 m pixel which had an altitude closest to the mean value within the relevant 100 m grid cell (4 x4 pixel neighbourhood). This assignment procedure was designed to minimise errors in relation to the spatial data layer (digital elevation model) from which most others were derived.

2.5 SPATIAL MODELLING

A hybrid decision tree/expert system technique was selected as the preferred approach for modelling the spatial distribution of forest ecosystems. This technique describes the distribution of map units using decision rules that comprise a series of quantitative statements about spatial variables connected by conjunctions. The distribution of each map unit may be described by one or more mutually exclusive rules. Reasons for choice of this method include:

i) the method is explicit and repeatable relative to intuitively based mapping techniques;

ii) the method is free from statistical constraints and assumptions about the structure of the data;

iii) the method is efficient because sets of decision rules are developed simultaneously for all map units, rather than individually; and

iv) the method allows for intervention by experts in an explicit manner through the choice and design of rules.

The main disadvantage of decision tree models relative to parametric models (for example, generalised linear and additive models) is that they utilise fewer and fewer samples as more variables are fitted. Consequently, inadequate sampling of environmental space may be more limiting, at least superficially, for decision tree models. Comparative studies on the prediction of distributions of individual species suggest that generalised linear models and generalised additive models return slightly more accurate predictions than decision tree models (Ferrier and Watson 1997). However, these trials excluded expert intervention. No comparative studies have yet been carried out on the modelling of multi-species assemblages.

Interactive modelling software (ALBERO) was developed to explore and implement alternative sets of decision rules. The software generates decision rules by statistical induction and facilitates expert intervention at various stages of model development. At each node in the decision tree, ALBERO displays all significant statements discriminating different ecosystems by spatial variables (within a user-specified critical value) and nominates appropriate thresholds for discrimination. Significance is calculated using the Chi-squared statistic. For continuous and ordinal variables, nodes are always split dichotomously at the significant value closest to the midpoint of variation. Non-ordinal categorical variables will split nodes into as many branches as account for significant discrimination of ecosystems. Where two or more spatial variables discriminate ecosystems significantly, the user chooses a selection. Users may reduce the critical value to help make a choice. A decision rule (ie. branch of the decision tree) is complete when there are no further significant splits at the nominated critical value.

ALBERO accommodates explicit expert intervention in the modelling process by offering a choice between multiple significant variables at each node, facilitating exploration of alternative tree structures, allowing non-significant splits to be forced, and allowing definition of data-free terminal nodes. The latter facility accommodates qualitative observations by experts where no quantitative data are available.

A decision-tree model of forest ecosystems in the Eden region was developed by selecting significant regional-scale spatial variables (parent material, rainfall and temperature) at early stages of tree construction, then turning to local-scale variables (for example, terrain) to discriminate smaller groups of samples representing different ecosystems. The model was developed iteratively by checking ecosystem distributions predicted by particular sets of rules and adjusting tree structure as necessary (see Section 2.7). Terminal nodes were allocated to the ecosystem represented by the greatest number of samples. Where there was a tie, expert knowledge was applied to choose the most likely option.

2.6 MAP COMPILATION

The final set of decision rules was applied to the full set of spatial data layers to allocate all 25 m grid cells in the study area to a forest ecosystem class. The resulting map represented the pre-1750 distribution of ecosystems. This was cut using the Landsat coverage of extant native vegetation cover (Table 2.5) to derive extant distributions of forest ecosystems.

2.7 MAP VALIDATION

2.7.1 Qualitative Checking

Checking procedures were incorporated into the development of the map. The decision-tree model was broken down into manageable components for proofing. The checking process was carried out by an experienced field botanist (David Keith) and consisted of the following steps.

1. A small number of rules were extracted from the model and implemented on the spatial data to display the distribution of respective forest ecosystems.
2. The mapped distributions of ecosystems were examined in relation to the regional distribution of their samples.
3. The fine scale distributions of ecosystems were examined with reference to topographic maps to determine whether appropriate landscape relationships were reflected (for example, that sheltered gullies generally support either similar or more mesic vegetation than adjacent ridges, but not less mesic vegetation).

4. The sources of all identified anomalies were traced to particular nodes in the decision tree and the sample data were examined to explore alternative rule pathways below the node identified.
5. The model and map were revised and proofing steps 1-5 were repeated until all identified anomalies were resolved.

When model development was well advanced, further refinements were sought from a second experienced field botanist (Doug Binns, State Forests of NSW).

2.7.2 Accuracy Quantification

Approximately 10% of the 1590 samples selected for data analysis were withheld from modelling for accuracy quantification. These validation samples were used to test model predictions against independent observations at a spatial scale relevant to map usage in the CRA. Validation samples were selected at random from all forest ecosystems excluding those with less than 20 samples so as not to unduly constrain modelling options for these less common units. Many of the less widespread ecosystems excluded from validation were modelled principally using aerial photograph interpreted spatial layers (for example, rainforests, heaths, swamps). It was thus assumed that they were mapped with reasonable confidence.

The aim of accuracy quantification was to determine the likelihood that selection of an area to represent a given ecosystem in a reserve actually contained the ecosystem predicted on the map. Planning units used for reserve selection in the Eden CRA varied in size from approximately 20 hectares to 240 hectares. Validation samples were thus compared to mapped ecosystems within neighbourhoods of 95 hectares to determine error rates at a spatial scale relevant to the planning exercise. The percentage of correct matches was recorded as an estimate of map accuracy.

3. RESULTS AND DISCUSSION

3.1 FOREST ECOSYSTEM CLASSIFICATION

Homogeneity analysis suggested that at least 33 groups were required to summarise major variation in the floristic data. Further interpretation of these 33 lineages resulted in recognition of 61 forest ecosystems. A further six ecosystems were recognised in the analysis of presence/absence data including samples from Wadbilliga National Park. Nine additional unsampled units including eight estuarine wetlands and one grassland were also recognised as forest ecosystems and described qualitatively. Appendix 1 describes the floristic composition, vegetation structure, physical habitat and distribution of samples for each forest ecosystem. Approximate floristic relationships between forest ecosystems are shown in the simplified dendrogram in Figure 3.1.

A number of dendrogram lineages identified from Homogeneity analysis were not split further. An example of one lineage in which splitting resolved complex variation into six forest ecosystems is described in the following steps (refer to first six ecosystems in Figure 3.1).

1. The parent lineage contains 90 samples with a diverse range of dry forest species. Samples encompass altitudinal range of 15 -915m on a range of granitoid, sandstone, mudstone and alluvial parent materials, across all aspects on flat and dissected terrain. Samples are distributed throughout the coast and southern parts of hinterland and tableland range.
2. The first split segregated a group of samples restricted to sandstone on steep northern and western aspects of Mt Imlay, Nungatta Mountain and Bondi Gulf at 330-750m elevation. Samples indicate a forest less than 20 m tall dominated by *Eucalyptus agglomerata* and prominent ground stratum. Further splitting failed to resolve substantial variation within this group. It was therefore recognised and mapped as Ecosystem 50.
3. The second split resulted in two further groups. The first of these included samples distributed widely on coastal ranges and inland mountains which, when split again, yielded one subgroup dominated by *E. sieberi* and largely confined to tonalite lithology in the Mumbulla Mountain area, and another subgroup dominated by *E. agglomerata*, *E. sieberi* and *Allocasuarina littoralis* restricted to sedimentary lithologies on coastal and hinterland ranges. Further splitting failed to resolve substantial variation within these subgroups which were recognised and mapped as Ecosystems 48 and 49, respectively.
4. The remaining sample groups in the lineage were resolved into three Ecosystems in a similar manner. They were: 46A (low forest dominated by *E. consideniana* restricted to granitoids and Tertiary alluvium in the Timbillica area); 46B (taller forest dominated by *E. gummifera* and *E. sieberi* confined to sediments and Tertiary alluvium on the coastal strip); and 47 (taller forest dominated by *Angophora floribunda* and *E. sieberi* confined to sediments south of Pambula).

Alternative interpretations of the hierarchy yielding greater and fewer ecosystem units were considered in the manner described above. It was decided and ultimately agreed by Steering Committee that the final classification of 76 ecosystems (47 eucalypt-dominated) provided a conservative summary of vegetation and habitat variation in the region and a reasonable interpretation of the JANIS (1996) definition of forest ecosystems. The conservative nature of the classification is demonstrated by a comparison with existing forest type mapping that covered approximately one-quarter (200 000 hectares) of the Eden CRA region. This classification addresses only variation in composition of the dominant tree stratum and, compared to the forest ecosystem classification, comprises approximately twice as many units (c. 150) in a smaller area.

Four of the 76 ecosystems were restricted to estuaries below low tide mark (sea grass meadows) and consequently were not mapped. A further four ecosystems were estuarine wetlands associated with the high tide mark. Of the remainder, 47 ecosystems were forests dominated by eucalypts, six were rainforests or scrubs with rainforest affinities, 12 were shrublands or heathlands and three were swamps.

Major groups of ecosystems include dry eucalypt forests with shrub-dominated understoreys, intermediate forests and riparian vegetation, dry eucalypt forests with grass-dominated understoreys, shrub-dominated heathlands, rock scrubs and swamps, rainforests, dry eucalypt forests with understoreys dominated by grasses in the Bega and Towamba Valleys, and vegetation of headlands and beaches.

The main changes to the classification relative to that described by Keith et al. (1995) are related to the addition of 140 000 hectares to the north-west the study area (Numeralla-Wadbilliga). Six additional forest ecosystems (W1-W6) are restricted to dissected sedimentary terrain in Wadbilliga National Park. One additional ecosystem (22B) is restricted to the Numeralla area. One additional ecosystem (46A) occurs in the Timbillica area. Previously, there had been insufficient data to distinguish this unit from other dry lowland eucalypt forest (46B). The other 68 ecosystems remain unaltered from the IFA analysis (Keith et al. 1996) and retain the same numbering system.

Ecological gradients and biogeographical relationships of vegetation in the Eden region are reviewed by Keith and Sanders (1990).

3.2 FOREST ECOSYSTEM MAP

A hybrid decision tree model/expert system comprising 400 rules was developed iteratively as described previously. The highest order statement in each rule referred to major structural formations (rainforest, eucalypt forest, tall scrub, riparian vegetation, heath, grassland, treeless swamp and estuarine vegetation). Eucalypt forests were subsequently distinguished by parent material and then climatic variables. Lower order statements in rules describing the distribution of eucalypt-dominated ecosystems were, in most cases, based on local terrain, geology and aerial photo-interpreted variables. The decision rules were implemented on the spatial data layers to produce the forest ecosystem map.

Forest Ecosystems 61 and 62 were mapped as a mosaic because stands of Ecosystem 62 were restricted to narrow beach strands and too small to map separately from adjoining stands of Ecosystem 61 at 25 m pixel scale. Appendix 1 shows the location of samples assigned to each ecosystem. The mapped extent of pre-1750 and 1997 area of each ecosystem is given in Table 3.1. The extant area of each ecosystem on different land tenures is also given in Table 3.1. The ecosystems most depleted by clearing are in the Bega and Towamba valleys (18, 19, 20 , 21, 39 and 40), on the Monaro Tableland (22A, 22B, 23A, 23B, 24 and 59) and along the coastal strip (36 and 60). The Eden Forest Ecosystem Map is available under licence from the NSW National Parks and Wildlife Service. The metadata statement is reproduced in Appendix 2.

3.3 MAP VALIDATION

3.3.1 Qualitative Checking

Qualitative checking revealed a number of mapping anomalies generated by the first iteration of decision rules. For example, some stands of Forest Ecosystem 58 (Swamp Forest) had initially been mapped along contours in the south-western part of the region. Comments on the field data sheets and our recollections from the field indicated that this type of vegetation occurs on flats along drainage lines. The anomaly was rectified by replacing maximum temperature and elevation with topographic roughness and wetness index in the appropriate decision rule. Other identified anomalies were similarly rectified.

3.3.2 Accuracy Quantification

One hundred and forty randomly selected samples were withheld from modelling for accuracy quantification. These samples represented Ecosystems 13, 14, 15, 31, 32, 33, 34, 37, 42, 46A, 46B, 47, 49, 61, 62, W1 and W6. Ecosystems assigned by floristic analysis to samples matched ecosystems mapped within 95 hectares circular neighbourhoods of the sample location in 92% of cases. This suggests that 92% of planning units will actually contain a forest ecosystem that is mapped within their boundary for which they may be selected to represent in reserves.

FIGURE 3.1: DENDROGRAM SHOWING FLORISTIC RELATIONSHIPS BETWEEN FOREST ECOSYSTEMS.

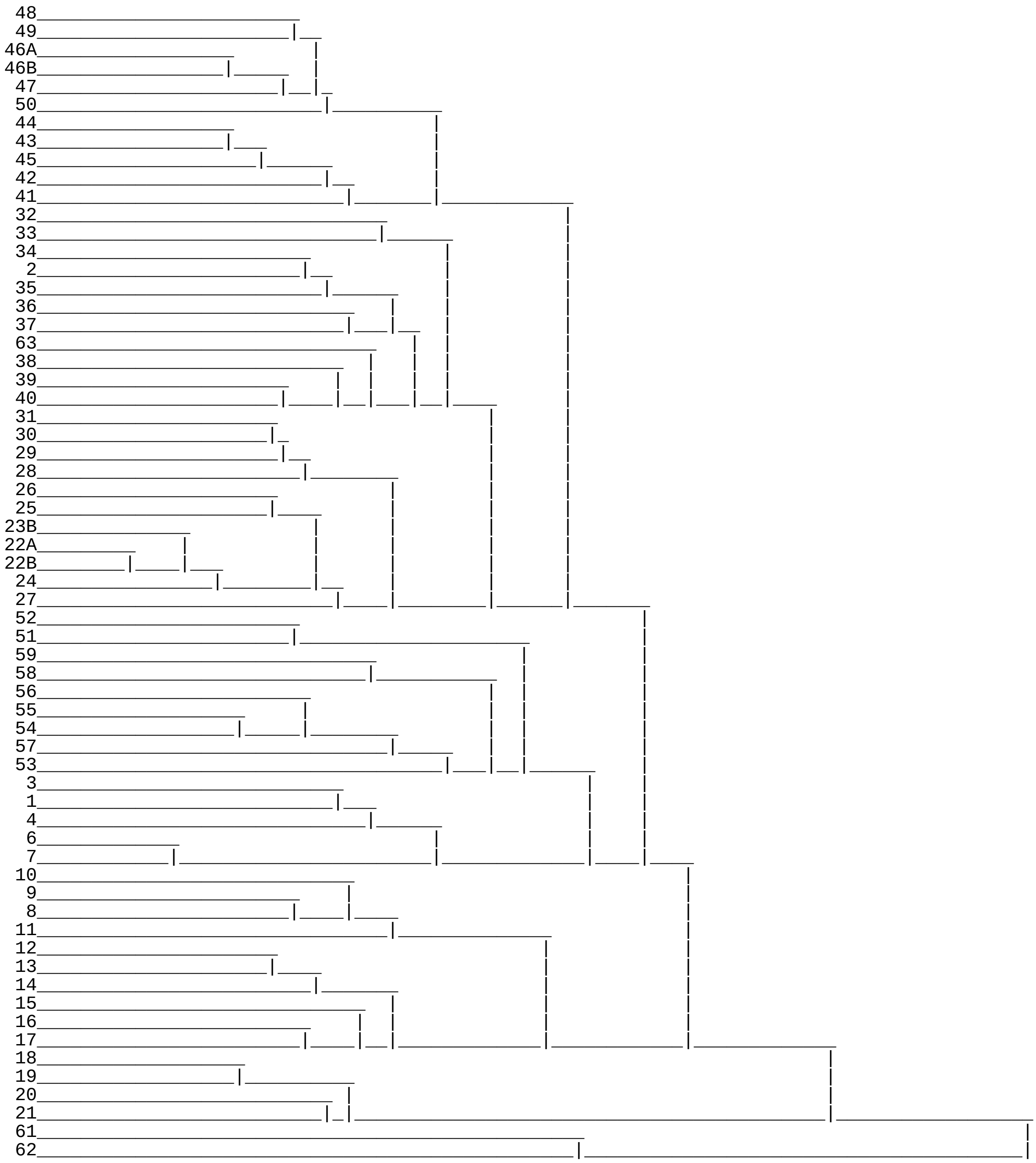

TABLE 3.1: **AREA OF FOREST ECOSYSTEMS**

Forest Ecosystem	Pre-1750 extent (ha)	Extant area 1997 (ha)	% cleared	National Parks & Nature Reserves (ha)	Flora Reserves (ha)	State Forest (ha)	State Forest plantation (ha)	Reserved Crown Land (ha)	Other Crown Land (ha)	Leased Crown Land (ha)	Private Land (ha)	Coastal Inlet (ha)
1 Dry Rainforest	47	42	11	30	0	0	0	0	0	3	9	0
2 Myanba Eucalypt/Fig Forest	333	333	0	322	0	0	0	0	0	0	10	0
3 Rocky Top Dry Shrub Forest	1188	1188	0	995	0	166	2	4	0	0	22	0
4 Brogo Shrub Forest	6673	6288	6	3617	0	16	0	8	1	6	2644	0
5 Bunga Head Rainforest	9	9	0	7	0	0	0	0	0	0	0	0
6 Coastal Warm Temperate Rainforest	6469	6393	1	2612	119	2223	13	34	5	0	1384	0
7 Hinterland Warm Temperate Rainfor.	3053	3027	1	1603	64	591	0	59	5	3	702	0
8 Cool Temperate Rainforest	1053	1053	0	850	4	119	0	0	0	1	79	0
9 Mountain Wet Layered Forest (Shining Gum)	2267	1813	20	1486	76	180	0	0	8	0	63	0
10 Mountain Wet Layered Forest (Brown-Barrel)	20033	17940	10	9059	28	5436	32	148	21	245	2982	0
11 Tantawangalo Wet Shrub Forest	792	790	0	723	0	59	0	4	0	0	4	0
12 Mountain Wet Fern Forest	2302	2259	2	1476	17	683	8	12	0	1	62	0
13 Hinterland Wet Fern Forest	48321	44040	9	23846	397	11375	38	207	95	104	7981	0
14 Hinterland Wet Shrub Forest	27004	25882	4	7707	90	13925	0	420	84	17	3633	6
15 Mountain Wet Herb Forest	41581	30875	26	12674	498	13345	294	110	35	78	3853	0
16 Basalt Wet Herb Forest	14904	12209	18	2764	35	3207	149	169	638	295	4964	0
17 Flats Wet Herb Forest	3553	2931	18	766	8	701	62	20	0	1	1377	0
18 Brogo Wet Vine Forest	7850	4306	45	778	27	557	0	9	1	10	2929	0
19 Bega Wet Shrub Forest	47749	16908	65	2058	8	2491	133	41	144	31	11990	0
20 Bega Dry Grass Forest	31952	3809	88	159	0	72	25	34	3	12	3512	0
21 Candelo Dry Grass Forest	17873	1463	92	89	0	0	0	2	2	0	1374	0
22A Monaro Dry Grass Forest	5427	3625	33	18	0	0	1	505	1167	630	1292	0
22B Numeralla Dry Shrub Woodland	11893	8248	31	467	0	16	0	122	47	642	6959	0
23A Monaro Grassland	6481	334	95	0	0	0	0	0	0	2	331	0
23B Monaro Basalt Grass Woodland	23567	3406	86	109	0	82	234	107	0	32	2825	0
24 Subalpine Dry Shrub Forest	95154	26604	72	2938	8	1616	443	662	355	2547	18056	0
25 Sandstone Dry Shrub Forest	1142	822	28	697	28	97	0	0	0	0	0	0
26 Tableland Dry Shrub Forest	28047	16115	43	4170	77	8170	97	75	6	231	3298	0
27 Waalimma Dry Grass Forest	1324	1324	0	294	0	1031	0	0	0	0	0	0
28 Wog Wog Dry Grass Forest	1304	922	29	757	0	138	3	0	0	0	23	0
29 Nalbaugh Dry Grass Forest	2597	1936	25	582	2	1005	78	3	0	12	256	0

30 Wallagaraugh Dry Grass Forest	1663	914	45	273	0	400	13	1	0	0	228	0
31 Hinterland Dry Grass Forest	32925	27586	16	9319	60	13104	282	107	2	49	4676	0
32 Coastal Dry Shrub Forest	24521	23401	5	5919	41	11956	0	861	173	25	4441	0
33 Coastal Dry Shrub Forest	16298	16136	1	7072	6	7930	19	15	33	5	1061	0
34 Brogo Dry Shrub Forest	16155	14155	12	4111	0	5137	0	219	113	46	4528	3
35 Escarpment Dry Grass Forest	34577	22007	36	6231	251	3731	411	390	70	103	10840	0
36 Dune Dry Shrub Forest	1023	604	41	240	0	5	0	91	24	0	245	2
37 Coastal Dry Shrub Forest	16153	15147	6	4770	285	8173	0	132	39	26	1722	1
38 Southern Riparian Scrub	611	516	16	128	5	197	9	0	0	0	178	0
39 Northern Riparian Scrub	761	485	36	39	0	13	6	0	2	2	426	0
40 Riverine Forest	81	65	19	0	0	0	0	0	0	0	65	0
41 Mountain Dry Shrub Forest	1865	1864	0	1361	22	418	0	3	0	6	54	0
42 Coastal Dry Shrub Forest	22044	21556	2	4596	1010	15215	2	20	22	2	687	0
43 Mountain Dry Shrub Forest	2492	2479	1	2229	0	96	0	0	0	0	154	0
44 Foothills Dry Shrub Forest	3326	3142	6	2037	22	970	67	0	0	0	46	0
45 Mountain Dry Shrub Forest	2024	1915	5	858	33	648	17	0	0	1	359	0
46A Timbillica Dry Shrub Forest	22917	22792	1	1164	610	20497	13	11	0	0	497	0
46B Lowland Dry Shrub Forest	15978	15121	5	6384	0	5941	8	521	145	0	2127	2
47 Eden Dry Shrub Forest	17797	17141	4	11727	108	4098	16	134	83	13	965	0
48 Bega Dry Shrub Forest	4497	4455	1	3167	0	971	0	69	17	0	231	0
49 Coastal Dry Shrub Forest	32334	31837	2	6739	794	21042	1	54	61	1	3150	0
50 Genoa Dry Shrub Forest	3702	3026	18	1996	42	776	11	0	0	1	200	0
51 Rock Shrub	51	51	0	22	19	10	0	0	0	0	0	0
52 Mountain Rock Scrub	202	202	0	168	18	10	1	0	0	0	6	0
53 Montane Heath	1751	1350	23	388	0	5	19	197	215	121	407	0
54 Mountain Nadgee Heath	371	371	0	365	0	6	0	0	0	0	0	0
55 Coastal Lowland Heath	1676	1630	3	1490	0	37	0	1	9	0	93	0
56 Swamp Heath	385	385	0	12	1	362	0	0	0	0	10	0
57 Lowland Swamp	2010	1892	6	908	145	676	0	12	5	3	141	0
58 Swamp Forest	1080	953	12	373	6	529	9	1	0	0	36	0
59 Sub-Alpine Bog	6636	1869	72	492	1	259	40	14	17	60	989	0
60 Floodplain Wetlands	9421	3281	65	296	0	240	0	187	137	10	2417	0
61 Coastal Scrub	2273	1505	34	1128	0	4	0	78	72	0	222	1
63 Estuarine Wetland (scrub)	3028	932	69	91	0	17	0	49	33	3	741	2
64 Saltmarsh	370	296	20	47	0	3	0	45	54	15	129	3
66 Estuarine Wetland (mangrove)	56	38	31	0	0	0	0	8	5	0	25	0
W1 Wadbilliga Dry Shrub Forest	27352	27341	0	26747	0	237	0	0	109	39	205	0
W2 Wadbilliga Range Ash Forest	1007	1007	0	1007	0	0	0	0	0	0	0	0
W3 Wadbilliga Mallee Heath	3085	3085	0	3060	0	0	0	0	0	2	24	0
W4 Wadbilliga Range Wet Forest	3501	3214	8	2536	0	111	0	48	51	109	343	0

W5 Wadbilliga Gorge Dry Forest	7748	7239	7	5461	3	930	0	0	6	0	823	0
W6 Wadbilliga River Valley Forest	1902	1897	0	1450	5	322	0	0	0	0	115	0
Total	809585	551772		210054	4973	192377	2556	6023	4114	5545	126220	20

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5. APPENDIX

5.1 DESCRIPTION OF FOREST ECOSYSTEMS

The following tables contain tables summarising data, where available, on species composition, vegetation structure and physical habitat. Maps show distribution of samples and photographs indicate typical visual appearance.

Nomenclature follows Harden (Flora of New South Wales, University of New South Wales Press , Kensington, 1990-1993).

Diagnostic species: Positive diagnostic species are those with a higher frequency (proportion of samples in which they are present) and higher median cover abundance among the samples of a particular forest ecosystem than in all other samples combined. Negative diagnostic species are those with the reverse pattern of occurrence (that is, widespread species that are absent from the target ecosystem). Frequent species are neither positive or negative diagnostic, but have a high frequency among the samples of a particular forest ecosystem, irrespective of their frequency among all other samples combined. Cover abundance estimates are medians with inter-quartile ranges in parentheses.