Forest Ecosystem Classification and Mapping for the Hunter Sub-Region in the Lower North East Comprehensive Regional Assessment

March 1999

Forest Ecosystem Classification and Mapping for the Hunter Sub-Region in the Lower North East Comprehensive Regional Assessment

Lower North East Comprehensive Regional Assessment

A project undertaken for
the Joint Commonwealth NSW Regional Forest Agreement Steering Committee
as part of the

NSW Comprehensive Regional Assessments

project number NL 10/EH and NL 02/EH

March 1999

For more information and for information on access to data contact the:

Resource and Conservation Division, Department of Urban Affairs and Planning

GPO Box 3927
SYDNEY NSW 2001

Phone: (02) 9228 3166
Fax: (02) 9228 4967

Forests Taskforce, Department of the Prime Minister and Cabinet

3-5 National Circuit
BARTON ACT 2600

Phone**:** 1800 650 983
Fax: (02) 6271 5511

ISBN 1 74029 079 8

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.

Acknowledgments

This project has been undertaken by the **CRA Unit of Sydney Zone NPWS:**
Daniel Connolly (Project management/Ecosystem Classification and Modelling)
Jeffrey Pickthall, Jedda Lemmon and Chris Pennay (GIS Data Management and Field Survey)
Steve Bell, Robert Payne and David Thomas were consultant botanists and provided personal data
Leander Wiseman (survey planning and analysis)
State Forests of NSW provided flora data for the Morriset Management Area
The advice, support and direction of David Keith and Michael Bedward made this project possible.

CONTENTS

PROJECT SUMMARY

This report describes a project undertaken as part of the comprehensive regional assessments of forests in New South Wales. The comprehensive regional assessments (CRAs) provide the scientific basis on which the State and Commonwealth Governments will sign regional forest agreements (RFAs) for major forest areas of New South Wales. These agreements will determine the future of these forests, providing a balance between conservation and ecologically sustainable use of forest resources.

Project Objectives

This report was undertaken to classify and map forest ecosystems for the Hunter Sub Region within the Lower North East, 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(EHTC), was to 'provide a map of the distribution of forest ecosystems occurring across all land tenures within the Lower North East CRA south of the Hunter River'.

Methods

To achieve this end, the project provided for the collection of new field data, compilation of existing data, and the development of a system of classification based on the multivariate analysis of field data. It was recognised by the EHTC that data standards were substantially poorer within the Hunter sub region and that the work developed for this project represented an initial classification system. Seventy-one forest ecosystems were classified and mapped in the Hunter Sub region, including 58 forests dominated by Eucalypts, Angophoras or Syncarpia, four rainforests, seven shrublands and heathlands, and two wetland/swamp ecosystems. Ecosystems were mapped using a hybrid decision tree model/expert system. The model related the occurrence of ecosystems to spatial patterns in mapped environmental variables (parent material, terrain and climate). The resulting map of pre-1750 ecosystems was cut using a 1990 Landsat coverage of extant native vegetation cover to derive extant distributions of forest ecosystems.

Key Results and products

It is anticipated that a new classification system which integrates new field data collected for this project and that of the Lower Hunter and Central Coast Biodiversity Program, will substantially improve upon the work completed here. A revised map and classification definition is expected to be available in late 1999.

The current forest ecosystem map for the Hunter Sub Region 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 Lower North East 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 logistical 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.

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 classify and map the distribution of forest ecosystems in the Hunter sub-region within the Lower North East CRA.

1.2 APPROACH

It was originally envisaged that a seamless forest ecosystem map could be developed over the entire Lower North East region using a consistent methodology. However, given the size of the region (over four million hectares) large variations in the quality of existing information and ecological characteristics were apparent. Separate mapping programs were thus required for the Hunter sub-region and Northern Tablelands in order to complete the data requirements for the North Coast RFAs within the timeframe.

Forest Ecosystem derivation for the area north of the Hunter River sought to integrate the use of floristic site data with research note 17 (SFNSW) vegetation mapping. It was recognised that the Hunter sub-region of the Lower North East Region would require an alternative approach given that less than 8% of the sub region was covered by mapping of this type. Options for the classification of forest ecosystems were discussed at a forest ecosystem workshop convened by RACAC on 17-18 July, 1997. The workshop concluded that the use of full floristic plot data should underpin the identification of all forest ecosystems.

As a result this project (as approved by the Environment and Heritage Technical Committee) was designed to undertake the following tasks for the development of a forest ecosystem map for the Hunter sub-region:

- collate all available floristic site data;
- complete new survey work in unsampled environments;
- derive forest ecosystems using statistical agglomeration techniques;
- extrapolate the derived ecosystems across all land tenures across the sub region;
- produce a map and report which identifies the variation and location of vegetation communities across the sub region;
- correlate the mapped communities to those that have been derived in the area north of the Hunter River; and,
- estimate the distribution of pre 1750 ecosystems.

1.3 STUDY AREA

The Hunter sub-region forms a unique bioregion within the Lower North East CRA. The area is characterised by heavily dissected sandstone plateaux and large flat coastal plains and valleys.

The area within the CRA boundary encompasses almost one million hectares of forest land that extends north from the Hawkesbury River to the Hunter River (Figure 1). The Colo River and the Wollemi National Park represent the western extent of the sub-region. The coastal plains from Gosford to Port Stephens form the eastern limit. It should be noted that a study area slightly larger than that of the RFA boundary was used in order to maximise the use of existing site data in poorly sampled areas of Wollemi National Park.

The land uses are dominated by a rapidly expanding urban environment along the eastern coastal plains in the areas of Newcastle, Wyong, Lake Macquarie, Gosford and Port Stephens. Large coal mining activities predominate across the Hunter Valley. The Eastern Ranges remain available for forestry activities in the SFNSW Morriset Management Area. Large areas of the dissected Sandstone plateaux are dedicated conservation reserves in the National Parks estate.

MAP 1: HUNTER SUB-REGION STUDY AREA

2. METHODS

2.1 VEGETATION SAMPLING

2.1.1 Data Audit

An audit of all systematic vegetation survey data was undertaken. Systematic vegetation survey sites conformed to the following characteristics:

- a fixed plot size within which an inventory of all vascular plant species are recorded;
- a measure of relative abundance for each species is recorded at each site; and,
- an accurate location reference (Australian Map Grid) to within 100 metres.

A total of 997 systematic vegetation sites were available for use in this project. Most sites have been extracted from systematic surveys completed within existing conservation reserves and state forests over the last 10 years. More recent regional surveys have provided systematic data across a range of different tenures (NEFBS 1992). The source of all site data used is shown in Table 1.1. All site floristics and attribute data (where collected) are now stored in the NPWS Flora Survey database.

Modifications to the existing site data were limited to a taxonomic review and a conversion of relative abundance scores used by Thomas (1998) to a six point Braun-Blanquet index. Table 1.2 provides the conversion table for these 58 sites.

TABLE 2.1: RELATIVE ABUNDANCE CONVERSION SCORES

Code	Relative Abundance	Braun-Blanquet Score
V: Very common	very common, usually single spp. dominant	4
C: Common	common, dominance is shared by 2 to 3 other spp	3
F: Frequent	frequent, a spp not sharing dominance but remains significant to the composition of the site	1 or 3 depending on spp.
O: Occasional	occasional occurrence	1 or 2 depending on spp.
R: Rare	rare, individuals infrequently seen, low count and crown cover	1 or 2 depending on spp.

No amendments were made to data based on variations in plot size. Preliminary analyses by Keith and Bedward (1998) using vegetation data from the Eden region found that cluster analyses was not sensitive to variations in sample size between 0.04 and 0.1 hectare.

Species taxonomy from each site was standardised to Harden (1993) except where obvious taxonomic changes were apparent. Sub species and variations were included except for those species where such information has been inconsistently collected or for species which have been subject to recent taxonomic revisions. The review ensured that a commensurate taxonomy could be used to compare more recent survey data to that collected over 10 years ago.

TABLE 2.2: VEGETATION DATA SETS

Reference	Location surveyed	No. of samples	Species recorded	Plot size (ha)	Abundance measure
Binns 1993	SFNSW Morriset Management Area	145	All vascular	0.1	Braun-Blanquet
Sanders et. al 1988	Yengo National Park	143	All vascular	0.04	Braun-Blanquet
Bell et. al.1993	Northern Yengo National Park	92	All vascular	0.04	Braun-Blanquet
Bell 1996	Myambat Army Base	22	All vascular	0.04	Braun-Blanquet
Bell 1998	Glenrock SRA, Awabakal SRA	43	All vascular	0.04	Braun-Blanquet
Bell 1998	Popran National Park	23	All vascular	0.04	Braun-Blanquet
Bell 1997	Manobalai Crown Reserve	21	All vascular	0.04	Braun-Blanquet
Bell 1997	Tomago National Park	38	All vascular	0.04	Braun-Blanquet
Thomas 1998	Singleton Army Base	58	All vascular	0.04	Relative Abundance
Bell 1997	Vales Point Power Station	52	All vascular	0.04	Braun-Blanquet
Bell et al.1999	Wollemi National Park	280	All vascular	0.04	Braun-Blanquet
NPWS 1994	NEFBS Northern Hunter Valley	14	All vascular	0.1	Braun-Blanquet
CRA 1997	Lower North East Northern Hunter Valley	15	All vascular	0.1	Braun-Blanquet
Peake 1998	Northern Hunter Valley	18	All vascular	0.04	Braun-Blanquet

2.1.2 Environmental Stratification for Site selection

A field survey program was planned in order to sample major gaps in site coverage across the study area. Environments requiring sampling were identified using a method akin to environmental domain analysis (Neldner et. al., 1995). Five data layers were used in the ARC View GIS system to highlight potential environmental variations. These were rainfall, temperature, dominant lithology, aspect and broad forest structure. The classes for each of these variables is set out in Table 2.3.

Of a possible 540 combinations of variables (herein described as strata), 436 were present in the study area. The spatial patterns of strata less than 500 hectares were examined to identify artefacts of the intersections of the GIS layers. If these strata were found to highlight fine scale landscape features such as basalt caps then the strata remained in the target strata group. Where strata were found to be highly fragmented, patchy and widely distributed and less than 500 hectares then they were excluded.

Over 200 strata were excluded based on the latter criteria. However, these strata combined represented less than .01% of the total study area. A total of 233 strata remained to be used to describe the environmental variation of the study area. The 997 sites obtained from the data audit were intersected with the strata. A table which lists the strata and the associated sampling objectives is presented in Appendix 1.

A proportional sampling strategy was employed to allocate survey effort to each strata. In other words the total number of sites in each strata should reflect the same proportion as the size of each strata within the study area. Resources allowed for the collection of approximately 300 new sites. The total expected number of sites at the end of the survey period was anticipated to be 1300. As an example strata *1221-Exposed* represented environments with low fertility/medium rainfall/medium temperatures and woodland on exposed slopes. This strata comprised 51 648 hectares or 4.2% of the study area. Using the sampling strategy, 4.2% of the total anticipated sites (63 sites) should then be located within that strata.

TABLE 2.3: ENVIRONMENTAL STRATIFICATION SCHEME

Lithology class	**Rainfall class (mm)**	**Temperature class (°C)**	**Aspect Class**	**Broad Forest Class**
Very High Fertility (basic igneous)	1.<800	<13	Exposed (NW-NE)	rainforest
High Fertility (acid volcanics, carboniferous sediments, alluviums)	2. 801-1100	13.1-16.6	Sheltered (SE-SW)	Moist forest
Moderate fertility (Fine grained sedimentary rocks	3 >1001	>16.6	Intermediate (SW-NW: NE-SE)	Dry Open forest and woodland
Low fertility (Narrabeen Sandstones, permian conglomerates)				
Very Low Fertility (Hawkesbury Sandstones, quaternary sands)				

2.1.3 Field survey

Three field teams were established to undertake five day field trips to survey unsampled or insufficiently sampled strata. Strata maps were prepared for each team to ensure sample points were located in the correct strata in the field. Where possible sites were located where access could easily be obtained, generally in public land. However, in many instances strata locations were restricted to private land only. In such circumstances permission was sought from relevant land owners to ensure adequate sampling in these areas.

The field survey collected data using standard NPWS field proformas. Field plots were fixed to 0.04 hectares based on 20m x 20m quadrats. Over 80% of the plots in the sub-region conform to this size and it was considered both consistent and time efficient to maintain this plot size in the region. Descriptions of field data used are described in more detail elsewhere (NPWS,1995 and NPWS, 1998).

Survey forms provided:

- lists of plant species with respective cover-abundance values. Cover-abundance values conformed to a six-point Braun-Blanquet scale (1-<5% and uncommon, 2- <5 and common, 3- 5-25%, 4- 25-50%, 5- 50-75%, 6- 75-100%;

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.

2.2 VEGETATION DATA ANALYSIS

2.2.1 Classification Analyses

A numerical classification of site floristic data was used to identify vegetation communities. The PATN analysis package (Belbin 1994) was used to group sites based on the similarities of species abundance scores between sites.

PATN provides a range of modules and algorithms from which to undertake an analyses of ecological data. ALOC, ASO, FUSE and DEND were used to establish the association matrix for hierarchical classification, clustering and the production of the dendrogram.

PATN analyses were performed on 997 sites identified from the data audit. Heavily contracted timelines prevented the inclusion of new field samples in the analyses. Despite obvious biases in the distribution of sites, the critical public land areas of State Forests and National Parks contained sufficient site data from which to derive a coarse interim map of forest ecosystems for these tenures.

The Bray-Curtis measure of association was used for the non hierarchical classification of sites. 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. A beta value of -0.1 was chosen from a range of iterations to reduce space distortion of the cluster. Limited opportunity was available to explore the sensitivities of the Beta value. The use of both the Bray Curtis measure and the beta value have been based on previous interpretations on subsets of the data used for this analyses. (Binns, 1993; Sanders *et. al.* 1988; Bell *et. al.* 1993).

Classification of site data was restricted to floristic data only. More thorough investigations are required to examine relationships between derived floristic groups and environmental factors. Previous analyses in site data (*ibid*) in the sub region were fundamental in the review of the biological basis of derived groups. The final groups employed a combination of the precedents described above and expert comment.

Dendrograms were used to show the degree of dissimilarity between individual sites and groups of sites. The identification of unique floristic groups within the dendrogram is essentially a subjective one (Binns, 1996). Options for the identification of groups can be achieved through the selection of a generic dissimilarity value between all groups or a variable value. The former establishes a value which separates all groups at the same dissimilarity value. The latter allows expert input to be included in the decision to split or amalgamate groups. The variable dissimilarity was used in this instance so that ecosystems containing clearly identifiable features in the field, were not hidden in the clustering of sites resulting from the application of a generic dissimilarity value. This was particularly important given the limited sampling effort for some ecosystems.

Forest ecosystems were clearly identifiable where clusters of sites described in existing reports (see Binns, 1996; Bell et al. 1993, Bell (1997, 1998)) did not group with other site data. Where sites did group in the dendrogram the floristic characteristics of the potential ecosystem was explored. Where groups remained robust to changes to group outputs and demonstrated a floristic homogeneity, the group was identified as an ecosystem.

2.3 DESCRIPTIVE TECHNIQUES

Each forest ecosystem was described using summaries of the sample data to produce profiles of species composition. These criteria were developed by Keith and Bedward (1998) and are reproduced here.

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
Target Eco-systems	Frequency ≥0.5 AND C/A ≥2	Constant	Positive diagnostic	Positive diagnostic
	Frequency <0.5 OR C/A <2	Negative diagnostic	Uninformative	Positive diagnostic
	Frequency =0	Negative diagnostic	Uninformative	-

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). For ease of presentation only those species identified as positive diagnostic species are listed in the community descriptions. In some instances a complete list of canopy species is given in order to assist with ecosystem descriptions.

2.4 SPATIAL DATA

Spatial data layers which describe the abiotic characteristics of the Hunter Sub Region were rasterised to 100 metre square grid cells for use in vegetation modelling. These data layers were derived by NPWS GIS staff in the following way:

- Terrain variables were derived from a 100 m grid digital elevation model supplied by the NSW Land Information Centre.

- Climatic surfaces (Table 2.5) were derived using ESOCLIM (Hutchinson 1989). Rainfall and temperature station data was provided by the Bureau of Meteorology. The accuracy of the data layer is as reliable as the location and number of weather stations. Large areas of the sub region (eg. Wollemi National Park) have few stations and modelled data is likely to be less reliable in such cases.

- Dominant lithological features were grouped from soil landscape mapping within the sub region (DLWC, 1992-7). Three different layers representing soil parent material were derived. The first represented a 14 scale class which amalgamated mapped landscapes according to their dominant lithology (tertiary alluvium, quartz sandstone, quaternary sand, quaternary sediments, quaternary alluvium, acid volcanics, basic igneous, granitic rocks, sedimentary (coarse grained) sedimentary (fine grained). The 14 class lithology was grouped into five classes to provide a relative index of soil fertility. This ranged from basic igneous as the highest fertility through to quartz sandstones at the lowest. The unique soil landscape code provided the third substrate layer.

- Existing vegetation mapping or structural mapping was not available as a consistent layer. Forest Type maps (Baur 1989) prepared by State Forests of NSW for the Morriset Management Area were included as were the 100k vegetation maps completed by the Royal Botanic Gardens for part of the region. This included the map sheets of St Albans, Gosford, Lake Macquarie, Wallerawang, Howes Valley (draft) and Mt Pomany (draft). (See Benson and Howell (unpublished), Keith and Benson (1988), Fischer and Ryan (1995) and Benson (1989).

- A 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. This work was supplemented by maps identifying plantation boundaries provided by SFNSW.

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)
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

GIS COVERAGE	DESCRIPTION
	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
Local Topographic Position (S)	Continuous index (0-100) representing proportional distance between local ridge (100) and local gully (0)
Neighbourhood Topographic Position (300)	Difference between altitude of a central cell and mean altitude of cells within a 3 x 3 neighbourhood
Neighbourhood Topographic Position (500)	Difference between the altitude of a central cell and mean altitude of cells within a 5 x 5 neighbourhood
Neighbourhood Topographic Position (700)	Difference between the altitude of a central cell and mean altitude of cells within a 7 x 7 neighbourhood
Neighbourhood Topographic Position (900)	Difference between the altitude of a central cell and mean altitude of cells within a 9 x 9 neighbourhood
Neighbourhood Topographic Roughness (300)	Standard deviation of altitude within a neighbourhood of 3 x 3 cells
Neighbourhood Topographic Roughness (500)	Standard deviation of altitude within a neighbourhood of 5 x 5 cells
Neighbourhood Topographic Roughness (700)	Standard deviation of altitude within a neighbourhood of 7 x 7 cells
Neighbourhood Topographic Roughness (900)	Standard deviation of altitude within a neighbourhood of 9 x 9 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)
5-class Parent Material	Major Fertility Classes based on amalgamation of geologies (Low Fertility- Hawkesbury Sandstone, Quartz sands to High Fertility -Basic Igneous)
14-class Parent Material	Dominant lithologies
393-class Parent Material	Raw Soil Landscape Codes
Vegetation Type	Vegetation Communities based on classifications derived by the Royal Botanic Gardens for four 100k map sheets in the study area.
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 sites file was created in order to intersect with all the environmental variables. Using the GIS Package 'ARC View' and an output file known as 'Envars' the value of each variable at each site was provided.

2.5 SPATIAL MODELLING

The technique used to describe the distribution of each ecosystem in the region mirrors that used by Keith and Bedward (1998) for the Eden CRA. This technique is a hybrid decision tree/expert system technique. The merits of this technique are also reviewed by these authors (*ibid*).

Interactive modelling software (ALBERO) (Keith and Bedward, 1998) was used to generate decision rules by statistical induction and expert input. The software is a tool to structure arguments which may describe relationships between the location of ecosystems and spatial variables. The software allows the presentation of hypotheses which may explain a distribution pattern rather than defining rules per se.

To produce a map a decision tree is made for all ecosystems within the region. The process used for developing a decision tree is presented in Keith and Bedward (1998) and is reproduced here. 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.

A decision-tree model of forest ecosystems in the Hunter sub-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. 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. Greatest effort was expended in ensuring that forest ecosystems that were known to occur on State Forest areas were reliably extrapolated. As a consequence, forest ecosystems that are restricted to large tracts of dissected sandstone plateaux may provide a less reliable picture of ecosystem distribution.

2.6 MAP COMPILATION

The final set of decision rules was applied to the full set of spatial data layers to allocate all 100 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

Checking procedures were limited to a qualitative review of mapped ecosystems against existing vegetation maps. Three main data sources were used for this purpose. Forest type maps were used to review the broad patterns on State Forests. Although forest type mapping depicts variations in canopy species only, it can provide a useful overview in order to identify gross errors in forest structures. Similarly, other intuitively derived maps in the region, notably the series published by the

Royal Botanic Gardens for the Lake Macquarie, St Albans, Howes Valley, Mt Pomany provided another means of identifying ecosystem distribution for portions of the region. Finally maps which have used quantitatively derived ecosystems were available for Yengo, Wollemi and smaller coastal reserves.

It is anticipated that additional work will be completed to quantify map accuracy. This will involve the integration of new survey data collected during this project.

2.8 COMPARISON OF ECOSYSTEMS NORTH AND SOUTH OF THE HUNTER RIVER

A comparison of forest ecosystems was undertaken across the regions of the Northern Tablelands, Hunter sub-region and the combined Upper and Lower North Coast. The purpose of this comparison was to identify similar ecosystems which could justifiably be amalgamated to apply a single conservation target. This avoids separate targets being applied to ecosystems derived from different methods and regions, which may occupy similar species composition, abundance and landscape niches.

To achieve this end an expert review of derived communities was completed by ecologists from NPWS and SFNSW. Species composition and abundance values within each ecosystem were used to combine or maintain separate classifications.

3. RESULTS

3.1 COLLATION OF EXISTING SURVEY DATA

The data audit resulted in the collation of 997 sites that contained information that could be used in the data analyses and modelling work. The location of these sites is shown in Figure 2. All sites are now included in the NPWS systematic flora survey database.

3.2 NEW SURVEY DATA

The field program obtained 318 new systematic vegetation plots for the sub region. The location of these plots is also shown in Figure 2. These sites have been added to the NPWS database.

Detailed floristic and structural data was collected for all plots completed during this project. The distribution of sites by land tenures indicates that 52% of sites were located on National Park, 22% on State Forests, 28% on private land with the remainder located on other Crown lands.

Sites were located in 32 previously unsampled strata and over 90 strata that were undersampled. A new plot density of 1 plot per 860 hectares has been achieved. While this density is still poor in comparison to well surveyed areas of the Upper North Coast it represents a significant improvement in base data for the region. Approximately 82% of all regional strata have now been surveyed. Appendix 1 provides the distribution of sites by strata matrix. Major gaps continue to persist in large areas of inaccessible country in southern and central Wollemi National Park. A summary of sampling achievements is illustrated in Map 3. Other areas considered to be undersampled lie in the Lower Hunter Valley and Central Coast regions. The shortfalls in these areas are currently being targetted by the Lower Hunter and Central Coast Biodiversity Conservation Strategy using identical field methods.

3.3 FOREST ECOSYSTEM CLASSIFICATION

A large dendrogram displaying the relationships and potential groups for all 997 sites was produced. Initial interpretation of the dendrogram identified that sites clustered heavily in relation to geology and position in the landscape. Clear potential clusters emerged which grouped sites by Hawkesbury and Narrabeen Sandstones, Permian Sediments, Basalts, Quaternary Sediments, Sands and Alluviums

The first major grouping identified dry shrubby forests and woodlands of the greater sandstone plateaux (Ecosystems 1-7 and 11-27). Variations within this group were identified by topographic position of the site. The first seven groups identified were characterised by areas of medium to high rainfall on low fertility soils. Typically this produced ecosystems dominated by overstorey species such *as Angophora costata, Eucalyptus piperata, Eucalyptus punctata, Eucalyptus sieberi* and a range of Stringybark species.

The third major delineation comprised ecosystems occurring on the coastal plain around Lake Macquarie and Newcastle on a range of permian geologies. While still considered to be dry shrubby or dry grassy forests and woodlands, they were characterised by distinctly different assemblages. Examples of these differences include the predominance of *Eucalyptus umbra, E. racemosa and E. capitellata*, and *Angophora inopina.*

The fourth main cluster of sites represented a distinct change in forest structure. Forest ecosystems 34 to 50 identified taller wet forests, rainforests and sandstone gully forests. Typically these sites were located on richer soils in higher rainfall areas. These ecosystems were marked by the presence of such over storey species as *Syncarpia glomulifera, Eucalyptus deanii, E. saligna, E. pilularis, E. acmenoides, E. paniculata.* Within the 16 tall wet forest groups two were dominated by rainforest canopies (Ecosystems 45 and 46).

Forests and woodlands unique to the tablelands region were identified in the fifth broad cluster. Within this nine ecosystems were identified. Overstorey species comprised *Eucalyptus melliodora, E.albens, E. rossii, E. blakleyii and A. floribunda.*

Heath, swamp and wetland ecosystems grouped strongly (62-66). Characteristic species for these groups were members of the *Banksia* genus at coastal heath sites and *Melaleuca quinquinervia, Eucalyptus robusta and E. tereticornis and E. amplifolia* at poorly drained sites.

Ecosystem 71 represented a stand-alone ecosystem for State Forest tenure only. This ecosystem delineates all rainforest structure as mapped from the Broad Old Growth Mapping Project (1996). As this is the only tenure in the sub region which contains this mapping it overrides all modelled communities for the State Forest tenure to ensure consistency with the remainder of the North Coast RFA.

In total, then, 70 ecosystems were identified from quantitative analysis of site data. Of these 58 are dominated by a Eucalypt, Angophora or Syncarpia overstorey. The remainder comprise seven heaths, three rainforests and two wetland ecosystems.

The breakdown of broad clusters in the dendrogram drew heavily on previous analyses of subsets of the data used for this project. Review of existing reports (Binns, 1994; Bell 1998; Sanders et al 1988) indicated where sites were likely to cluster for subsets of the data.

MAP 2: LOCATION OF FLORISTIC SITES IN THE HUNTER SUB-REGION

MAP 3: KEY UNDERSAMPLED STRATA IN THE HUNTER SUB-REGION

These communities were adopted by the Environmental Heritage and Technical Committee as the forest ecosystems of the Hunter sub-region.

A description of the species composition of each forest ecosystem is presented in Appendix 2. Copies of the dendrogram used for the analyses can be obtained on request from NSW National Parks and Wildlife Service.

3.4 FOREST ECOSYSTEM MAP

The decision tree model used all available environmental predictors to guide the mapping process. Each ecosystem contains its own unique rule set or equation that rely upon different combinations of data values from the suite of data layers described in Table 2.5.

All rule sets developed in the decision tree model relied on parent material as the first predictor. From this initial node over 350 rules were developed to spatially define the distribution of each ecosystem. Generally, the construction of rule sets used broader regional variables such as rainfall patterns within geological type. Further refinements were then made using topographic descriptors (eg. aspect). The absence of a consistent data layer which described variations in vegetation structure across the whole study area restricted the mapping of some ecosystems in portions of the landscape. Most notably, the assignment of heath communities has probably seen an overestimation of their distribution in some instances, with a concomitant underestimation of some forest and woodland ecosystems. This is most apparent on the coastal plains and dunes where interchange of these structures is not immediately apparent using regional predictors.

Ecosystems derived from sites located on State Forest tenure were given priority and were subject to several iterations of rule set development. This ensured that those ecosystems which were likely to be used in the review of land use decisions would be most reliable within the time permitted.

Considered to be of most priority were those ecosystems which supported productive timber resources. These were forest ecosystems 8 and 9 (Hunter Valley ecosystems) and ecosystems 38, 39, 40, 41, 42, 43, 44, 47 and 48 (Blackbutt, White Mahogany, Spotted Gum and Blue Gum dominated ecosystems).

Less critical were those which are characteristic of the drier infertile conditions of the dissected sandstone plateaux of Wollemi and Yengo National Parks. The mapped distributions of these ecosystems (eg. Ecosystems 11,12,16, 17, 52) are only the first iterations of rule set development.

The mapped extent of the pre-1750 and 1992 areas of each ecosystem is given in Appendix 3. The extant area of each ecosystem on different land tenures is also given in Appendix 3. Clearing has greatly affected ecosystems once located in the Hunter Valley (Ecosystems 8,9,10) and on the coastal plains of the Central Coast (Ecosystems 26, 28, 29, 30, 31, 32, 33). It is these ecosystems that have poorest representation in formal conservation reserves. As would be expected very little change has been evident in the extent of most drier sandstone ecosystems.

The Hunter Sub-Region Forest Ecosystem Map is available under licence from the NSW National Parks and Wildlife Service.

3.5 MAP VALIDATION

The map produced represents an early iteration of the modelling of quantitatively derived forest ecosystems. The quality and accuracy of the mapping is a product of three key parameters:

- sampling intensity;
- accuracy of derived forest ecosystems;
- accuracy of predictive data layers;

- accuracy of rule set development.

3.5.1 Sampling Intensity

Sampling intensity has been greatly improved as a result of new field survey work. However, the initial map produced did not use new data made available to the project as a result of time constraints. Sampling intensity can improve map accuracy by either refining the classification of ecosystems with more discrete niches in the landscape, or by providing a greater foundation of data points from which to base a spatial extrapolation.

In the Hunter sub-region low levels of sampling intensity are likely to affect both the definition and distribution of ecosystems in central Wollemi and Yengo National Parks, the Upper and Lower Hunter Valley, Wollombi Valley, and the Wyong, Gosford and Newcastle Local Government Areas.

By way of contrast, some areas have received intensive sampling (eg. small conservation reserves such as Tomaree National Park; Glenrock and Awabakal Nature Reserves). In these instances fine scale patterns in vegetation types may not be repeated consistently across a region. This may result in erroneous extrapolations based on highly localised variations.

3.5.2 Predictive Data Layers

The key predictive layers used in the decision tree modelling were those relating to substrate, rainfall and topographic variations. The substrate mapping was obtained from the soil landscape series which identifies soil patterns at a scale of either 1:100K for the coastal areas or at 1:250K for the broader Hunter River Catchment. The 100K soil landscape series provides for a finer level of resolution, although features less than 50 hectares are generally not mapped. Consequently, important variations in soil characteristics such as shale lenses in sandstone complexes are not likely to be mapped, and local inaccuracies in the forest ecosystem map are possible. These characteristics are exacerbated for soils mapping at the scale of 1:250K.

Climatic layers rely on access to long term weather stations distributed across the landscape. Reliability of modelled climatic layers such as rainfall are dependent on intensity and location of weather stations. Portions of the Hunter Sub Region contain a paucity of such stations particularly across the areas of Wollemi National Park. Other areas are affected by the location of the station itself, notably the Watagan Mountain range where orographic affects on rainfall patterns are considered to be underestimated.

Topographic indices were generated from a 100m digital elevation model (one hectare grid). At this scale variations in topographic position are likely to simplified in highly dissected terrain. This may affect the relative location and assignment of ecosystems to each grid cell.

3.5.3 Accuracy of Derived Ecosystems

Ecosystem mapping in the Hunter sub-region has been derived from floristic data which has with the exception of Thomas (1998) been used in agglomerative classification procedures by other researchers (see Sanders *et. al*, 1988; Bell *et. al.* 1993; Binns, 1994). The previous work has been invaluable in providing an indepth focus and knowledge for portions of the landscape. This work has in essence examined how these previously identified communities relate to one another across the broader region where the individual works have been conducted.

The amalgamation of all sites has achieved two ends. First, it has amalgamated broader groupings of sites. This is particularly prevalent in work in similar environments completed by Binns (1994) and Bell (1998) in comparing sites of Putty State Forest and Wollemi National Park and again with Yengo National Park and Pokolbin State Forests.

Second, it has enhanced the strength of some previously identified communities such as those of the Lake Macquarie Coastal Plain (Bell, 1997). The position of these sites on the dendrogram maintained strong independence from sites located across the Watagan State Forests and the Yengo and Wollemi National Parks.

Given the intensity of previous investigation of virtually all sites used in this analysis, it is considered that those communities described in Appendix 3 are valid representations of patterns in the field.

3.6 VALIDITY OF THE SPATIAL DISTRIBUTION OF THE ECOSYSTEMS

The assessment of the spatial reliability of the map was restricted to a qualitative comparison of the derived map to existing mapped work. While caution is required because the mapping methodology of previous works is different (eg. Fischer and Ryan, 1996; Forest Type Mapping (Anon); Bell et. al 1993), such comparisons highlight potential gross distribution errors. This approach revealed initial errors in the overestimation of Ecosystem 38 (Blackbutt) to include areas in Yengo National Park. Similarly, Ecosystem 8 (Hunter Valley Spotted Gum) was overpredicted across the mid to upper Hunter Valley. Correction of such areas was achieved through modifications to rule sets, in this case a revision of the rainfall criteria. Other errors indicated variations in forest structure. These were considered more serious, as they were likely to result from the absence of a key data layer describing variations in forest structure. Where possible, existing vegetation mapping was used to provide refinement to delineation of heath/forest complexes or moist forest/dry forest where these layers had not previously been used in rule set development.

Corrections were made to the model only as a result of obvious errors in comparison to existing mapping or to existing knowledge of NPWS ecologists.

3.7 ECOSYSTEM COMPARISON NORTH AND SOUTH OF THE HUNTER RIVER

A direct comparison of species composition and abundances was made for separate communities north and south of the Hunter River and with the Northern Tablelands. Twenty-three of the 71 communities were considered of sufficient similarity to warrant merging. Appendix 4 reviews the reason for amalgamating or maintaining unique ecosystems between regions.

Amalgamated ecosystems were those that joined near the amalgamation of the study areas. Hunter Valley ecosystems containing Redgum and Grey Box were merged as were the coastal ecosystems found on quaternary sands. Ecosystems 47 and 48 comprising *(E. saligna and E. acmenoides*) were also merged. Ecosytems supporting swamp mahogany forests were combined as were several tablelands ecosystems (Ecosystem 54, 59 and 50).

The comparison was restricted by clear differences in the numbers of sites used to define each community. Additional sites in the Hunter Sub region may justify more amalgamations and refinement of ecosystem definition in the future. However, distinct differences did appear in the data sets of the two regions. Variations in overstorey provide an example of the species changes.

1. Stringybark (*E. sparsifolia* does not occur north of the Hunter River), Scribbly Gum (*E. signata* to the north of the river is replaced by *E. haemastoma/racemosa* to the South*)*, Grey Gum (*E. propinqua* replaced by *E. punctata)* and Ironbark species, varied north and south of the Hunter River for dry shrubby forest ecosystems.
2. Moist ecosystems south of the River do not share Brush Box *(Lophostemon confertus)* as a co-dominant or associate species. Round-leaved Gum *(Eucalyptus deanii)* rather than Sydney Blue Gum *(E. saligna)* is also the prevalent bluegum across the majority of the Hunter sub-region, mostly in association with Turpentine *(Syncarpia glomulifera)* and Rough Barked Apple *(Angophora floribunda). Tallowwood (E. microcorys)*, while present in the coastal escarpment of the Hunter sub region, occurs only in low frequencies

and low abundances. North of the Hunter River this species emerges as at least a co-dominant.

The merged ecosystems and final table were approved by the environment and Heritage Technical Committee to describe forest ecosystems of the Lower North East Region.

4. ACHIEVEMENTS

The completion of the forest ecosystem classification and mapping for the Hunter sub-region represents the first iteration and should be viewed as such. While data limitations have only started to be addressed by this project, it is worth noting that the following has been achieved:

- the compilation of all systematic flora survey data into one regional survey database, a first for the region;
- the compilation of key predictive variables that can be used in future regional planning exercises and the refinement of the vegetation map;
- an initial description of forest ecosystems and their location in the study area;
- an assessment of the conservation status and degree of threat currently facing each ecosystem across all land tenures;
- further validation that predictive modelling from field survey data provides for a cost effective means to undertake regional conservation planning.

4.1 FUTURE WORK

Work is currently underway in Sydney Zone, NPWS to integrate new survey data into a review of the Hunter sub-region forest ecosystem classification and map.

A high demand exists in the region for a single mapped classification of forest ecosystems. The rapidity of urban expansion and associated environmental planning issues in the areas surrounding the cities of Lake Macquarie, Newcastle, Port Stephens, Wyong and Gosford are driving this need.

The NPWS is currently linking the CRA vegetation mapping exercise with a new biodiversity initiative of the Department of Planning and the Local Councils of the Lower Hunter and Central Coast. This program amongst other things is collecting new survey data on private land in the region to fill gaps in the current sampling regime. The survey project is using identical methods to that employed during the CRA, and as a result will provide a unique opportunity to develop a systematic and thorough review of ecosystems and there distribution across all land tenures. Outputs will also consider non forest ecosystems in the mapping exercise.

It is anticipated that the outputs from the combination of these projects will be available in the last quarter of 1999.

5. REFERENCES

AUSLIG (1992) National Public and Aboriginal Lands – Digital Data User guide. Belconnen ACT

Baur, G.N. (1965) Forest Types in New South Wales. *Forestry Commission of NSW, research Note No. 17.* Reprinted and revised 1989.

Belbin, L. (1994). PATN. Pattern analysis package. CSIRO, Canberra.

Bell, S., Vollmer, J. & Gellie, N. (1993). *Yengo National Park and Parr State Recreation Area: for use in fire management.* Unpublished report for the N.S.W. National Parks and Wildlife Service.

Bell, S.A.J. (1997) Flora and Fauna survey and Assessment: Vales Point Power Station Perimeter Lands - Supplementary Flora Report. Ecotone Ecological Consultants - Report to Delta Electricity

Bell, S.A.J. (1997) Tomaree National Park Vegetation Survey: A Fire management Document East coast Flora Survey - Report to the National Parks and Wildlife Service

Bell, S.A.J. (1998) Wollemi National Park Vegetation Survey: A Fire management Document East coast Flora Survey - Report to the National Parks and Wildlife Service

Bell, S.A.J. (1998) Lake Macquarie SRA, Pulbah Island Nature Reserve, Tingira Heights NR - Vegetation Survey A Fire Management Document East coast Flora Survey - Report To National Parks and Wildlife Service

Bell, S.A.J. (1998) Popran National Park Vegetation Survey: a Fire Management Document Eastcoast Flora Survey - Report To National Parks and Wildlife Service

Benson, D.H. (1986). The natural vegetation of the Gosford and Lake Macquarie area.. *Cunninghamia Volume 1 No 4*: *541-596*.

Benson, D.H. (1992). The natural vegetation of the Penrith 1:100 000 map sheet. *Cunninghamia* 2: 541-596.

Benson, D. & Howell, J. (1994). *Hawkesbury-Nepean Catchment studies explanatory notes for the Sydney 1:100 000 vegetation map sheet.* Cunninghamia Vol 3 No. 4 Royal Botanic Gardens, Sydney..

Benson, D. & Howell, J. (1995a). *Hawkesbury-Nepean Catchment vegetation mapping: explanatory notes for the Mt Pomany 1:100 000 vegetation map sheets.* Royal Botanic Gardens, Sydney. Unpublished report to the Water Board.

Benson, D. & Howell, J. (1995b). *Hawkesbury-Nepean Catchment vegetation mapping: explanatory notes for the Howes Valley 1:100 000 vegetation map sheets.* Royal Botanic Gardens, Sydney. Unpublished report to the Water Board.

Benson, D.H. & Keith, D.A. (1990). The natural vegetation of the Wallerawang 1:100 000 map sheet. *Cunninghamia* 2: 305-335.

Benson, J.S. & Fallding, H. (1981). Vegetation survey of Brisbane Water National Park and environs. *Cunninghamia* 1: 79-113.

Binns, D. (1996). Flora survey, Morisset Forestry District, Central Region New South Wales. Morisset Forestry District EIS. Supporting document No.3. Research division, State Forests of New South Wales, Sydney.

Bureau of Meteorology (1979). *Climatic survey: Sydney Region 5 New South Wales*. Australian Government Publishing Service, Canberra.

Commonwealth of Australia (1991). National Forest Policy Statement: a new focus for Australia's forests. Advance Press, Perth.

Commonwealth of Australia (1995). Australia's National Biodiversity Strategy. Australian Government Publishing Service, Canberra.

Harden, G.J. (ed.) (1990-1993). *Flora of New South Wales*, Volumes 1-4. New South Wales University Press,

Hutchinson, M. F. (1989) A new objective method for spatial interpolation of meteorological variables from irregular networks applied to the estimation of monthly mean solar radiation temp., precipitation and windrun. CSIRO Division of Water resources Technical Memorandum 89/5:95-104

JANIS (1997). Proposed Nationally Agreed Criteria for the Establishment of a Comprehensive, Adequate and Representative Reserve System for Forests in Australia. A report by the Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee (JANIS).

Keith D and Bedward M, (1998) Forest Ecosystem Classification and Mapping for the Eden Comprehensive Regional Assessment of New South Wales. A report undertaken for the NSW CRA/RFA Steering Committee.

Keith, D.A. & Benson, D.H. (1988). The natural vegetation of the Katoomba 1: 100 000 map sheet. *Cunninghamia* 2: 107-143.

King, D.P. (1994). Soil landscapes of the Katoomba 1:100 000 sheet. Department of Conservation and Land Management.

Kovac, M. & Lawrie, J.W. (1991). Soil landscapes of the Singleton 1:250 000 sheet. Soil Conservation Service of NSW.

Murphy, C.L. (1993). Soil landscapes of the Gosford - Lake Macquarie 1:100 000 sheet. Department of Conservation and Land Management.

NPWS (1994) The north East Forests Biodiversity Study: A scientific Introduction" *The North East Forests Biodiversity Report No. 1* NSW National Parks and Wildlife Service ,(unpublished)

Roberts G, (1992) Report to NPWS Regions- Progress on Eastern Bushlands Database. Unpublished.

Sanders, J., Bedward, M., Leahy, B., Robinson, M. & Sheringham, P. (1988). *Preliminary report on the vegetation of Yengo National Park and Parr State Recreation Area*. Report to the N.S.W. National Parks and Wildlife Service.

Thomas, D (1998) *Vegetation Communities of the Singleton Military Area*. Unpublished report to the Department of Defence.