

# Native Vegetation of the Southern Forests: South-east Highlands, Australian Alps, South-west Slopes, and SE Corner bioregions

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**Abstract:** The Southern Forests study area covers an area of about six million hectares of south-eastern New South Wales, south of Oberon and Kiama and east of Albury and Boorowa (latitude 33° 02'–37° 06' S; longitude 146° 56' – 147° 06' E). The total area of existing vegetation mapped was three million hectares (3 120 400 hectares) or about 50% of the study area. Terrestrial, wetland and estuarine vegetation of the Southern Forests region were classified into 206 vegetation groups and mapped at a scale between 1: 25 000 and 1: 100 000. The classification was based on a cluster analysis of detailed field surveys of vascular plants, as well as field knowledge in the absence of field survey data. The primary classification was based on 3740 vegetation samples with full floristics cover abundance data. Additional classifications of full floristics presence-absence and tree canopy data were carried out to guide mapping in areas with few full floristic samples. The mapping of extant vegetation was carried out by tagging vegetation polygons with vegetation codes, guided by expert knowledge, using field survey data classified into vegetation groups, remote sensing, and other environmental spatial data. The mapping of pre-1750 vegetation involved tagging of soils mapping with vegetation codes at 1: 100 000 scale, guided by spatial modelling of vegetation groups using generalised additive statistical models (GAMS), and expert knowledge. Profiles of each of the vegetation groups on the CD-ROM\* provide key indicator species, descriptions, statistics and lists of informative plant species.

The 206 vegetation groups cover the full range of natural vegetation, including rainforests, moist eucalypt forests, dry shrub forests, grassy forests, mallee low forests, heathlands, shrublands, grasslands and wetlands. There are 138 groups of *Eucalyptus* forests or woodlands, 12 rainforest groups, and 46 non-forest groups. Of the 206 groups, 193 were classified and mapped in the study area. Thirteen vegetation groups were not mapped because of their small size and lack of samples, or because they fell outside the study area.

Updated regional extant and pre-1750 vegetation maps of southern New South Wales have been produced in 2005, based on those originally prepared in 2000 for the southern Regional Forest Agreement (RFA). Further validation and remapping of extant vegetation over 10% of the study area has subsequently improved the quality of the vegetation map, and removed some of the errors in the original version. The revised map provides a reasonable representation of native vegetation at a scale between 1: 25 000 and 1: 100 000 across the study area.

In 2005 native vegetation covers 50% of the study area. Environmental pressures on the remaining vegetation include clearing, habitat degradation from weeds and nutrification, severe droughts, changing fire regimes, and urbanisation. Grassy woodlands and forests, temperate grasslands, and coastal and riparian vegetation have been the most reduced in areal extent. Over 90% of the grassy woodlands and temperate grasslands have been lost. Conservation of the remaining vegetation in these formations is problematic because of the small, discontinuous, and degraded nature of the remaining patches of vegetation.

*Cunninghamia* (2005) 9(2): 219–254

## Introduction

The Comprehensive Regional Assessments (CRAs) were designed to provide scientific information to create a Comprehensive, Adequate, and Representative (CAR) conservation reserve system on public lands, and at the same time set up systems of Ecologically Sustainable Forest Management (ESFM) within designated forest regions in New South Wales, Victoria, Queensland, Tasmania and Western Australia. One of the key pieces of scientific information needed was a map of forests and non-forests

within the forest regions. The JANIS report (JANIS 1996) placed considerable emphasis on using 'forest ecosystems' as general surrogates for the range of biodiversity. The JANIS report defines a forest ecosystem as:

*The aggregate of plants, animals and other organisms, and the non-living parts of the environment with which these organisms interact.*

*.....an indigenous ecosystem with an overstorey of trees that have a greater than 20% canopy cover. These ecosystems*

\*CD-ROM is inside back cover

*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 conservation representativeness of forest ecosystems in a given region was a key factor in the conservation assessment of a forest region, along with other criteria including flora and fauna species, wilderness, cultural values and old growth. Keith & Bedward (1999) have detailed a comprehensive summary of the validity of forest ecosystems as surrogates for biodiversity. Section 6.1.1 of the JANIS report also specifies additional requirements relating to the derivation and use of forest ecosystems in the CRA/RFA process:

These broad specifications provided the framework for developing a regional scale vegetation map for the Southern Forests of New South Wales. The approach adopted was designed to be consistent with the vegetation classification in the Eden CRA Region (Keith & Bedward 1999); to incorporate the range of field survey and mapping data already available; and to use an overstorey mapping layer to help delineate the extent of each forest and non-forest ecosystem. In this paper forest and non-forest ecosystems are synonymous with the more generic term vegetation groups.

This study presents up-to-date versions of the extant and pre-1750 vegetation maps of the Southern Forests, based on a thorough revision of the original CRA work completed in 2000. The specific objectives of this study are to document the data and methods used to produce these maps, to illustrate the more recent changes and revisions, to describe a newly developed hierarchical vegetation classification scheme and to indicate the current status of vegetation groups across the study area.

#### *The Southern Forests study area*

The Southern Forests study area covers six million hectares (6 174 400 hectares) of south-eastern New South Wales (latitude 33° 02'–37° 06' S; longitude 146° 56'–147° 06' E) (Fig. 1). The northern boundary extends from the Crookwell and Oberon Plateaus, across to the southern part of the Illawarra near Kiama. The eastern boundary follows the South Coast down to the boundary of the Eden Forests region. The south eastern boundary excludes the South-East Forests region and then follows the NSW state border to Albury. The western boundary more or less follows the Hume Highway to Bookham and then heads due north to the Abercrombie River. The study area includes hardwood forest regions, based on NSW State Forest's administration regions at the time of the CRA, and areas covered by the CRA wilderness assessment including:

- the Jamberoo escarpment, up to the Southern Highlands highway between Moss Vale and Kiama;
- small areas of southern Blue Mountains National Park, for wilderness assessment;

- hardwood forests of Jenolan State Forest adjoining Kanangra-Boyd NP;
- Pulletop and Livingstone State Forests, south of Wagga.

#### *Landscapes*

The landscapes of the study area fall within five IBRA bioregions (Thackway & Creswell 1995): Australian Alps, South Eastern Highlands, South-East Corner, Sydney Basin, and the NSW South-Western Slopes (Fig. 1).

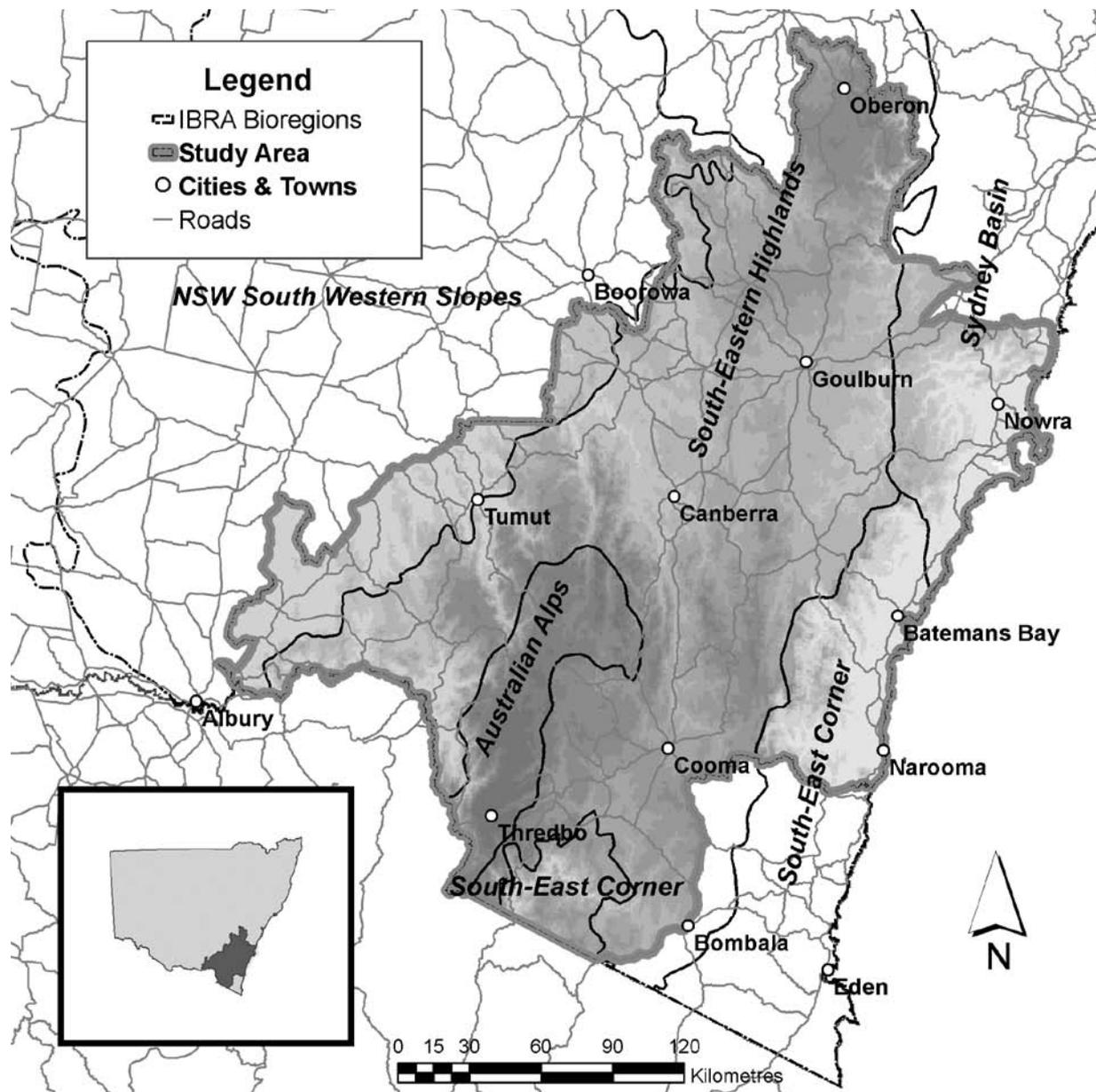
The elevated plateau of the Australian Alps bioregion extends from the Victorian border to the Australian Capital Territory. The highest point is Mount Kosciuszko, 2228m above sea level. Altitude decreases to 1350 metres in the northern part of the Alps, within the Australian Capital Territory. The Australian Alps were formed primarily from large intrusive granite batholiths, interspersed with metamorphic schists, gneists, and acid volcanics.

The Murray River drains the high western escarpments of the Australian Alps. Landscapes on the western footslopes have formed on granite and granodiorites, and Ordovician metasediments, including siltstones, mudstones and shales. Quaternary riverine alluvium fills the valleys of the larger streams and rivers.

On the south-eastern side of the Australian Alps, the Snowy River dissects the dry rainshadow areas of the Byadbo and Delegate catchments of mainly Silurian siltstones and shales. This dry landscape forms part of the South-East Corner bioregion and shares affinities with the drier rainshadow areas of the south coast.

The Murrumbidgee River and its tributaries drain the central eastern and northern sides of the Kosciuszko and Brindabella Ranges. On the eastern side of these mountain ranges, the landscape is mainly undulating high plateaus 600 to 900 m in elevation with intervening high ranges up to 1400 m, such as the Yaouk, Cooma, Tinderry, Numeralla, and Gourouk Ranges. The geology of the Numeralla and Gourouk ranges consists of a complex series of Cambrian-Ordovician schists. The Yaouk and Cooma Ranges consist of Ordovician and Silurian sediments and shales, interbedded with acid volcanics in the ranges further to the East. The Cooma-Monaro plains comprise Tertiary basalt. Further to the south and east of these plains, Ordovician and Silurian sandstones are interbedded with Silurian and Devonian granites and Ordovician metasediments. Cainozoic alluvial plains can be found on the broad plains to the west of Goulburn in the upper parts of the Lachlan River catchment. The landscapes that have formed on these geologies fall largely within the South Eastern Highlands bioregion.

The abrupt fall on the eastern escarpment coincides with the catchments of the eastern flowing river systems dissecting the broad Morton plateau in the north and the Deua and Wadbilliga ranges in the central and southern parts of the South Coast escarpment. These ranges comprise Ordovician



**Fig 1.** The Southern Forests study area showing bioregions

conglomerates, sandstone, siltstone, and shale, overlying a thin belt of Comerong acid volcanics, which produce some of the rugged high outcrops in the Deua ranges. The foothills of the South Coast are undulating low hills made up of Ordovician shales, conglomerates, and siltstones, interspersed with scattered basalt outcrops at Mount Dromedary, south-west of Narooma, and at Mount Durras, north of Batemans Bay. These landscape types extend from the South-East Forests region in Eden up to the edge of the Morton and Budawang ranges in the lower and middle parts of the Clyde valley to underlie the coastal foothills extending southwards through Yadbore and Dampier State Forests. Alluvial landscapes are found in the lower Shoalhaven, Deua and Tuross River catchments. The coastal area between

Bermagui and the Illawarra has numerous estuarine lake systems. Granite batholiths intrude along the coast and are found west of Nelligen, around Moruya and Bodalla, and in the central section of the Tuross catchment. These landscapes extending up from Victoria through Eden and Bega form the northern part of the South-East Corner bioregion.

Permian siltstones, shales, and sandstones dominate the geology of the Morton and Budderoo plateaus on the northern part of the South Coast escarpment and extend in a wedge down to Mount Durras, north of Batemans Bay. These are part of the Sydney Basin bioregion. The north-eastern boundary of the study area straddles the Illawarra escarpment, a high rainfall part of the Sydney Basin bioregion.

The northern part of the study area comprises undulating high plateaus of granite and basalt, surrounded by Devonian and Ordovician sandstone, quartz sandstone, siltstones and shales. These plateaus include Oberon, Kanangra-Boyd, and Crookwell-Taralga, and, with elevations from 900 to 1300 m, define the Great Divide. To the east of the northern high plateaus, highly dissected hills 300 to 400 m in elevation, rapidly descend to the Kowmung and Wollondilly Rivers. In the dissected valleys, Devonian quartzites, sandstones, and shales predominate.

### *Climate*

Mean annual rainfall ranges from 465 mm at Cooma on the Monaro plains to over 2300 mm at Charlottes Pass in the Snowy Mountains. Rainfall is lowest on the Monaro plains, increasing east towards the coast and west to the mountains. Deep valleys or lower plateaus on the leeward side of higher mountain ranges result in areas of lower rainfall, examples of which are found in the rain-shadow valleys of the Araluen Valley, the Monaro plains and the middle Snowy and Murrumbidgee catchments. By contrast, average annual rainfall above 1200 mm is found on the Kanangra-Boyd plateau, and along the South Coast escarpment extending from Kiama down to the Wadbilliga ranges.

During winter snowfalls are common above 1000 m on the Australian Alps and the Central and Southern Tablelands. Snow covers the higher parts of the Australian Alps, above 1600 m, for periods up to four months. Heavy frosts are a frequent occurrence over most of the South-East Highlands and Australian Alps during the winter months, becoming more severe in broader deep valleys fringing the mountain ranges, as a result of cold air drainage.

Mean annual temperature ranges from 2° C near Mount Kosciuszko, to 16° C along the coastal plains north of Ulladulla. Temperature increases as the elevation falls in both easterly and westerly directions away from the higher mountain ranges and the Great Dividing Range, which splits the region in half from north to south (NPWS 1998). These extremes greatly influence the distribution and pattern of vegetation. Seasonality of rainfall also varies across the study area. The northern coastal escarpment around Kiama shows a strong summer peak in rainfall, while the western side of the Kosciuszko ranges shows a strong winter rainfall peak.

### *Land Use History*

European land use across the study area has been mainly forestry, agriculture, mining and human settlement. On the Central Tablelands and Western Slopes, large areas were opened up to pastoral development from the 1830s onwards. Much of this land was covered in grassy woodlands. The steeper, more infertile and more remote forested land on the Tablelands was either occasionally cleared or left for rough grazing and selective logging. Evidence of these activities is still present in the forest structure on private or public land today.

Mills and Jakeman (1995) provide a detailed account of the land use changes in the Illawarra and adjacent Southern Highlands. They document the remorseless cutting and clearing of the Kiama and Shoalhaven coastal foothills, as well as the forests on basalt. Harvesting of *Toona australis* (Red Cedar) commenced in 1810, following the first allocation of land grants to settlers. By 1850 the settlers had cut out most of the cedar trees. Expansion of farming caused the clearance of coastal rainforests and forests in the southern Illawarra, Gerringong, and lower Shoalhaven causing major losses to the Illawarra Brush. Clearing of sub-tropical rainforest on the coastal lowland rainforests began after the 1860s. The Yarrawa Brush and the tall moist forests on basalt near Robertson were cleared for agriculture. Kangaroo Valley was not settled till the 1870s because of poor access, but the open grassy forests in the valley were gradually cleared for farming thereafter.

From about 1880 until 1950, significant areas of Crown Land in the central and northern parts of the study area were made available for free selection and selective timber cutting. State forests were established during this period to protect the forest resource, in response to excessive forest clearing for agriculture, grazing, and mining. Bago, Buccleuch and Meragle State Forests in the western highlands had a long history of forest harvesting since the late 1800s. These sub-alpine forests were also grazed from time to time under occupational grazing permits. From 1900 to the early 1950s state forests were the principal means of conserving forests, although more intensive harvesting became more widespread as bullock teams, axe, and crosscut saws were replaced with mechanised machinery, chainsaws, and a more extensive road network to gain access to more of the timber resource after the Second World War.

A succession of major wildfires burnt through the Snowy Mountains and Brindabella Ranges in 1926, and again in 1939, causing significant soil loss, and changes in the forest structure (Costin 1954). These fires, coupled with the intense grazing of the alpine areas, brought about the need to protect water catchments for hydro-electricity and water conservation schemes. In 1944 Kosciuszko State Park was gazetted over the alpine and sub-alpine areas of the Snowy Mountains plateau.

With the formation of the National Parks and Wildlife Service in 1967, further Crown Land was dedicated as National Park including Kanangra-Boyd and southern Blue Mountains National Parks in 1975, and Morton National Park in 1976. Although run by a conservation trust from the 1930s, Deua and Budawang National Parks were formally gazetted in 1977, and Abercrombie and Brindabella National Parks in 1996.

Extensive pine plantations were established on State Forests on the eastern slopes of the Tumbarumba and Tumut districts, on the Oberon Plateau and in Tallaganda State Forest during the 1960s and 1970s. These pine plantations were established on areas cleared of native *Eucalyptus* forest. Clearing of native

forest for pine plantation ceased in the late 1970s as public concern grew about the impact of large scale conversion of publicly owned native forest to pine plantation.

During the 1960s, private plantation schemes tried to convert significant areas of forest into pine plantation. These schemes concentrated on clearing of woodlands and heathland in the Oalen Ford-Braidwood area. Because the schemes overlooked the infertility and shallowness of the soils, patches of failed pine plantation remain amongst partially disturbed areas of native forest in this area. Pine plantations since then have been established on privately owned pastoral land.

On the South Coast the more rugged and steep areas remained in public tenure, mainly as State Forest and Crown Land. Since the 1880s the more fertile flats and valleys have been cleared for small dairy farms and residential development close to towns. Since the 1970s, much of the Crown Land along the South Coast escarpment has been progressively dedicated as national park. National parks were established to protect the coastline environment during the 1980s and 1990s and since 1990 tourism has become a major contributor to regional economies of the South Coast, ACT, and the Snowy Mountains. The introduction of intensive tourism or nature-based tourism poses new challenges for nature conservation.

## Methods

### *Auditing Vegetation Samples*

A thorough compilation of field survey data was made from major surveys carried out by CSIRO (Gunn et al. 1969, Austin 1978, Austin and Cawsey 1996, Austin et al. 1996, Doherty 1996, 1997, 1998a, 1998b), State Forests (Binns 1997a and 1997b, Jurskis et al. 1995, State Forests 1999a, 1999b, and 1999c) and individual consultants such as Gilmour (1982, 1983, 1985, 1987), Helman (1983, 1988), Ingwersen (1972, 1983, 1988), Keith and Bedward (1999), Mills (1996a, 1996b and 1999), and Taws (1997). These field surveys datasets were then sorted into four categories of data and classified according to their major roles in the project (Table 1).

Category I data, comprising full floristics with cover abundance samples, were used in the analysis and derivation of vegetation ecosystem groups. The primary classification method was based on a hierarchical classification method described in Keith and Bedward (1999) in the Eden RFA Region, using procedures developed by Belbin (1991).

The selection of a classification dataset followed Keith and Bedward (1999). Flora data selected for classification fulfilled the following criteria:

- Samples with a location on the Australian Map Grid, with a precision of at least 100 metres;
- The area of plot samples confined to 0.04 or 0.1 hectares;

- Complete list of vascular plant species within the plot; and
- Species abundances recorded on the six point Braun-Blanquet cover abundance scale or on a three point scale used by Gilmour (1982, 1983, 1985, 1987), and Helman (1983, 1988).

The Gilmour and Helman full floristic survey data, met three out of the four inclusion criteria for classification of vegetation groups and their slightly different scaling of cover was considered similar in its assessment of cover abundance on most survey plots, and comparable with survey samples assessed using the Braun-Blanquet scaling method.

Category II data were used to derive a presence-absence classification. The classification method used was identical to that used with Category I data, except presence-absence measures was used instead of the Braun-Blanquet scale. For comparison between the classifications developed for both category I and II data, survey data with Braun-Blanquet cover abundance data (Category I) were converted into presence-absence scale.

Categories III and IV were primarily intended for classification of canopy trees to check the quality of the mapping of canopy vegetation and support the mapping of vegetation groups. The classification method used with a combined dataset of categories III and IV was identical to that used with category II data.

### *Field Survey Methods*

Survey work conducted during the CRA project was designed to fill environmental and geographical gaps across the study area to produce an equal spread of sites across the range of predefined environmental strata. In the western and northern sub-regions, the absence and/or scarcity of substantial patches of remnant vegetation with an undisturbed ground-cover, was a major limitation in sampling flora sites evenly across all environmental strata.

**Table 1. Field Survey Data Categories**

Data Category	Flora Survey Data Type	Project Role
I	Full floristics, cover abundance	Full Floristic classification – derivation of vegetation groups
II	Full floristics, presence/absence	Full Floristic classification – support vegetation mapping in critical geographic gaps of Category I survey data
III	Canopy only, presence/absence	Canopy classification – guide mapping of vegetation groups and check quality of API mapping, and validation
IV	Partial floristics, cover abundance	Similar role in project to category III survey data

Within identified gaps, sites were located across a variety of topographic positions to sample as much of the range of local environmental gradients as possible. Survey samples were located in areas with adequate access to maximise survey efficiency. Where possible, four locations were sought: one on a sheltered midslope, an exposed midslope, an exposed ridge and in a sheltered gully. Within restricted environmental strata, generally less than 5000 hectares, and where access was restricted, fewer sites were surveyed. Sites were positioned as close as possible to the targeted field location while avoiding ecotonal boundaries between different forest and non-forest vegetation; or heavily disturbed sites.

To reflect 'pre-1750' vegetation patterns as much as possible, less disturbed areas based on local knowledge and the expert opinion of the botanists involved, were surveyed. One of the greatest limitations in extrapolating to pre-1750 vegetation patterns, especially those mostly cleared, is unknown past disturbance.

Field survey methods followed plot-based sampling used in previous CRAs in NSW (DUAP 1999). A standard site data sheet was based on the one developed for the North-East CRA flora surveys. The survey approach included collection of floristic, structural, and physical data in a plot 20 metres by 20 metres in size, nested within a larger plot of 20 m by 50 m. This was to ensure compatibility with larger scale regional surveys of canopy species that had used quadrats 20 m by 50 m in size, while at the same time maintaining compatibility with other full floristic data collected using the smaller quadrat size. Floristic data recorded in the 20 m by 20 m plot included a list of all vascular plant species present and a visual estimation of the cover abundance of each species according to a modified Braun-Blanquet system of cover abundance classes (Poore 1955).

Details of each site were recorded, including locality description, map name, Australian Map Grid easting and northing, area name, stratification and site number. Within a 50 m by 20 m plot, physical data such as altitude, slope, aspect, horizon visibility and azimuth, soil depth and type, geology, land morphology and element and the presence of outcropping were also recorded. After completion of the survey of the vascular plants present, community structure was estimated over an area of 50 m by 20 m in size. The structure of the vegetation in terms of the dominant vegetation layers was described, and could include an overstorey layer, up to three mid-stratum layers, and up to three lower or ground layers. The predominant growth form in each stratum, the upper and lower heights and the percent cover, as well as three most dominant species, were recorded. Growth stage of senescent, mature or regrowth categories was also estimated within the plot.

Disturbance history of fire, logging and grazing was also noted, estimating severity and time since disturbance. The accuracy of these estimates varied, depending on the apparent field evidence available, and the subjective assessment of field botanists. Finally, an estimate of the

overall condition of the site was made, incorporating factors such as the degree of weed infestation as well as the species and structural diversity.

#### *Preparation of Survey Data*

Survey data (sites, floristics, and a master species list) were stored in an electronic database to allow error checking, manipulation, and retrieval for analysis. Site records were checked for geographical accuracy by comparing the relevant 1: 25 000 map sheet against site locality descriptions and grid coordinates as they appeared on the survey forms. This information was compared to the location of the site in ArcView GIS. Accuracy to within 100 m or better was generally achieved. All grid references were checked in the GIS to ensure that they fell within the Southern CRA boundary. Throughout the classification process, there were random checks of relationships between species associations and physical site characteristics such as morphology and geographic position, and corrected any errors.

Duplicate record checks were conducted in all the database tables especially the floristics table. Discrepancies found in floristics records were identified and corrected where possible or quarantined from analysis. Checks were also conducted to ensure that all species in the floristics table had either a cover abundance value or a letter P to indicate species presence.

The database was used to compile a species inventory to check nomenclatural standards and errors in field identification. Synonyms were identified and standardised according to Harden (1990, 1991, 1992 & 1993) or more recent publications. Species occurrences were compared to published geographical ranges to identify errors in identification or data entry. Where species names had simply been changed, names were updated, but in many cases a previous plant taxon may have been split into two or more new plant taxa. In these cases the geographic distribution and ecological niches of the new plant taxa were determined and site data information updated accordingly. Plant taxa were aggregated to the species level unless there was some clear geographic or ecological distinction to enable them to be consistently distinguished in the data set.

Some of the field survey data, such as Ingwersen (1992), had their cover values converted to Braun-Blanquet scores so that they could be used in the full floristics cover-abundance classification dataset. Where possible the data were referred to the original surveyor for advice on conversion to the Braun-Blanquet scoring method. Unknown species, as well as exotic species and non-vascular plant species, which had been recorded in some data sets, were masked out of the data set to be used for classification. The masking of these categories of plant species helped to remove any confounding influences of anomalous records of native plant species and the influence of non-native species data on the PATN classification.

### *Environmental spatial data*

A variety of spatial data layers describing climate, terrain, and lithology were compiled from spatial data prepared at a mapping scale of either 1: 25 000 or 1: 100 000 (Table 2). Climate and terrain variables were derived from digital elevation data provided by the NSW Land Information Centre, using algorithms described by Hutchinson (1989). Most of the data layers were prepared at a resolution of 1: 100 000, which equates to a 100 metre grid cell size. The climate, terrain, and geology layers were collated and prepared for use in modelling of the spatial extent of vegetation groups, whereas the CRAFTI API layer was used as the primary data layer for mapping extant vegetation.

LANDSAT Thematic Mapper imagery of the whole region was acquired to facilitate the planning of field work, checking of survey data, and to assist mapping of vegetation. Two complete Landsat scenes were prepared as TIFF images, using bands 3, 4, and 5. The data projection of the remotely sensed data was set to Zone 55, AGD66, which followed the standard set in the CRA. Two LANDSAT scenes were then digitally enhanced and cut into 8 overlapping sub-scenes that covered the full extent of the study area, with the exception of the eastern end of the Jervis and the Beecroft Peninsula in the Shoalhaven area.

### *Air Photo Interpretation (API) and Mapping*

A classification of canopy presence-absence forest data, collated and analysed by Austin and Cawsey (1996) was adapted to enable a more direct comparison between field survey data and tree canopy associations. A region-wide classification of tree canopy species formed a better basis on which to associate field survey samples with API mapping data than forest types based on Research Note 17 (Baur 1989). A correspondence table between canopy floristic codes and Austin's canopy associations was developed to guide the coding of polygons of canopy floristic types drawn on each air photographic overlay. The detail of these eucalypt forest codes can be found in a separate report (DUAP 2000a). The coding of rainforest and non-forest component of the vegetation was based on a collaborative expert agreed classification. The non-forest API codes covered the full range of non-eucalypt and non forest types in the study area: rainforest, tall shrubland, heath, swamp, native grassland, and coastal estuarine vegetation.

Structural and floristic data layers for all forested lands were derived from 1997-98 air photos at a scale of 1: 25 000 (except in the Crookwell area where 1: 50 000 scale photos were used). Contract air photo interpreters used stereoscopic equipment to delineate canopy floristics and structural information onto overlays mounted on 1: 25 000 scale air photographs of each 1: 25 000 map sheet. Contextual information available to interpreters included other existing vegetation mapping and survey data. Familiarisation and fieldwork was limited to two to three days per 1: 25 000 mapsheet, depending on the

coverage of native vegetation, the difficulty of access, and the extent of previous API work. Contractual constraints confined the API mapping to forested areas outside of forested land in urban areas, intensively developed agricultural land and rural-urban subdivisions, as well as some large pine plantations within eucalypt forest remnants. Within the fragmented woodlands and forests in the western part of the study area, additional remnant vegetation patches were mapped subsequently by a small team contracted to validate and refine the API mapping (Maguire & Hunter 2000). A comprehensive account of the API methods is contained in a separate report (DUAP 2000a).

Following scanning and rectification, the layer was merged with previous canopy floristics mapping undertaken by State Forests using Research Note 17 (Bauer 1989) and existing mapping within selected national parks and nature reserves (Doherty 1996, 1998a). The canopy floristics mapping show patches of extant forest down to 10 hectares in size and patches of non-forest vegetation down to 2 hectares. It covers most of the study area with the exception of an area north of Holbrook.

Mapping of native grasslands was not undertaken in the canopy floristics mapping, being outside the scope of the CRAFTI project. A mapping layer of pre-1750 grasslands through the South-Eastern Highlands bioregion was produced, based on earlier mapping in the southern part of the study area (Costin 1954), with additional mapping in the ACT, Gunning, Crookwell, Mulwaree, Oberon, Tallaganda, and Yarrowlumla Shires (Rhewinkel & Gellie unpubl.). Fig. 2 shows the final compiled temperate pre-1750 grasslands map. In 2005 the larger patches of temperate grasslands still surviving on Crown reserves and travelling stock routes were mapped.

### *Historical Parish Portion Data*

State Forests of NSW (1999a) collected historical information on vegetation cover from a sample of original portion plans in parishes in the study area. Information that was collected for each portion plan included the map sheet name, parish name, portion number, plan number, date of record, notation on vegetation type and topography, point data on corner trees used to fix survey points, comments or notes and grid references of corner survey points. SFNSW (1999a) cited a study by Ryan and Stubbs (1996), which showed that where the destruction of the vegetation has been complete, the historical record, and in particular the conditional purchase plans, was indispensable in reconstructing the pre-settlement pattern of vegetation.

Where relevant, the historical data layer was used in a contextual sense by expert botanists when assigning forest types to cleared areas, but limitations of the data set included the overly broad nature of many of the early surveyor descriptions, such as *gum*, *peppermint*, or *stringybark*, which made it difficult to correlate with individual eucalypt species.

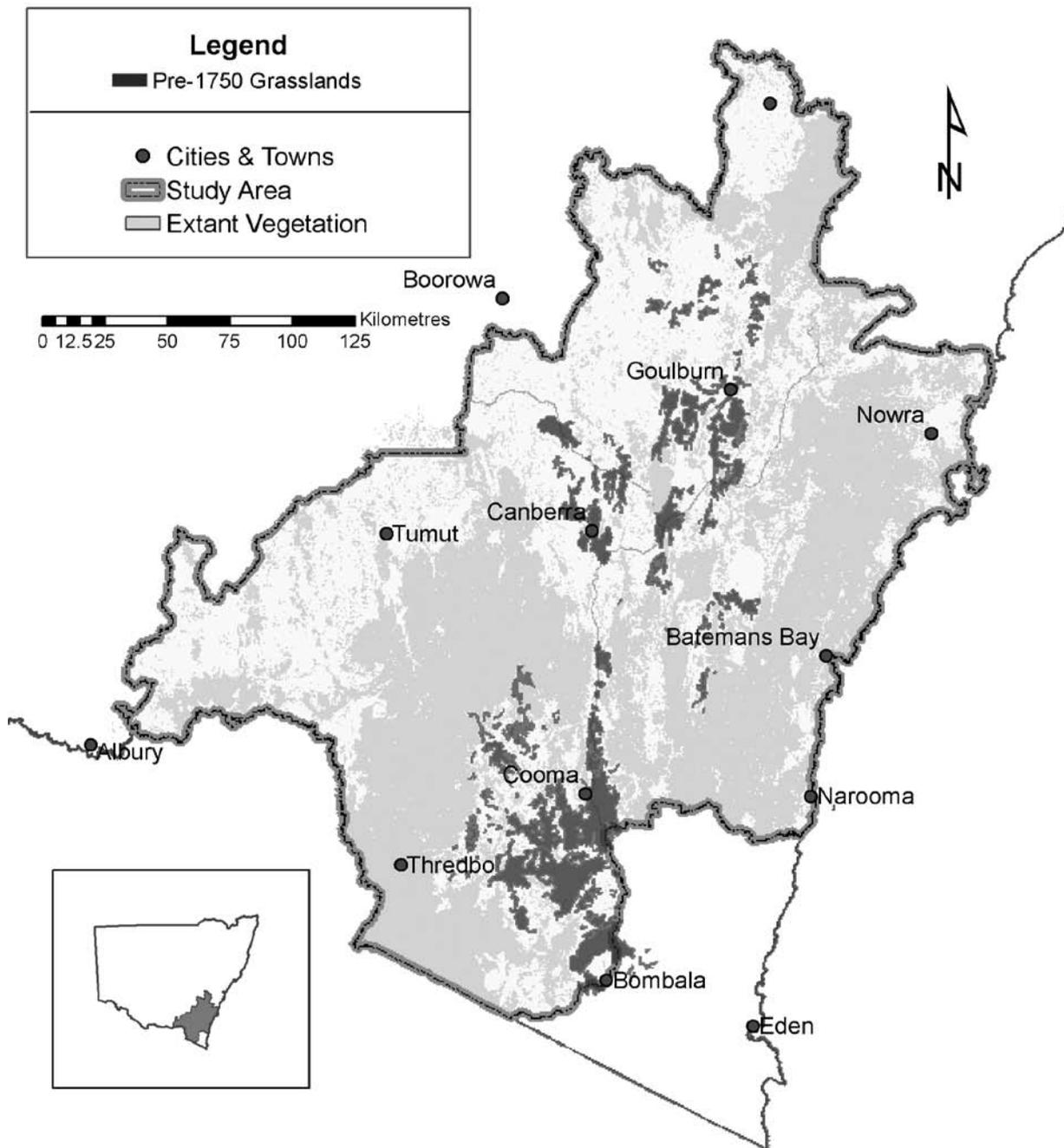
**Table 2. Spatial data layers used in modelling and mapping (adapted from Thomas et al. 2000)**

GIS Layers	Resolution of Data	GIS Layers	Resolution of Data
<b>Climate</b>		Ruggedness (3) - Standard Deviation of Elevation Values within a 1: 100 000m window around the cell	1: 25 000
Evaporation Average	1: 100 000	Skidmore Index (position on a slope from ridge to gully)	1: 25 000
Precipitation Annual Average	1: 100 000	Slope (degrees)	1: 25 000
Precipitation of the Coldest Quarter	1: 100 000	Topographic Position of a cell in relation to the mean of a 250m window around the cell	1: 25 000
Precipitation of the Driest Period	1: 100 000	Topographic Position of a cell in relation to the mean of a 500m window around the cell	1: 25 000
Precipitation of the Driest Quarter	1: 100 000	Topographic Position of a cell in relation to the mean of a 1000m window around the cell	1: 25 000
Precipitation of the Warmest Quarter	1: 100 000	Wetness Index (volume of water draining into a cell, adjusted for ability to retain water due to slope)	1: 100 000
Precipitation of the Wettest Period	1: 100 000		
Precipitation of the Wettest Quarter	1: 100 000	<b>Vegetation</b>	
Precipitation Seasonality	1: 100 000	Eastern Bushlands Vegetation Database (EBDB) (NPWS 1995)	1: 100 000
Temperature (Maximum) of the Warmest Period	1: 100 000	API Mapping of Canopy Floristics – State Forests Data (SFNSW 1989)	1: 25 000
Temperature (Mean) of the Coldest Quarter	1: 100 000	API Mapping of Canopy Floristics – CRAFTI Data (DUAP 2000a)	1: 25 000
Temperature (Mean) of the Driest Quarter	1: 100 000	API Mapping of Canopy Floristics – CSIRO Data (Doherty 1996, 1997, 1998a, 1998b);	1: 25 000
Evaporation Average	1: 100 000	API Review of CRAFTI Mapping Nicholas Graham-Higgs Pty Ltd (2002a, 2002b, 2002c, 2004, 2005) and EcoGIS (2002, 2004a, 2004b, 2004c)	1: 25 000
Precipitation Annual Average	1: 100 000		
Precipitation of the Coldest Quarter	1: 100 000	<i>Classification</i>	
Precipitation of the Driest Period	1: 100 000	Classification of the data was undertaken using hierarchical classification techniques (Belbin 1991). The approach to classification was based on methods described by Keith and Bedward (1999). The analyses were carried out using the PATN computer program (Belbin 1994). Dissimilarity between samples was calculated using the Kulczynski coefficient applied to un-standardized cover-abundance data. Clustering of samples into a hierarchical classification used the unweighted pair-group arithmetic averaging technique (UPGMA). The initial number of vegetation classes within the classification dataset used in this project was determined using the homogeneity program (Bedward 1999). This program measures the extent to which further splitting of groups yields improved homogeneity of groups.	
Precipitation of the Driest Quarter	1: 100 000		
Precipitation of the Warmest Quarter	1: 100 000		
Precipitation of the Wettest Period	1: 100 000		
Precipitation of the Wettest Quarter	1: 100 000		
Precipitation Seasonality	1: 100 000		
Temperature (Maximum) of the Warmest Period	1: 100 000		
Temperature (Mean) of the Coldest Quarter	1: 100 000		
Temperature (Mean) of the Driest Quarter	1: 100 000		
Temperature (Mean) of the Warmest Quarter	1: 100 000		
Temperature (Mean) of the Wettest Quarter	1: 100 000		
Temperature (Minimum) of the Coldest Period	1: 100 000		
Temperature Annual Mean	1: 100 000		
Temperature Annual Range	1: 100 000		
Temperature Average	1: 100 000		
Temperature Average Maximum	1: 100 000		
Temperature Average Minimum	1: 100 000		
<b>Context</b>			
Rivers and Streams	1: 100 000		
Roads and Easements	1: 25 000		
<b>Insolation</b>			
Solar Radiation Annual Total (11 month)	1: 100 000		
Solar Radiation of the Coldest Quarter	1: 100 000		
Solar Radiation of the Driest Quarter	1: 100 000		
Solar Radiation of the Warmest Quarter	1: 100 000		
Solar Radiation of the Wettest Quarter	1: 100 000		
Solar Radiation Seasonality	1: 100 000		
<b>Lithology &amp; Soils</b>			
Lithology divided into 5 broad groups	1: 100 000		
Lithology divided into 13 groups based on mineralogy and geomorphology	1: 100 000		
Soils Landscapes Mapping	1: 100 000		
Acid Sulphate Soils Mapping	1: 25 000		
<b>Terrain</b>			
Digital Elevation Model	1: 25 000		
Digital Elevation Model	1: 100 000		
Aspect	1: 100 000		
Distance from the Coast	1: 25 000		

### Classification

Classification of the data was undertaken using hierarchical classification techniques (Belbin 1991). The approach to classification was based on methods described by Keith and Bedward (1999). The analyses were carried out using the PATN computer program (Belbin 1994). Dissimilarity between samples was calculated using the Kulczynski coefficient applied to un-standardized cover-abundance data. Clustering of samples into a hierarchical classification used the unweighted pair-group arithmetic averaging technique (UPGMA). The initial number of vegetation classes within the classification dataset used in this project was determined using the homogeneity program (Bedward 1999). This program measures the extent to which further splitting of groups yields improved homogeneity of groups.

A dendrogram of the classification analysis was used to view the results and to refine the classification. Appendix 1a on the CD-ROM provides a summary view of the final classification, based on a grouping of the vegetation groups into vegetation mapping classes. The suggested vegetation groups in the classification were evaluated according to three criteria: the groupings of samples made sense floristically and spatially; the groups were readily identifiable in the field; and the groups related to the vegetation patterns apparent in the landscapes of the study area. The first step was to check that each group was floristically distinctive. The second step involved a spatial assessment of each vegetation group. Further splits were



**Fig. 2.** Map of Pre-1750 Grasslands

made if sub-groups were floristically distinct and spatially or ecologically distinct. The distribution of samples of each vegetation group was also checked at the same time within Arcview GIS to reveal the location of the samples in relation to geology, terrain and exposure. The floristic composition of geographic outliers of the vegetation samples were checked within the site floristics database to determine if these samples belonged to other vegetation groups. A vegetation group was further split if it contained a clearly defined sub-group at a slightly lower level in the dendrogram tree. This was only undertaken where the identified sub-group, and the remainder of the original broader vegetation group could

be readily related to environmental variables and mapped, or had previously been identified and mapped, and as such, met the JANIS requirements for a forest ecosystem. In some instances some closely related groups were lumped if they could not be related to geology or terrain.

Patterns of elevation, lithology, exposure, and other topographic variables were related to the spatial distribution of samples of each vegetation group on the GIS. For example, if the samples of a vegetation group, such as Yellow Box Grassy Woodlands, were found within the expected range of that vegetation group, such as on valley floors with richer

soils, then those relationships were used to map that vegetation group. This process was repeated for each vegetation group until all groups had been checked on the GIS. Where there was no recognisable relationship in the distribution of the sites of a vegetation group on the GIS, further investigations of possible splitting or lumping of that group were undertaken. Checks on the floristics of that sample were further undertaken to identify any field identification or nomenclature errors. The first two iterations in the classification and checking of vegetation of groups on the GIS, revealed some vegetation groups with no obvious spatial pattern. This necessitated some revision of species nomenclature and exclusion of field survey samples with errors in field identification or with low numbers of native species present.

An iterative classification and validation process was followed by which classification was checked and errors in field identification and nomenclature removed, leading to a usable and stable classification of field survey data. Small errors in the identification of common species appeared to affect the vegetation classification. Where errors were suspected, the plant species and their cover abundances were investigated. If errors were found, any suspect plant identifications and distributions were checked with Flora of NSW (Volumes 1–4), and with other field botanists. Amendments were made to the original database file. The PATN analysis was re-run and the positions of sample sites were checked on the dendrogram, to see if the changes made any differences to the results. There were a few instances where anomalous groups that either made no geographic sense or had no obvious indicator species were formed. The sites in these anomalous vegetation groups were either reallocated to other vegetation groups or were not used in the vegetation mapping.

After satisfactory relationships between each of the vegetation groups and geology and terrain were found on the GIS, the iterative classification process was ended. Every site within the PATN Dendrogram was assigned its final vegetation number and the FIDEL program was run to provide a final profile of species found in each vegetation group. A file containing all the floristic samples allocated to vegetation groups in the final classification was then imported into the GIS for use in the vegetation mapping across the study area. The groups derived from this final classification step then were defined as *vegetation groups*, for the purposes of mapping, description, and reporting. In the original version of the vegetation mapping, these were termed forest or non-forest ecosystems, depending on whether they were forest or non-forest vegetation (Thomas et al. 2000).

A further classification of the vegetation groups into vegetation classes was undertaken using the same method to derive the primary classification (Appendix 1a on the CD-ROM). Instead of the field samples being treated as objects, a cluster analysis was performed on the vegetation groups to lump the vegetation groups into broader vegetation types. This further analysis produced vegetation classes that became

the next level in the vegetation hierarchy. The vegetation classification of the study area could now be analysed or viewed at two levels instead of one created from the original cluster analysis. To complete the hierarchy, a third level vegetation formation was added to conform to the state-wide classification of Keith (2004).

#### *Description of Vegetation Groups*

The FIDEL software program (Bedward 1999) was used to profile indicator species of groups at any level within a vegetation classification. This program calculates the relative median cover-abundance and frequency of occurrence of plant species within and outside a vegetation group. The default cut-offs in the FIDEL were used to define the FIDEL output values. The default cut-offs were attribute scores set at the 50th percentile; group score cut-offs set to a cover abundance of 2 and group frequency of 50%, non-group scores set to a cover abundance of 2 and group frequency of 50%. Table 3 summarises the definitions of indicator species within vegetation groups.

An indicator or diagnostic species has high relative frequency within the Target Vegetation Group and a relatively low frequency in other vegetation groups. These plants species are usually described as Positive Species. Plant species which are described as Negative or Constant are considered unreliable indicator species. In some instances, species that occurred at a frequency between 30 and 50% were still regarded as useful indicator species, even though FIDEL labelled them as uninformative. These are described as 'Less Informative' species in Table 3. When combined with 'Positive Diagnostic' indicator species they contribute to the description and profile of a vegetation group.

Based on the information summarised in the FIDEL file, a description of each vegetation group was derived. The vegetation groups were assigned vernacular names following the conventions of Keith and Bedward (1999). The last part of the name describes the vegetation structure, such as rainforest, forest, woodland, scrub, heath, swamp, or grassland. The name may include a place name if it is found in a distinct part of the study area. A description of the understorey is generally included to give a more complete description of the vegetation group.

Descriptive profiles of vegetation groups, the first level in the hierarchy, were produced to enable identification of these in the field. These vegetation profiles are available on the CD-ROM accompanying this paper (Appendix 5). Each profile includes information about the floristic composition, structure, habitat, and occurrence of each ecosystem. Floristic data is presented in a table showing vegetation group frequency and cover-abundance of each species within the described unit, together with its frequency and abundance in all the other vegetation groups. Fidelity classes in the table describe possible indicator species in each vegetation group.

The naming convention of the second level in the hierarchy, the vegetation class, is based on regional descriptors and levels of moistness in the understorey, where appropriate to give more detailed vegetation descriptions that reflect the environmental and physiographic conditions of that vegetation class. A regional descriptor was based on botanical regions, such as South Coast, Southern Tablelands, and South-West Slopes. If a vegetation class fell within a particular part of the study area, it was given a sub-regional name descriptor, such as Lower Snowy or Morton Plateau to help with locating that vegetation class within the study area. Finally a vegetation structural descriptor completed the description of the vegetation classes, using commonly used terms for vegetation formation or sub-formations, such as rainforest, moist eucalypt forests, ash type eucalypt forests, montane eucalypt forests, dry shrub eucalypt forests, grassy eucalypt woodlands or forests, grasslands, heathlands, and shrublands, swamps and swamp heaths, sub-alpine and alpine herbfields and ferns, and coastal vegetation. The term moist shrub or layered shrub forest replaces the term wet sclerophyll, as some forests in this formation can have a variety of understorey types. For example Vegetation class 2c, Moist Layered Shrub Forest, has a mixed layered understorey, comprising rainforest, broad and fine leaved shrub plant species. A second example is vegetation class 2d, Tableland Grass/Fern Forest, has or a mixed grassy or ferny ground layer, with a layer of scattered shrubs, depending on the site and past disturbance.

The third and highest level in the hierarchy of vegetation classification is the vegetation formation. The naming convention for a vegetation formation follows of Keith (2004), with some additional formations to cover Grassy Forests, and Montane Tablelands Forests, Wet Heaths/Swamps, Vegetation on Rock Outcrops, Sub-alpine Grassy Forests, and Riparian Forests. The Montane Tableland Forests are neither grassy nor shrubby and fall into a category between Wet and Dry Sclerophyll Forests. Coastal and Tableland Grassy Forests are termed Grassy Woodlands in Keith (2004). In the study area the Coastal and Tablelands Grassy Forests have a forested rather than a woodland cover. In places with higher levels of clearing and disturbance, the current forested cover may have been reduced to a woodland

state. These Grassy Forests are distinctively different from the Grassy Woodlands found further west on the tablelands and south-west slopes.

*Mapping of extant vegetation*

To facilitate mapping, the study area was divided into three subregions based on operational regions of State Forests of NSW and modified somewhat to conform to bioregions. The Commonwealth and State Governments adopted these sub-regions as negotiation regions for the RFA. The sub-regions were:

- **South Coast** sub-region, encompassing State Forests of NSW' hardwoods region, extending west to the Monaro Highway and including southern part of Wingecarribee and Kiama local government areas;
- **Western** sub-region, encompassing the State Forests of NSW' hardwood region in the Riverina and including the ACT;
- **Northern** sub-region, covering the southern Central Tablelands, and the northern half of the Southern Tablelands.

The mapping method is based upon an expert knowledge system of vegetation mapping that correlates the vegetation groups, defined in the cluster analysis, with environmental spatial data. The spatial distribution of each vegetation group was related primarily to the CRA forest type layer (CRAFTI) which was used as the primary mapping layer for mapping existing vegetation. Other key environmental data to guide the mapping were geology, elevation, aspect, and topographic position. The Landsat Thematic Mapper (TM) layer was used as a photographic image on which all the key environmental layers and classified survey data were overlain. The patterns of dry and wet sclerophyll forest were clearly visible and in most cases matched the lines drawn by air photo-interpreters to distinguish the broad vegetation types, such as rainforest, wet sclerophyll, dry sclerophyll, heath forest, grassy forests, heaths and swamps. It also became an important tool in investigating spatial patterns of each vegetation group, as it helped to differentiate between wet and dry sclerophyll sites

**Table 3. Definitions of Diagnostic Species (after Keith & Bedward 1999) using frequency and cover abundance C/A**

Target Vegetation Group	Other Vegetation Groups			
	Frequency ≥ 0.5 and C/A > 2	Frequency ≥ 0.5 and cover abundance (C/A) > 2	Frequency < 0.5 or C/A < 2	Frequency = 0
Frequency ≥ 0.5 and C/A > 2	Frequent	Positive Diagnostic	Positive Diagnostic	Positive Diagnostic
Frequency < 0.5 or C/A ≤ 2	Negative diagnostic	Less Informative	Uninformative	-
Frequency = 0	Negative diagnostic	Uninformative	-	-

on opposing aspects, the more productive forests on valley floors or along riparian zones, and any sharp transitions in vegetation, usually associated with geology or soil type.

The mapping method depended on an accurate and reliable air photo interpretation to produce a high quality vegetation map. The CRA forest type layer was first checked to ensure that it was a satisfactory base layer for vegetation mapping purposes using a two step process:

- a) a preliminary check of air photo-interpretation of the CRAFTI layer in the office. All available mapped and site data was used to check polygon boundaries and API codes with the CRAFTI layer, using expert local and regional knowledge of the distribution of tree species;
- b) field checks of API polygons, using a hard copy map version of the CRAFTI layer, as well as expert knowledge of the distribution of tree species during travel between flora surveys in the field.

An Arcview project within Arcview GIS 8.3 was created to enable mapping of vegetation against a backdrop of Landsat TM imagery and other contextual spatial data. Requisite spatial data was loaded into the view window. Data loaded into this view included:

- classified site data taken from the PATN analysis;
- remotely sensed imagery;
- environmental spatial data; and
- other contextual layers such as roads and utility easements and reserve boundaries.

The mapping sub-regions, South Coast, Western, and Northern, were then progressively mapped in that order. Small sections of a sub-region were mapped at a time to make the mapping of vegetation groups consistent within and between different sections of the sub-region. Each vegetation group in that section of the map was mapped using the sample sites allocated to that vegetation group in PATN, and by applying extensive expert knowledge of the likely spatial pattern of that vegetation group in the landscape. If there was a clear relationship between the expected pattern and the boundaries of CRAFTI polygons, then a numeric vegetation code corresponding to the vegetation group was placed in the vegetation code field of the CRAFTI layer.

Generally there was a clear relationship between the expected vegetation pattern and the CRAFTI mapping, and vegetation codes were directly assigned to the relevant API polygons. Some polygons required refining to adjust boundaries or to split into finer polygons to match the expected vegetation pattern. These changes were made in Arcview GIS and the vegetation group codes reassigned as appropriate.

Using this highly repetitive process across 3 120 400 hectares, three botanists, Phil Gilmour, Nic Gellie, and Michael Doherty completed the vegetation map of the three mapping sub-regions in three months (Table 4). The mapping of extant

vegetation by this method proved to be the only efficient, consistent, and repeatable method within the time constraints imposed by the Regional Forest Agreement (RFA) process.

The three maps were amalgamated to create a uniform and consistent vegetation map across the whole Region. The most recent version of the extant vegetation map has recent national parks and nature reserves mapping overlain on the region-wide vegetation maps. Recent mapping includes the vegetation maps of new RFA reserves in the South-West Slopes, South Coast, and Far South Coast Regions of the Department of Environment and Conservation (EcoGIS, 2002, 2004a, 2004b, 2004c, Graham-Higgs Pty Ltd (2002a, 2002b, 2002c, 2004, and 2005).

### *Models of vegetation*

Modelling of the distribution of vegetation groups was undertaken simultaneously with the mapping of extant vegetation. The modelling was seen as a supportive process to the expert vegetation mapping of extant and pre-1750 vegetation and was used to test some of the assumptions held by the mapping experts about the distributions of vegetation groups within a regional landscape setting. The use of Generalised Additive Modelling (GAMS) was consistent with methods devised by Austin & Belbin (1982) and Yee & Mitchell (1991). A modelling software program, based on S-PLUS and Arcview GIS, was adapted for this purpose (Ferrier 2002). The modelling of vegetation groups' distributions were based on the classified site samples arising out of the classification phase of the project, as well as the detailed environmental layers (Table 2). GAM models were prepared for those vegetation groups that had been significantly cleared and that had sufficient plot data (at least 10 vegetation samples) to produce a valid model. Table 5 summarises which vegetation groups had GAM models run in each sub-region of the study area. The number refers to the map legend number of the vegetation groups.

Within this subset of vegetation groups, all the sites within a given vegetation group were assigned to presence sites, while the remaining sites in the other groups were assigned to absence sites. With up to 3400 absence sites available, the GAM models produced reasonable models when there were at least 20–30 samples assigned to presence data, with a reasonable distribution of samples assigned as absence data. Some of the models were also useful in identifying possible sites to reallocate to other vegetation groups.

The next stage of model production involved setting realistic minimum thresholds for the probability distribution for each model that would correspond to a realistic map of the pre-1750 distribution of each vegetation group. The spatial extent of a GAM model was usually constrained to the spatial extent of the sample sites within each vegetation group. Where there was an over-prediction in the spatial extent of a model, the model's minimum probability thresholds were adjusted higher to ensure that the model produced a

tighter fit. In some cases the models were constrained with a geographic area mask, set by an expert botanist, to eliminate spurious predictions outside the known or expected range of vegetation groups.

#### Map validation

Occasional short trips were undertaken during mapping of a sub-region to confirm the vegetation patterns in recognisable problem areas. These field checks helped to compare the vegetation to the vegetation classification and evaluate the accuracy of the CRAFTI or mapping of state forests. Field trips also helped to resolve problematic areas such as geographic limits of similar vegetation groups that are separated by understorey components rather than canopy species, and are not well differentiated in the API layer. Additional full floristic surveys were also undertaken in areas identified as problematic for vegetation mapping.

To assist the office validation of the mapping, outside experts reviewed the extant vegetation map of the South Coast and Western sub-regions, and feedback and recommendations were incorporated into subsequent versions. Representatives of State Forests and the National Parks and Wildlife Service were involved in these reviews.

In the 2005 version of the extant vegetation map, more recent vegetation surveys and mapping have been used to validate the classification and the mapping. The mapping of RFA reserves on the South Coast and in the western parts of the study area have been used to validate sections of the vegetation map and to confirm the validity of vegetation groups in the vegetation classification. The Department of Environment and Conservation provided reports prepared by Nicholas Graham-Higgs Pty Ltd (2002a, 2002b, 2002c, 2004, 2005) and EcoGIS (2002, 2004a, 2004b, 2004c), which were incorporated into the current version of the vegetation map. Additional field survey information was kindly made available for the alpine areas (McDougall & Walsh in prep.) and for the temperate and grassy woodlands (Rhewinkel unpubl.).

#### Derivation of a Pre-1750 Vegetation Map

Two maps in GIS format were used to model the previous extent of vegetation on cleared land: maps of acid sulphate soils along the coastal strip, and soil landscapes maps throughout the rest of the study area. The acid sulphate soils layer (Murphy et al. (1998), based on detailed soil survey and mapping of acid sulphate soils of the lowland coastal areas of the South Coast, was essential for modelling the extent of previously cleared vegetation groups.

A separate CRA project, Lithology and Soil Landscape Mapping, produced a soil landscapes maps for the entire study area (DLWC 2000). This soil landscapes layer was a multi-attributed polygon coverage that used the CSIRO (1997) classification of lithology as a basis for the mapping of soil landscapes. Within cleared areas of each CRA sub-region, the soil layers were assigned to vegetation groups, based on the relationship between the broad soil landscapes and assigned API polygons on the adjoining forested area, and the overlay of GAMS. These relationships were explored visually within ARCVIEW GIS to help determine the possible distribution and extent of vegetation groups within the soil landscapes. As soil landscapes were mapped at a scale of 1: 100 000, some mapped landscapes were larger than the corresponding API polygons, mapped more finely at a scale of 1: 25 000. In these instances the detailed pattern on the extant vegetation map could not be transferred, and the most dominant vegetation group was mapped on the adjoining cleared land.

The pre-1750 vegetation map was prepared using the following GIS layers:

1. Extant Vegetation of the South Coast, Western, and Northern sub-regions
2. Pre-1750 Temperate Grasslands
3. Acid Sulphate Soils of the South Coast (DLWC 1998)
4. Soil Landscapes (DLWC 2000)

**Table 4. Mapping of extant vegetation across mapping regions. The South Coast Region includes Commonwealth lands adjoining Jervis Bay and the Western Region includes the ACT.**

Mapping Region	Area of Sub-Region hectares (ha)	Area of Extant Vegetation (ha)	Mapping Experts	Completion Time (months)
South Coast	1 842 600	1 255 200	Phil Gilmour and Nic Gellie	2
Western	2 912 600	1 446 700	Phil Gilmour, Michael Doherty, and Nic Gellie	2
Northern	1 436 800	418 400	Nic Gellie	1
<b>Total Area</b>	<b>6 192 000</b>	<b>3 120 400</b>		

**Table 5. List of GAMS models (Thomas et al. 2000)**

Southern Forests CRA Sub-Region	Vegetation Groups
South Coast	2, 5, 9, 15, 16, 21, 48, 57, 58, 59, 61, 62, 68, 73, 74, 75, 90, 109, 112, 113, 114, 146, 160, 161, 171, 174,
Western	76, 80, 82, 85, 97, 98, 103, 106, 107, 110, 111, 116, 117, 120, 146, 147, 153, 154, 157, 158, 160, 161, 162
Northern	15, 17, 73, 89, 90, 100, 109, 121, 113, 115, 121, 122, 125, 133, 134, 135, 116, 153, 161, 162

A sequential merging of the above vegetation layers, converted to 25 m grids, was undertaken. The pre-1750 vegetation map was compiled in the order and presence of grid cell values from each of these layers. The grid cell values were taken from the extant vegetation layer first, and then from the next vegetation layer, the pre-1750 grasslands layer, and then from the pre-1750 soils layers, until all the grid cells in the study area had a value of a vegetation group. The final merged product was checked to see if there were any missing grids or values in the final map. The pre-1750 vegetation map was recompiled after removal of unassigned polygons in the extant vegetation or pre-1750 soils maps.

## Results

### *Audit of existing survey data*

The data audit produced 9656 samples that could be potentially used in classification and mapping in the study area. Of these 2395 samples met the audit criteria for vegetation classification using full floristics cover-abundance data, plus 1415 additional samples from the South-East Forests region (Table 6). Tables 7, 8, 9, and 10 summarise the datasets.

Categories II, III, and IV were datasets from survey work carried out in the last 25 years that failed to meet criteria for the initial classification but were used for supplementary analyses to test for additional groups and to support the preparation

and validation of the extant and pre-1750 vegetation maps. Previous flora surveys have centred on selected state forests and conservation reserves and catchment areas within the Brindabellas, Tinderry, Tallaganda, Deua and Budawang Ranges (Fig. 3). Smaller flora surveys have been carried out in the ACT and Monaro grasslands, Eurobodalla coastline, Jervis Bay and Beecroft Peninsular, in Kosciusko National Park, and in the Crookwell and Gunning Shires.

### *Field surveys*

Between 1997 and 1999, CRA flora surveys added 1216 full floristic cover abundance survey samples, as well as another 359 canopy only presence-absence samples. The latter dataset was used mainly in the validation of the API layer. The surveys focussed principally on major gaps in survey effort in state forests and national parks (Fig. 3). There were also some field surveys done on Crown Land to supplement the other surveys. Private land was only surveyed with agreement from private landholders

Between 2001 and 2005, 418 additional field survey samples have been added to the survey database (EcoGIS, 2002, 2004a, 2004b, 2004c). This additional data has been used to validate the first version of vegetation classification and maps produced in 2000. Survey data from reports by Graham-Higgs Pty Ltd (2002a, 2002b, 2002c, 2004, 2005) and the P5MA mapping (Tindall et al., in prep.) are not included in the current database.

The current survey database contains 5444 full floristic survey samples with cover abundance data, of which about 4180 samples have been used in the more vegetation classification in 2005. An additional 6675 samples were also catalogued and checked that included either partial floristics data with cover-abundance scores; or canopy floristics data; or full floristics data with presence absence scoring values.

The field surveys since the audit have added another 33% of full floristic cover abundance samples across critical environmental gaps in the study area. While the extra sampling has not covered all the geographical and environmental gaps, it has provided sufficient samples for a region-wide classification to be undertaken with some

**Table 6. Audited sample sites available for classification and mapping.**

Data Category	Flora Survey Data Type	Southern Forests No of Samples	South-East Forests No of Samples	Total
I	Full floristics cover abundance	2395	1415	3810
II	Full floristics presence absence	612	589	1201
III	Canopy only presence absence	4442	0	4442
IV	Partial floristics cover abundance	0	203	203
<b>Total</b>		<b>7449</b>	<b>2207</b>	<b>9656</b>

**Table 7. Full Floristic Cover-abundance Datasets (Thomas et al. 2000)**

Reference	Location	No of Samples (ha)	Plot size
<b>Southern Region</b>			
Benson 1994	Monaro Grasslands	62	0.01
Binns 1997a	Bago & Meragle SF	102	0.1
Binns 1997b	Carabost & Woomargama SF	7	0.1
CSIRO 1999	Clyde Mountain and Escarpment	47	0.1
Doherty 1996	Tinderry NR	50	0.04
Doherty 1997	Mundoonen NR	17	0.04
Doherty 1998a	Brindabella NP	130	0.04
Doherty 1998b	Burrinjuck NR	33	0.04
Eurobodalla Shire Council & NPWS 1998	Eurobodalla Shire	30	0.04
Forward et. al. 1997	Kosciuszko NP - fire monitoring plots	49	0.04
Gilmour 1985	Deua National Park	127	0.1
Gilmour et al. 1987	Williamsdale and Mt Tennant locality in the Namadgi NP	113	0.04
Helman 1983	Clyde River and Mt Dromedary Rainforest Surveys	231	0.1
Helman 1983	South Coast Random Rainforest Survey	40	0.1
Helman et al. 1988	Upper Cotter catchment, ACT	135	0.04
Hibberd and Taws 1993	Gunning, Crookwell, Boorowa Travelling Stock Route Surveys	321	0.04
Ingwersen 1992	Namadgi NP	201	0.04
Jurskis et al. 1995	Queanbeyan/Badja EIS	112	0.1
Lockwood et al. 1997	Eurobodalla NP	55	0.04
NPA 1998	Benanderah SF	30	0.04
Sharpe 1991	ACT grasslands	30	0.01
Skelton and Adam 1994	Beecroft Peninsula	168	0.04
Steenbecke 1990	Middle Kowmung River, Kanangra-Boyd NP	150	0.04
Taws 1997	Booderee National Park	101	0.04
Togher 1996	Abercrombie National Park	32	0.04
<b>Eden Region</b>			
SFNSW 1999a	SFNSW - miscellaneous Eden	81	0.04
SFNSW 1999b	SFNSW Mt Pericoe Flora Reserve	24	0.04
SFNSW 1999c	SFNSW Mt Waalimma Flora Reserve	22	0.1
Dodson et al. 1988	Glenbog SF	30	Unknown
Fanning & Rice 1989	Bondi SF	50	0.1
Keith 1999	Wadbilliga - mallee heath survey	14	0.1
Keith & Bedward 1999	NPWS Eden CRA Survey	269	0.1
Keith & Bedward 1999	South-East Forests Combined Surveys since 1991	698	0.04
Keith & Bedward 1999	Eden CRA Validation Surveys	136	0.1
Williams 1997	NPWS Bermagui NR, Biamanga NP, Goura & Wallaga Lake NRs	91	0.04

confidence. The addition of the new samples has helped to validate some of the earlier mapping decisions made in the absence of good coverage of field survey samples, as well as expert field knowledge.

#### *Vegetation classification*

2273 samples from the audit were combined with the 1216 samples from the field surveys, together with a sub-set of 251 samples from the Eden dataset, selected within an adjoining buffer zone within the South-East Forests Region. It was decided to use a smaller number of samples from the South-East Forests to remove any bias in the vegetation classification from the much higher density of sampling in that region. The combined number of Southern and South-

East Forest survey samples amounted to 3740 using samples with all vascular plants and cover abundance measures. This final dataset included some datasets such as Helman (1983), Gilmour et al. (1987), and Helman et al. (1988) which had comparable methods of assessing vegetation cover to that of the modified Braun-Blanquet method (Poore 1955). The authors of the original surveys were consulted about making consistent and repeatable changes to the cover-abundance scores, to make the datasets consistent with other surveys with Braun-Blanquet scoring systems.

Preliminary testing of levels of vegetation classification used classification levels between 100 and 200 groups. Homogeneity analysis (Bedward (1999) of 3740 floristic samples grouped into ascending number of groups (Fig. 4) was used to select a potential starting point in the vegetation

**Table 8. Presence-Absence Survey Datasets (Thomas et al. 2000)**

Reference	Location	No of Samples	Plot Size (ha)
<b>Southern</b>			
Clarke 1989 length transects	NSW Coastal Vegetation Survey	72	20m
Gunn et al. 1969	Queanbeyan Shoalhaven area	261	0.04
Ingwersen 1972	Black Mountain Nature Park	59	0.04
Ingwersen 1983; Ward & Ingwersen 1988	Tidbinbilla Nature Reserve	81	Presumed 0.04
Ingwersen et al. 1974	Mount Ainslie and Majura Nature Park	139	Presumed 0.04
<b>Eden Region</b>			
Breckwoldt and Breckwoldt 1979	Eden/Southern Coastal Vegetation Survey in Goura, Bermagui, & Bournda NRs, as well as Mimosa Rocks and Wallaga Lake NPs	374	0.04
Outhred 1986	NPWS Eden Survey of Wadbilliga NP	215	Nested Quadrats

**Table 9. Canopy Floristics Survey Datasets (Thomas et al. 2000)**

Reference	Survey location	No of Samples	Plot Size (ha)
<b>Southern</b>			
CSIRO 1999	Canopy Surveys - South Eastern NSW	3921	0.1
NPWS 1996	Tumut Interim Assessment Project	521	0.1

**Table 10. Partial Floristics Cover Abundance Survey Datasets (Thomas et al. 2000)**

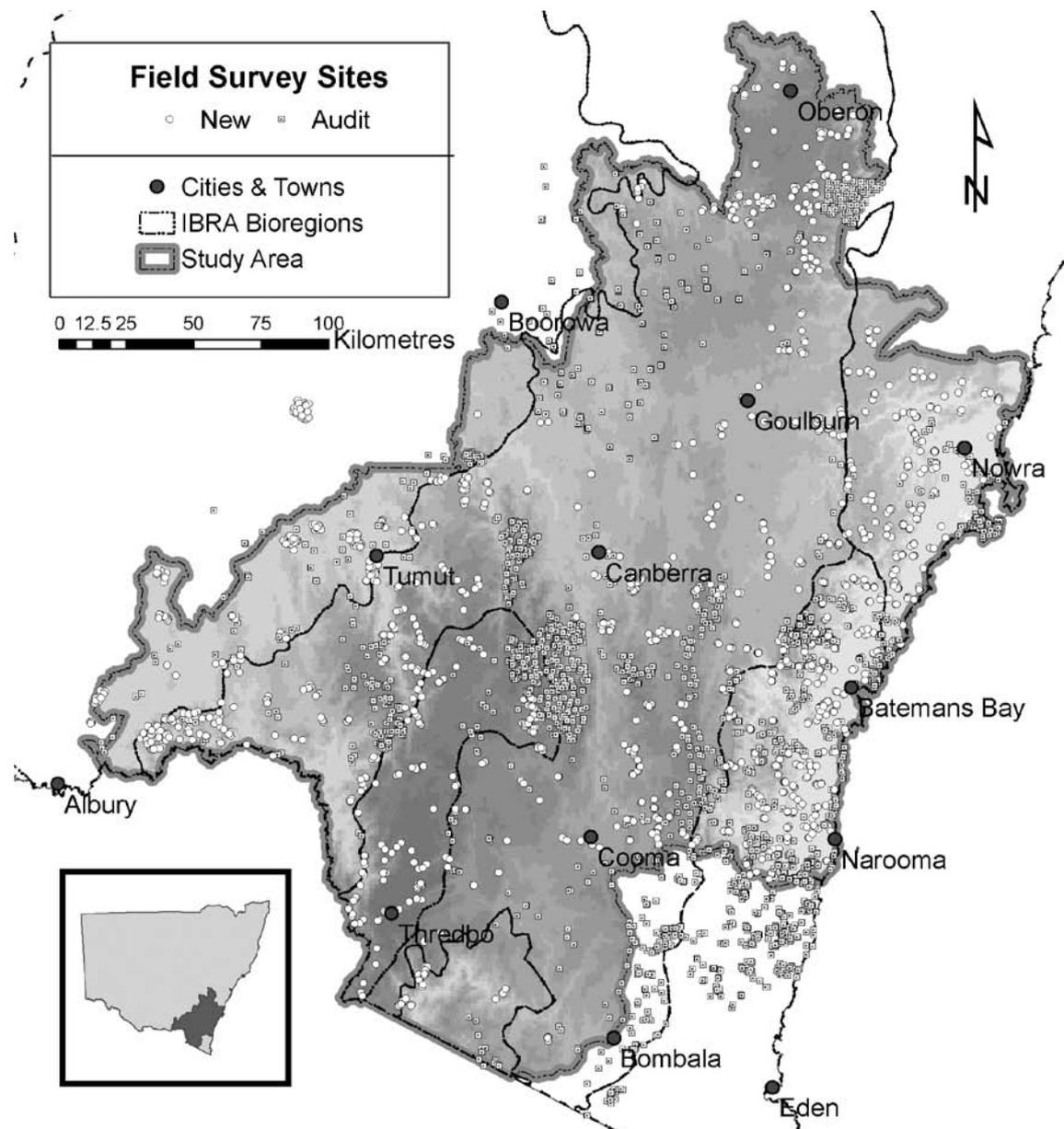
Reference	Location	No of Samples	Plot Size (ha)
<b>Southern</b>			
Mills, 1996a, 1996b and 1999	Conjola, Cudmirrah, Illawarra, Jervis Bay, Kangaroo Valley, Nowra, Red Rock NR, and Ulladulla localities	182	Presumed 0.04
Mills, 1999	Coastal Shoalhaven	21	Presumed 0.04

classification. The upper inflection point in the curve (Fig. 4) occurred between 150 and 200 groups. After reviewing the classification between 150 and 200 groups, an intermediate starting point of 170 groups was selected, with the intention of adding further groups if field knowledge and data supported further splitting of some of the 170 groups.

A classification of 170 vegetation groups provided sufficient detail to show the pattern of vegetation at the scale of forest compartment, between 100 and 300 hectares in size, or equivalent to a small water catchment of similar size. This level of classification seemed to correspond to vegetation units that could be mapped at a scale of 1: 25 000 and provided sufficient detail to distinguish forest types on the basis of overstorey and understorey species that could be readily identifiable in the field. A 170 group classification appeared to fulfill the classification and mapping requirements outlined in the Introduction section. The dendrogram of the 170 group

classification showed that samples from the adjoining South-East Forests region fell into similar groups classified by Keith and Bedward (1999). This meant that the vegetation groups in the study area had equivalents in the South-East Forests Region and provided inter-regional comparability in vegetation classification.

In addition to the vegetation groups classified using vegetation samples, a number of vegetation groups were derived from expert knowledge of gaps in the sampling effort. These were often in unsurveyed areas, in remote terrain, or could not be sampled adequately because of extensive clearing of native vegetation. New vegetation groups were created to correspond with those derived in previous vegetation mapping work or which corresponded with anomalies identified in either the CRAFTI layer or on the remotely sensed images (Appendix 1b on the CD-ROM)



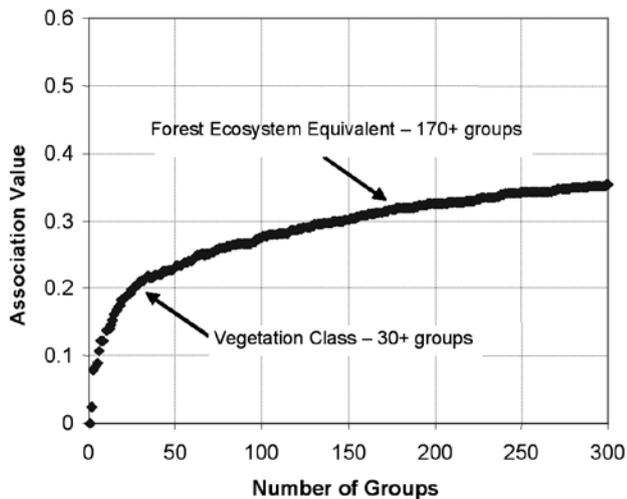
**Fig. 3.** Distribution of full floristic cover abundance survey samples

A lower point of inflection can be found at the level of 30 groups (Figure 4) and seemed to correspond to a much broader ecological classification, equivalent to a vegetation class (Keith 2004). This intermediate classification fell somewhere between a vegetation formation and a vegetation group. The underlying heterogeneity in some of the original 30 vegetation classes required further differentiation into separate vegetation groups to produce a classification of 48 vegetation classes. A hierarchical classification of 48 vegetation classes was created, based on a hierarchical grouping of the 170 vegetation groups derived from the PATN analysis (Appendix 1a on the CD-ROM). The rest of the vegetation groups, with group numbers greater than 170, appear in a separate table after the dendrogram (Appendix 1b

on the CD-ROM). A further 6 vegetation classes were created from the expert derived vegetation groups, after matching where possible to the existing 48 vegetation classes in the classification dataset (Appendix 2 on the CD-ROM).

A complete list of the vegetation groups (Appendix 3 on the CD-ROM) includes the vegetation group numeric code; the vegetation group name; whether it was forest or non-forest; its mode of derivation in terms of classification, such as whether it was derived directly from the cluster analysis or instead was expert derived.

As well as a full floristic classification, a canopy only dataset of 9139 samples was created by merging the full floristics cover abundance and presence-absence datasets with the



**Fig. 4.** Graph of Homogeneity Values, showing possible starting points in the vegetation classification

canopy only dataset (Table 11). This is less than the final number of 10238 samples available in 2005. This dataset, once classified, was a significant aid in mapping vegetation where there were few full floristic survey samples available in the more remote parts of the study area. Areas where these proved valuable included the central parts of Kosciuszko National Park, the lower footslopes of the South-East Highlands bioregion, and in the middle Shoalhaven River catchment.

### Mapping

The map of extant vegetation covers 3 120 400 hectares of forests and non-forests. 193 vegetation groups were mapped on the extant vegetation map, and 199 on the pre-1750 vegetation map. 12 vegetation groups were not mapped because they occurred in small patches or as narrow lineal features and had insufficient floristic samples to map them accurately (11, 39, 72, 84, 85, 142, 155, 182, 199, 202) or they fell outside the study area (6, 52). A digital version of the extant vegetation map can be found in the mapping directory on the CD-ROM. It is produced in both Arcview grid and shapefile formats.

To map each of the ecosystems separately was considered cumbersome. Vegetation classes, which reveal some of the broader patterns and relationships of the vegetation class classes to physiography, climate and soils at regional and sub-regional scales, were mapped. Maps of vegetation classes were grouped by formation according to Keith's (2004) statewide classification. Maps of each of the vegetation formations have been prepared (Appendix 4 on the CD-ROM), in accordance with the hierarchy laid out in Appendices 1a and 1b.

Table 12 shows estimates of pre-1750 and extant areas of vegetation formations, together with other statistics on the vulnerability classes, the extent of remaining vegetation, as

well as areas of each vegetation groups within conservation reserves. The most widespread and dominant vegetation formation is Dry Grass/Shrub Forest, with 1 026 800 hectares (~33% of the total extant area of vegetation). The next most common formation is Dry Shrub Forests mainly situated on the eastern side of the study area, within the South-East Corner and Sydney Basin bioregions. It covers 481 400 hectares (~16%). This is closely followed by Montane Tableland Forests with an area of 474 500 hectares (~15%), which occupies the central part of the study area, at higher elevations than the Dry Grass/Shrub Forest formation. The Moist Eucalypt Forest formation occupies a slightly lesser area of 445 800 hectares (~14%).

The vegetation formation of Heath Forests/Heathlands/Mallee Low Forests has an area of 150 300 hectares (~5%). The Sub-Alpine Forests/Woodlands formation covers an area of 112 800 hectares (4%) similar in area to that of Ash Eucalypt Forests, which covers an area of 110 700 hectares (4%). In the Alpine Area bioregion, the Alpine/Sub-alpine Complexes formation has a somewhat smaller area of nearly 80 400 hectares (~3%). Because of extensive clearing and modification of the both woodland and grassland ground cover, the once extensive vegetation formation of Grassy Woodlands and Grasslands now occupy only 89 600 hectares (~3%). It once occupied a possible area of 1 314 800 hectares previously. Vegetation on rock outcrops amounts to 48 300 hectares (2%), scattered in small pockets through out its range. Much smaller areas of the remaining formations, including Wet Heaths & Rainforests, Sedgelands, Riparian Forests, Freshwater Wetlands and Coastal Complexes, make up the remainder of the area. Their areas vary between 10 000 and 30 000 hectares in specialised habitats of the study area, ranging in areal extent between 0.3 and 1%.

## Discussion

### Classification and mapping

The vegetation mapping, with some extensive subsequent revisions between 2000 and 2005, has produced a map with 193 native vegetation groups. Some of the smaller and finer vegetation groups, such as linear riparian vegetation, have not been mapped. In 2000 the primary focus was to map forested ecosystems. In 2003 the scope of the study was broadened to map to cover the full range of vegetation in the study area. 418 samples were added to the original 3740 flora survey samples. The more recent classification in 2003 confirmed some of the vegetation groups suggested by botanists in the first version of the vegetation map and confirmed most of the original vegetation groups created in the first stable version of the vegetation classification in 1999. Detailed checking of vegetation in the new RFA reserves has largely confirmed the stability of the vegetation classification (Graham-Higgs Pty Ltd (2002a, 2002b, 2002c, 2004, 2005) and EcoGIS (2002, 2004a, 2004b, 2004c)).

184 mapped vegetation groups have remained stable in the classification, while the remaining 8 vegetation groups, together with some individual samples have remained inherently unstable in the hierarchical classification (e.g. 31, 59, 64, 66, 89, 97, 99, 100). These elastic and unstable samples and vegetation groups either form new groups or mix in with other samples of more stable vegetation groups. This complexity and instability in a hierarchical classification is an ever-present and complicating factor in a classification of this size.

In the South-East Forests region, Keith & Bedward (2000) identified 72 vegetation groups in an area of 550 000 hectares. By comparison the Southern Forests study area here has 193 vegetation groups for an area of vegetation of three million hectares (3 120 400 hectares). Gilmour (pers comm) contended that the classification of vegetation groups in the Southern Forests study area should have been finer than that used in the final vegetation map. A finer classification however, might make the task of identifying ecosystems in the field more difficult, because there could be a smaller range of indicator species to separate similar vegetation groups.

The larger size of vegetation groups in the Southern Forests study area may be related to the broader environmental gradients operating over the flatter topography and less diverse soils, particularly on the tablelands and western slopes. There is a higher number of vegetation groups found on the more rugged and diverse topography of the Kosciuszko and Namadgi Ranges. It is possible that the higher number of groups in the Brindabella Ranges may be due to the heterogeneity created by different flora surveys, using slightly different survey methods. Doherty (pers comm) has indicated that disturbance patterns and observer bias may have contributed to some of the extra variation and detailed ecosystems in the Brindabella area.

26 vegetation groups in the South-East Forests region (Keith & Bedward 1999) were found to be directly comparable with those in the Southern Forests study area (1, 2, 7, 13, 18, 22, 23, 28, 32, 33, 35, 47, 48, 49, 53, 54, 55, 61, 64, 134, 135, 138, 157, 164, 165, 166) (Appendix 3 on the CD-ROM).

#### *Map accuracy*

The API mapping layer was only checked during the Southern CRA in small areas (Hunter 2000). The API mapping layer often had inconsistent polygon API codes which reflected the varying interpretations made by air photo interpreters. These inconsistencies meant that assigning vegetation group codes to API polygons became quite complex and involved a great deal of checking using all available site and mapping data. In these instances the mapping expert had to use the classified floristic data and local knowledge to guide the assignment of API polygons to vegetation. Difficulties in vegetation mapping were also experienced in places where there was an inadequate coverage of site data. In these situations

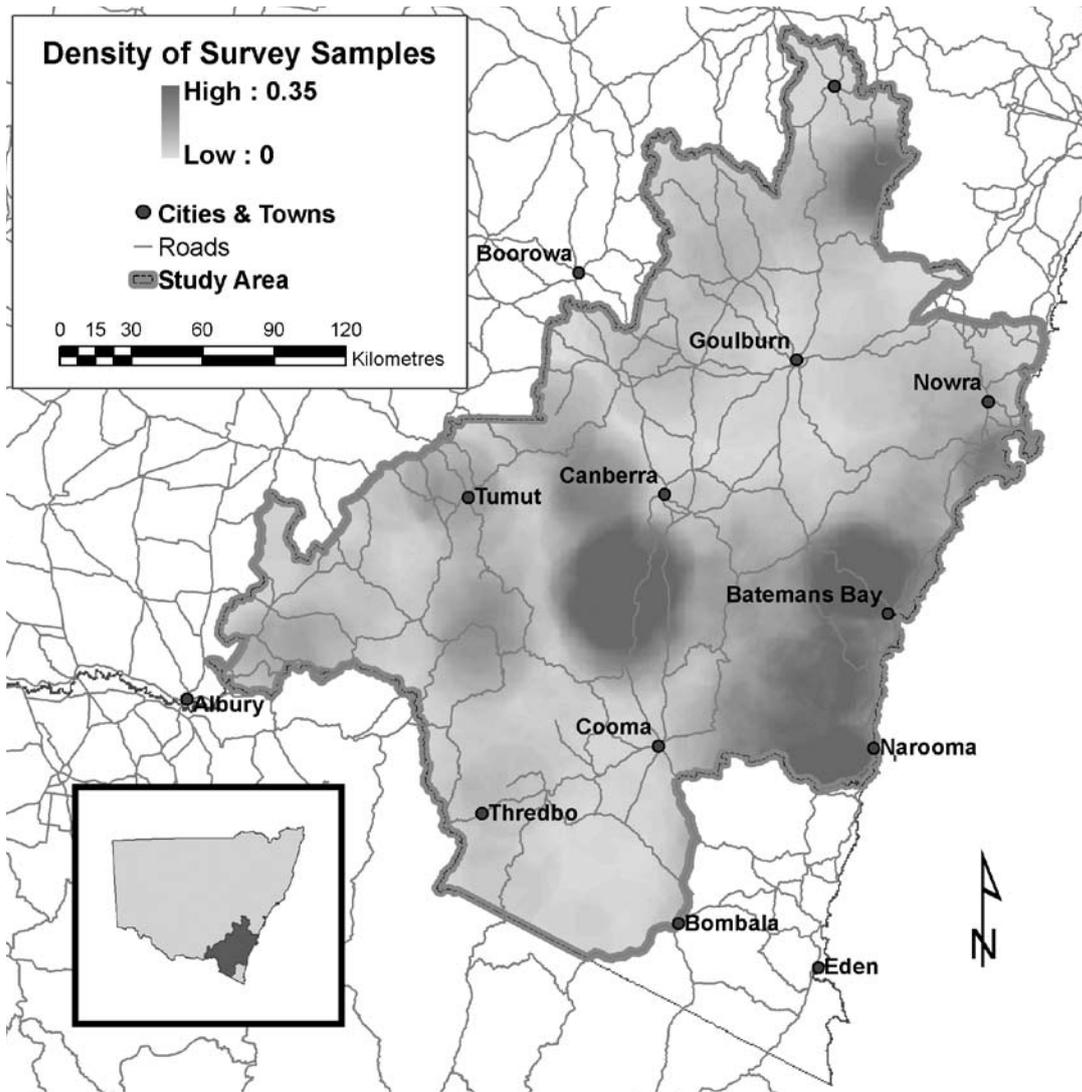
the mapping expert would refer to previous mapping of vegetation and reports to infer possible relationships between the API polygons and the classified site data. The canopy-only site data proved to be invaluable in places where there was no full floristic data.

The 2005 version of the vegetation map may still contain errors in places where there has been inconsistent or erroneous air photo interpretation, and where there is a scarcity of field survey data, and lack of local knowledge. One of the main limiting factors was having well stratified floristic samples across the full range of environmental gradients. Though many gaps in the geographical coverage of survey samples have been filled by ongoing survey, some areas still remain undersampled. However the average sample density across the study area has reached 0.06 samples per square kilometre, with a range from 0.01 up 0.33 samples per square kilometre (Fig. 5). The highest density of samples is found in Namadgi National Park, Jervis Bay, Bago and Meragle State Forests, and in the middle Kowmung catchment in the Blue Mountains. The sampling density is just under one third the average density of 0.18 in the South-East Forests region (Keith and Bedward 1999), and 0.2 in the survey of the Cumberland Plain of western Sydney (Tozer 2003). A sampling density between 0.1 and 0.15 samples per square kilometre in this study area would need a further 500 to 750 floristic samples. As most of the study area has less variable landscape than those in the South-East Forests region, a lower density of between 0.1 and 0.15 samples per square kilometre may be acceptable.

Since the production of the vegetation map in 2000, there has been ongoing survey, and verification of the API. Most of the new data has come from validation surveys of new RFA reserves in the Western and South Coast sub-regions. The vegetation map has also been updated in problematic areas. There has been a major update of the mapping of Grassy-Shrubby Forests, Ash Forests, Heathlands, and Alpine & Sub-alpine Complexes, indicated by the lighter grey areas in Fig. 6. In total 330 000 hectares, representing about 10% of the area has been remapped. Despite this more remapping work, the extant vegetation map requires further checking within some of the larger national parks, such as southern Blue Mountains, Kosciuszko and Morton National Parks, as well as on private and Crown lands through the northern part of the study area.

Recommended areas for further checking and revision of the map include:

- the northern sub-region in grasslands, grassy woodlands, and dry forests in the central and upper parts of the Abercrombie catchment and on the Crookwell and Goulburn plateaus;
- the western sub-region in grassy woodlands and montane grass/shrub forests, the northern part of the Cotter catchment in the ACT, a vast tract of central and northern Kosciuszko National Park, the western and eastern



**Fig. 5.** Map reliability - the mean number of samples per square kilometre, within circular radii of 20 kilometres, across the Southern Forests study area

escarpments of Kosciuszko National Park, the Snowy River catchment and Delegate areas, and all through the sub-alpine and alpine complex, particularly in the non-forest areas, with particular focus on the grasslands, bogs, alpine herbfields, and feldmarks; and finally,

- the eastern escarpment sub-region in central Morton and Budawang National Parks, the grassy woodlands and grasslands through the broad valleys in Numeralla and middle Shoalhaven river catchments, and through the Numeralla and Wadbilliga ranges. Some of the additional sampling has already been completed in the northern part of the study area under the auspices of the P5MA project (Tindall et al., in prep).

#### *Biogeographical and environmental relationships*

The study area spans five bioregions, the South-east Highlands (SEH), Australian Alps (A), South-Western Slopes (NSS), South-East Corner (SEC), and Sydney Basin (SB). The bioregions reflect the varying dominant influences of geological substrate and climate that apply at a continental scale. At a regional scale the vegetation in the study area largely conforms to these bioregions with a strong gradient between warm and moist climates in the Kiama-Illawarra escarpment area, to the cooler and drier tableland plateau, and finally onto the moist and cool alpine areas. The vegetation responds to these general environmental gradients, as well as the underlying soil fertility.

### 1. Rainforests

The rainforest formation is found mostly in the South-East Corner bioregion comprises sub-tropical, warm-temperate, and cool temperate elements (Map 1 on the CD-Rom). Along the Southern Illawarra, Deua, and Budawang escarpments, vegetation class 1a forms mist forests in narrow sheltered gullies, on moderately fertile soils derived from Ordovician and Permian siltstones, in moderately cool temperatures and high rainfall. Gondwanan elements include plant species *Eucryphia moorei*, *Fieldia australis*, *Dicksonia antarctica*, and *Pyrrosia rupestris*. An outlier of cool temperate forest is found in moist gullies in the Geehi catchment of Kosciuszko NP, where the dominant tree is *Atherosperma moschatum*. In the milder and warmer climes below the coastal escarpment a warm-temperate/subtropical rainforest (vegetation class 1b) predominates on sites with moderately fertile soils, high rainfall, and finds full expression around the Kiama and Kangaroo Valley escarpments. Warm temperate rainforest species, such as *Acmena smithii*, *Ficus coronata*, and *Claoxylon australe*, are common throughout vegetation class 2b. *Doryphora sassafras* and *Ceratopetalum apetalum*, are more common dominant tree species in the warm temperate rainforests. In the sub-tropical/warm temperate rainforests, more northern rainforest species, such as *Dendrocnide excelsa*, *Baloghia inophylla*, and *Livistona australis* are represented. In the northern part of SEC bioregion, warm temperate rainforests tend to be found on the cooler sheltered slopes and aspects, whereas the warm temperate sub-tropical rainforests are found on the warmer and more exposed slopes.

### 2. Moist Eucalypt Forests

Moist Eucalypt Forests, sometimes adjoining rainforests, are found in four distinct bands, corresponding to areas with high annual average rainfall between 1100 and 1700mm and fertile soils, such as kraznozems and red earths. The vegetation classes, 2a, 2b, and 2c, are mainly found below the escarpments of the South-East Corner and the southern Sydney Basin bioregions. Outlying pockets of vegetation class 2a, Brown Barrel Moist Shrub Forest, are found east of Canberra in the Brindabella ranges, and around Blackjack Mountain in southern Kosciuszko, and along the Alpine Way in the Upper Murray valley catchment, where high rainfall and fertile deep soils coincide. Vegetation class 2a is found along the high parts of the South Coast escarpment between Deua and the northern Budawangs, with another area around the Robertson and Macquarie Pass areas (Map 2 on the CD-ROM).

Vegetation class 2b, South Coast and Hinterland Layered Shrub Forests, is more restricted to the sheltered slopes and gullies of the South Coast hinterland in lower rainfall areas on moderately fertile soils. Common tree species in this vegetation class are *Eucalyptus muelleriana*, *E. cypellocarpa*, and *Angophora floribunda*. The understorey

can be a diverse mixture of shrubs, ferns, grasses, and forbs and may include in the shrub layer *Acacia mabellae*, *Synoum glandulosum*, *Acacia falciformis*, *Notelaea venosa*, *Pittosporum undulatum*, and *Hibbertia dentata*, as well as vines *Cissus hypoglauca*, *Tylophora barbata*, *Pandorea pandorana*, and *Eustrephus latifolius*. In the ground layer ferns *Pteridium esculentum* and *Doodia aspera* may be dominant, along with a scattered layer of grasses and herbs such as *Poa meionectes* and *Schelhammera undulata*.

Vegetation class 2c, South Coast/Central Coast Hinterland Moist Shrub/Fern Forests, occurs on deep soils on sheltered slopes, derived from Permian mudstones below the escarpment and along deep gullies closer to the Coast. It is probably the most productive forest type in the study area, has as dominant eucalypt species, *Corymbia maculata*, *Eucalyptus saligna/botryioides*, and *E. pilularis*, over an understorey of rainforest species, including *Synoum glandulosum*, *Elaeocarpus reticularis*, *Livistona australis*, as well as ferns, *Calochlaena dubia* and *Blechnum cartilagineum*.

Vegetation class 2d, Tableland Moist Fern/Herb-Grass Forests, occurs on moderately fertile soils on elevated mountain plateaus with rainfall between 1100 and 1300 mm rainfall through the South-East Highlands bioregion. This tableland forest type does not quite fit either the typical wet or dry sclerophyll categories of Keith (2004), having a *Poa* spp. tussock grasses, intermixed with moist herbs, and scattered shrubs. The dominant trees are usually *Eucalyptus dalrympleana*, *E. robertsonii* subsp. *robertsonii*, with sub-dominant trees of *E. viminalis*.

### 3. Ash Eucalypt Forests

The Ash Eucalypt Forests occupy specific environmental niches on the exposed eastern and western escarpments between 900 and 1400 metres, usually on the lee side of main ridges in better developed soils, such as kraznozems, and deep red earths (Map 3 on the CD-ROM).

Vegetation class 3a, South Coast Escarpment White Ash Shrub Forests, tends to be an ecotonal vegetation type between vegetation class 2a Brown Barrel moist shrub forest and vegetation class 7e, South Coast Escarpment Peppermint-Silvertop Ash Forests. It has as its dominant trees, *Eucalyptus fraxinoides*, *Eucalyptus cypellocarpa*, *Eucalyptus fastigata*, and *Eucalyptus sieberi*. The understorey is intermediate between wet and dry sclerophyll forest, with elements of moist shrub and heath elements intermingling in the understorey. Vegetation class 3b, Sub-Alpine Ash Shrub Forest, has an overstorey usually dominated by *Eucalyptus delegatensis*, with co-dominant tree species *Eucalyptus pauciflora*, and *Eucalyptus dalrympleana*. It has a drier understorey, comprising sub-alpine shrubs, such as *Polyscias sambucifolia* subsp. *B*, *Daviesia latifolia*, *Coprosma hirtella*, *Tasmannia xerophila*, and *Tasmannia lanceolata*. A more exposed, higher altitude variant of this vegetation class is vegetation group 86, whereas vegetation

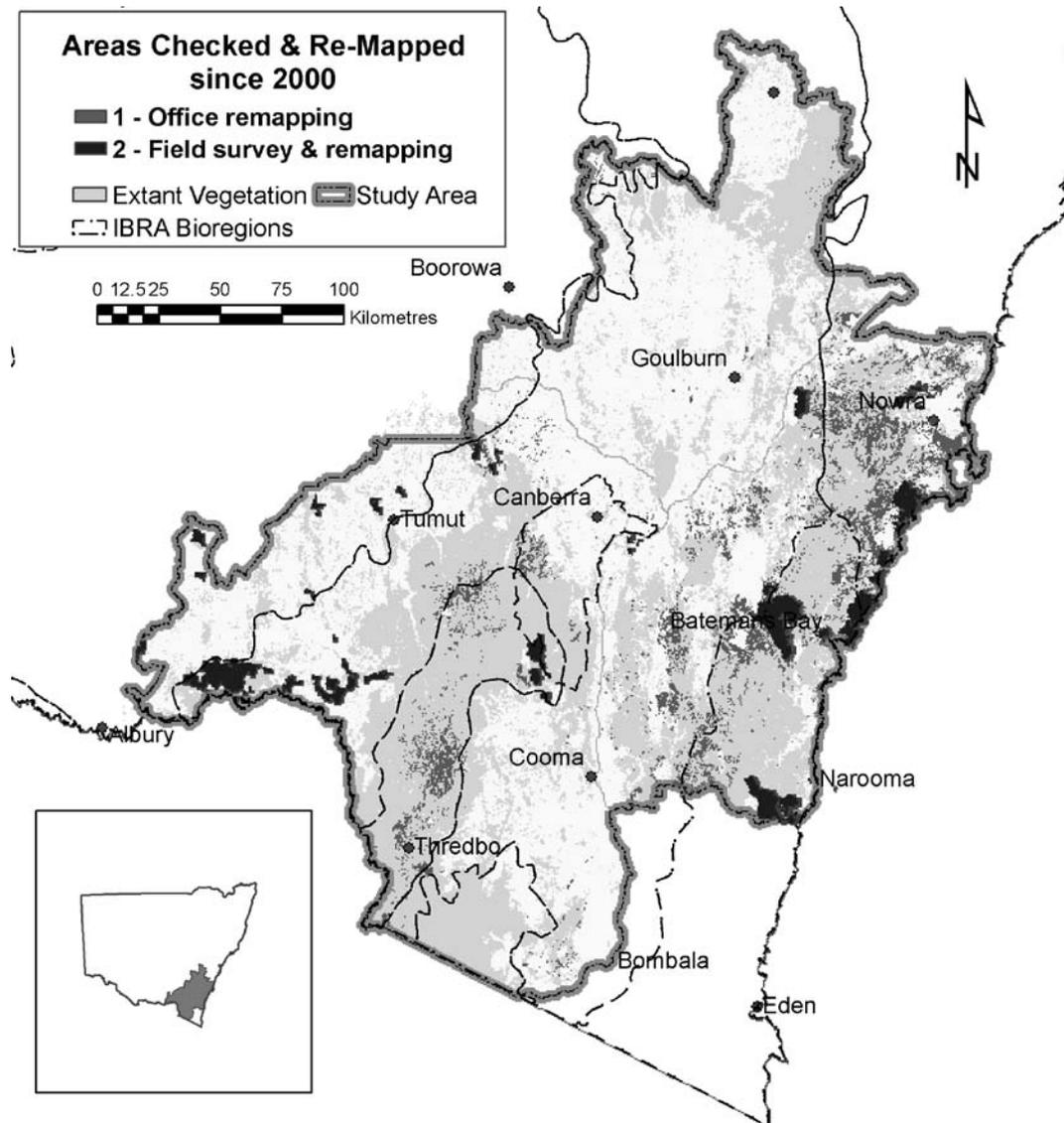


Fig. 6. Extent of mapping and validation work since 2000.

group 87 is found in more montane, sheltered slopes, mainly in the central western parts of Kosciuszko National Park. Vegetation classes 3a and 3b represent the typical fire sensitive montane tall forests, which can succumb to stand replacing fires at intervals as short as 40 and 60 years. Because of the local site conditions, Ash Eucalypt Forests are fast growing and highly productive in their respective montane and sub-alpine environments.

#### 4. Montane Tableland Forests

A widespread formation through the higher parts of the South-East Highlands bioregion is the Montane Tableland Forests, which comprise 3 main vegetation classes, 4a, 4b, and 4c (Map 4 on the CD-ROM). Its vegetation classes tend to be found on less well developed soils in areas of slightly less rainfall than either vegetation formations 2 or 3. These forests are commonly associated with yellow podzolics and red earths on granites and metamorphic rocks. Vegetation class 4a

corresponds to the more productive vegetation class Montane Narrow Leaved Peppermint Forests, which occupies sheltered slopes between 700 and 900 metres on the flatter plateau around Tumut, Black Andrew, and Woomargama to the west and north of the Kosciuszko ranges, and Blackjack Mountain in southern Kosciuszko National Park. Typical forest tree dominants include *Eucalyptus dalrympleana*, *Eucalyptus robertsonii* subsp. *robertsonii*, *Eucalyptus macrorryncha*, and *Eucalyptus bridgesiana*. The understorey comprises *Platylobium formosum* subsp. *formosum*, *Daviesia latifolia*, *Poa sieberiana* var. *sieberiana*, and *Pteridium esculentum*.

In the northern part of the South-East Highlands bioregion, vegetation class 4b, Southern/Central Tablelands Montane Shrub/Grass Forests, is a forest dominated by *Eucalyptus pauciflora*, *Eucalyptus dalrympleana*, and *Eucalyptus dives*. It occupies the more productive red earths in the Crookwell and Oberon plateau with moderate to high rainfall. The understorey is not that dissimilar to vegetation class 4c.

Vegetation class 4c can be found in the higher parts of the range of this formation, between 900 and 1300 metres. A complex suite of vegetation groups occupy a range of sites from exposed and rather infertile soils to deeper and moderately fertile soils. The dominant eucalypts are *Eucalyptus pauciflora* and *Eucalyptus dalrympleana* subsp. *dalrympleana*. In drier and lower elevations of this formation, *Eucalyptus dives* and *Eucalyptus rubida* becomes more dominant tree species, with *Daviesia mimosoides*, *Persoonia chamaepeuce*, and *Poa sieberiana* subsp. *sieberiana* becoming more dominant in the understorey. On moister sites the understorey changes to a moderate cover of *Poa* spp. and *Daviesia latifolia*, with a greater range of herbs, such as *Stellaria pungens*, *Asperula scoparia*, *Viola betonicifolia* subsp. *betonicifolia*, and *Acaena novae-zelandiae*.

### 5. Grass/Shrub Forests

The Grass/Shrub Forests occupy considerable areas of the South-East Highlands bioregion on moderate to steep slopes with red and yellow podzolic soils on sedimentary and acid volcanic rocks. They occur as far south as the lower Snowy near Byadbo, and skirt the eastern edge of Kosciuszko and the Namadgi ranges. They occupy a large part of the Numeralla ranges, as well large areas of the Crookwell and Oberon plateaus. They are also found on the western and north-western parts of the study area on steep or rolling hills above valley floors. Refer to Map 5 on the CD-ROM.

Vegetation class 5a comprises dry grassy forests found on granite batholiths and in rocky gorges of the South-East Corner and Sydney Basin bioregions. Vegetation group 54 is found on undulating slopes on clay loams derived from granite in the coastal valleys from Wallaga Lake to the Illawarra district. Tree dominants are *Eucalyptus globoidea*, *Eucalyptus tereticornis*, and *Angophora floribunda*, with a sparse shrub understorey of *Bursaria spinosa* and *Leucopogon juniperinus*, and a grassy understorey of *Themeda australis*, *Echinopogon ovatus*, and *Eragrostis leptostachya*. The gorge forests comprise vegetation groups 51 and 174, which are found in the Araluen and Bungonia gorges. In the Araluen Valley an open grassy forest of *Eucalyptus melliodora* and *Eucalyptus maidenii* predominates while in the Bungonia gorges, *Eucalyptus tereticornis* is found in the deeper parts of the lower gorges while *Eucalyptus moluccana* and *Eucalyptus bosistoana* are common eucalypts in the open grassy forests at the top of the gorge.

A mosaic of vegetation classes 5b, 5c, 5d, and 5e found within the South-Eastern Highlands bioregion. Vegetation class 5b is found on red podzolic clay soils where average rainfall ranges between 600 and 800 mm. Trees dominants include *Eucalyptus mannifera*, *Eucalyptus dives*, *Eucalyptus rossii*, and *Eucalyptus macrorryncha*, with a common ground cover of *Daviesia leptophylla*, *Joycea pallida*, *Poa sieberiana* subsp. *sieberiana*, and *Gonocarpus tetragynus*. Vegetation class 5c is a western and northern variant of vegetation class 5b, occupying the transition between the western Southern

Tablelands and the South-West Slopes. Dominant tree species in unit 5c are *Eucalyptus macrorryncha*, *Eucalyptus nortonii*, and *Eucalyptus polyanthemos*, over an understorey of mixed grasses and herbs, such as *Danthonia* spp., *Elymus scaber*, *Hydrocotyle laxiflora*, *Daucus glochidiatus*, *Gonocarpus tetragynus* and *Lomandra filiformis* subsp. *coriacea*. Vegetation class 5d, Central Southern Tableland Dry Grass Forests, contains a diverse range of vegetation groups which occupy the valley floors and slopes on heavier clay podzolics and yellow earths. The dominant eucalypts of this class are *Eucalyptus dives*, *Eucalyptus rubida*, *Eucalyptus bridgesiana*, *Eucalyptus viminalis*, and *Eucalyptus pauciflora*. Common species in the understorey include grasses *Themeda australis*, *Poa sieberiana*, and *Dichelachne* spp., as well as low shrubs, such as *Bossiaea buxifolia* and *Pultenaea procumbens*.

### 6. Grassy Woodlands and Grasslands

The Grassy Woodlands and Grasslands are found principally in the flatter lower valleys of the South-East Corner and South-West Slopes bioregions in areas of rainfall between 600 and 800 mm (Map 6 on the CD-ROM).

Vegetation class 6a, Lower Snowy White Box Woodland, is a distinct unit found in the lower Snowy gorges on shallow soils on granitic and metamorphic rocks in rainshadow areas below 650 mm annual average rainfall. The forest canopy comprises *Eucalyptus albens* and *Callitris glaucophylla*, with a sparse understorey of grasses *Themeda australis* and *Austrostipa* spp., along with scattered shrubs of *Acacia deanei* subsp. *parvipinnula*, *Chrysocephalum* spp. and *Lissanthe strigosa*. Vegetation class 6b is found on the western side of the Kosciusko ranges, on the extreme edge of the study area in the South-West Slopes bioregion, on moderately fertile clays on undulating terrain from Holbrook up to Boorowa Shires. An open tree canopy of *Eucalyptus albens*, *Eucalyptus blakelyi*, and *Eucalyptus polyanthemos* subsp. *polyanthemos*, overtops a grassy ground layer of *Microlaena stipoides*, *Danthonia racemosa* var. *racemosa*, and *Austrostipa scabra* subsp. *scabra*.

Vegetation class 6c, Southern Tablelands Yellow Box/Apple Box Grassy Woodland, is found in the central and central northern parts of the South-East Highlands bioregion on red and yellow podzolics on sedimentary rocks. A woodland cover of trees *Eucalyptus blakelyi*, *Eucalyptus melliodora*, and *Eucalyptus bridgesiana* overtop a grassy understorey of *Themeda australis*, *Danthonia racemosa* var. *racemosa*, *Microlaena stipoides* var. *stipoides*, and *Austrostipa scabra* subsp. *falcata*.

Vegetation class 6d, Temperate Grasslands, have been included in this vegetation class as they show close similarity to vegetation class 6c in the vegetation classification. Within this class, there are two distinct sub-regional groups, the Monaro Grasslands comprising vegetation group 158 in the Cooma-Monaro district, and vegetation groups 152, 153, and 157 in the Canberra and Yass localities. Common species

found in both sub-regional groups include *Themeda australis*, *Poa sieberiana* subsp. *sieberiana*, *Danthonia caespitosa*, *Chrysocephalum apiculatum*, *Geranium solanderi* var. *solanderi*, and *Calocephalus citreus*. Vegetation class 6d is commonly found on the Monaro plains and through the Canberra region, on red podzolic soils derived from basalt or sedimentary siltstones, where frosts are reasonably common, and the average annual rainfall varies between 500 and 700mm.

### 7. Dry Shrub Forests

Dry Shrub Forests dominate in the eastern part of the study area, principally in the South-East Corner and Sydney Basin bioregions (Maps 7.1 and 7.2 on the CD-ROM). Despite the relatively high rainfall these areas receive, the low fertility and water holding capacity of the shallow soils limit growth of more lush and taller plants. The Dry Sclerophyll Forests formation is made of 9 different heterogeneous vegetation classes that reflect the diversity of overstorey and understorey species and life forms, mainly reflecting the drier and more infertile soil types.

Vegetation class 7a, South Coast/Hinterland Dry Shrub Forests, is primarily found on shallow yellow/orange infertile podzolics on dry bare ridges at elevations between sea level and 700 metres. The average rainfall varies between 850 and 1100 mm. Common tree species in this vegetation class are *Syncarpia glomulifera*, *Corymbia gummifera*, *Eucalyptus agglomerata* and *Eucalyptus sieberi*, overtopping a sparse cover of shrubs *Acacia obtusifolia*, *Oxylobium ilicifolium*, *Leucopogon lanceolatus*, and in the ground layer *Platysace lanceolatus*, *Entolasia stricta*, *Joycea pallida*, and *Dianella caerulea*. On the more undulating slopes and ridges, closer to the South Coast, vegetation class 7b can be found on yellow podzolics derived from metamorphic sediments and Permian siltstones. Common tree species in this vegetation class are *Corymbia maculata*, *Eucalyptus longifolia*, *Eucalyptus muelleriana*, and *Eucalyptus paniculata* subsp. *paniculata*. Typical understorey species include *Allocasuarina littoralis*, *Oxylobium ilicifolium*, *Platysace lanceolatus*, *Hardenbergia violacea*, and grasses *Entolasia stricta*, *Poa meionectes*, and *Imperata cylindrica* var. *major*. Towards Jervis Bay and the lower reaches of the Shoalhaven River, an interesting and diverse vegetation class 7c, South Coast Mixed Species Dry Shrub Forests, can be found on yellow earths and podzolics on clay rich sedimentary rocks. The overstorey commonly has *Eucalyptus punctata*, *Eucalyptus eugenioides*, *Eucalyptus pilularis*, and *Corymbia maculata*, while the understorey has the tall shrub *Allocasuarina littoralis* as a common feature, and common small herbs and grasses, including *Brunoniella pumilio*, *Entolasia stricta*, *Lagenifera gracilis*, and *Gahnia radula*.

Vegetation class 7d, Coastal Bangalay /Blackbutt Dry Shrub Forests, is found on pockets on coastal dune deposits

around Jervis Bay and Moruya on sandy podzolic soils. The forest overstorey comprises *Eucalyptus botryoides*, *Eucalyptus pilularis*, and occasionally *Corymbia gummifera* in the Jervis Bay area. The understorey has tall heath shrubs *Banksia serrata*, *Banksia integrifolia*, *Monotoca elliptica*, and *Acacia longifolia* subsp. *sophorae* closer to the beach. The ground layer is usually a bracken/grass understorey, comprising *Pteridium esculentum*, *Lomandra longifolia*, and *Imperata cylindrica* var. *major*, as well as *Lepidosperma laterale* and *Gonocarpus teucrioides*.

Along the boundary between the coastal and the South-Eastern Highlands bioregions, vegetation class 7e, South Coast Escarpment Peppermint-Silvertop Ash Forests, occurs on high ridges and plateaus, on red podzolic soils on Ordovician fine sediments, usually in areas of moderately high average rainfall between 900 and 1100m. The dominant trees are *Eucalyptus dalrympleana* subsp. *dalrympleana*, *Eucalyptus radiata* subsp. *radiata*, and *Eucalyptus sieberi*, usually with a bracken understorey comprising *Pteridium esculentum*, and other heath and grass-like species such as *Oxylobium ellipticum*, *Leucopogon lanceolatus* subsp. *lanceolatus*, *Dianella tasmanica*, and *Lomandra obliqua*. Within the Kanangra and Cocks River Gorge country, vegetation class 7f occupies steep ridges and slopes on Devonian sediments below vegetation class 7e, in areas of average annual rainfall between 800 and 950 mm. Common tree species are *Eucalyptus punctata*, *Eucalyptus blaxlandii*, *Eucalyptus agglomerata*, *Eucalyptus tereticornis*, and *Eucalyptus melliodora*. This dry forest type has scattered shrubs, such as *Olearia viscidula*, *Persoonia linearis*, *Styphandra glauca*, and herbs *Pratia purpurascens* and *Gonocarpus tetragynus*. Further to the south, vegetation class 7g represents a complex mixture of forests dominated by *Eucalyptus sieberi*, *Eucalyptus agglomerata*, and *Eucalyptus dives*. This type occurs on yellow podzolic soils on undulating topography on low fertility sediments in areas with average annual rainfall between 700 and 900 mm. The understorey is usually an open heath understorey with common species such as *Allocasuarina littoralis*, *Lomatia silaifolia*, *Dianella revoluta* subsp. *revoluta*, and *Entolasia stricta*.

Outliers of the dry shrubby forest formation occur further to the west on the western escarpment of Kosciuszko. These include vegetation class 7h, Western Southern Tablelands Dry Shrub Forests, which is found on the steep rocky slopes above the Tumut River. Vegetation class 7i, South-West Slopes Red Ironbark Dry Shrub/Grass Forests, is found further to the west on raised foothills of the South-Western Slopes bioregion. These two vegetation classes occur in small pockets on shallow red podzolic soils in very specific environmental niches. Descriptions of these types can be found on the enclosed CD-ROM. These two vegetation classes represent dry sclerophyll forests that could be classified as heath forests, as the understorey can be quite dense in places.

### 8. Heath Forests, Mallee Low Forests, and Heathlands

Several structural formations are included on the one vegetation class as they share a dense heath understorey either in the open or underneath a tree canopy. Heathy forests, heathlands and mallee low forests are located on infertile sediments derived from Permian sandstones or granites, mainly in the South-East Corner and Sydney Basin bioregions (Map 8 on the CD-ROM).

Vegetation class 8a, Sandstone Plateau Heath Forests, contains five closely related vegetation groups that are found on relatively poor yellow or red podzols on Permian sandstones on the Morton plateau or on Ordovician sediments in the Clyde River catchment in areas of annual average rainfall between 1000 and 1200 metres. Overstorey dominants include *Eucalyptus sclerophylla* and *Corymbia gummifera*, with *Eucalyptus sieberi* becoming dominant along the escarpment and western Morton plateau. Common shrubs include *Banksia ericifolia*, *Banksia paludosa*, *Hakea teretifolia*, *Leptospermum trinervium*, *Petrophile sessilis*, *Aotus ericoides*, and *Allocasuarina distyla*, along with smaller forbs and grasses, such as *Epacris microphylla* subsp. *microphylla*, *Actinotis minor*, *Entolasia stricta*, *Leptocarpus tenax* and *Lomandra glauca*.

The next vegetation class 8b, South Coast/Hinterland Heath/Shrublands, occurs either primarily along the coast on infertile wet shallow clay podzolic soils within reasonably close proximity to the coast or higher up on the Cambewarra and Kiama escarpments on organosols with average annual rainfalls between 1400 and 1500 mm. This class of wet heaths has *Banksia ericifolia*, *Hakea teretifolia*, *Leptospermum squarrosum*, *Leptospermum juniperinum*, *Epacris obusifolia*, *Epacris microphylla* subsp. *microphylla*, *Darwinia leptantha*, and *Dillwynia floribunda* as common heath plant species, with a diverse array of sedges and ferns present in the ground cover layer. The ground cover layer includes sedges adapted to wet impeded soils, such as *Restio fastigiatus*, *Lepidosperma filiformis*, *Leptocarpus tenax*, *Xanthosia resinosa*, *Gleichenia dicarpa*, *Lepidosperma forsythii*, and *Gymnoschoenus sphaerocephalus*.

An extensive area of this vegetation class is found on shallow yellow podzolic soils, in areas of average yearly rainfall between 950 and 1200mm on Permian mudstone through Morton and Budderoo National Parks. It bears close floristics resemblance to 8a, Sandstone Plateau Heath Forests. Overstorey species may include *Eucalyptus sclerophylla*, *Eucalyptus tenella*, *Eucalyptus sturgessiana*, *Eucalyptus langleyii*, and *Corymbia gummifera*. The heathy understorey may include *Allocasuarina distyla*, *Leptospermum lanigerum*, *Kunzea capitata*, *Hakea teretifolia*, and *Banksia ericifolia*. The ground cover may be a mixture of forbs, sedges and grasses, such as *Lepidosperma urophorum*, *Entolasia stricta*, *Lepyrodia scariosa*, and *Schoenus ericatorum*.

Vegetation class 8c, High Plateau Mallee Low Open Forests, is found on shallow infertile poorly drained organosols on the Kanangra Boyd Plateau and Murrumbidgee stock route in well defined mallee patches on Permian sandstones, with an average annual rainfall between 800 and 1000 metres. There is usually a moderately dense layer of *Allocasuarina nana*, alongside mallee clumps of *Eucalyptus stricta*, with a dense cover of *Hakea dactyloides*, *Banksia ericifolia*, *Banksia marginata*, *Leptospermum trinervium*, *Isopogon anemonifolius*, and *Playsace linearifolius*. The ground cover comprises *Carex appressa*, *Ptilothrix deusta*, *Patersonia fragilis*, and *Lindsaea linearis*.

A closely related vegetation class 8d, Eastern Montane Heath/Tall Shrubland, occurs along the western spine of the South Coast escarpment from Nerriga down to Wadbilliga National Park. The soils are usually lithosols, derived from hard quartzite or shale rocks, in areas with average annual rainfall between 700 and 950 mm. The heaths are usually found on open windswept ridges, in moderately cool climatic conditions. This vegetation class contains two vegetation groups, 134 and 135, which have a number of plant species in common. In the heath shrub layer *Allocasuarina nana* is dominant, with *Brachyloma daphnoides*, *Banksia canescens*, *Hakea dactyloides*, *Hibbertia pedunculata*, and *Kunzea sp C*, while the ground cover layer may have *Lomandra glauca*, *Stylidium graminifolium*, *Gonocarpus tetragynus*, *Austrostipa pubinodes*, *Lepidosperma gunnii*, and *Amperea xiphioclada* var. *xiphioclada*.

### 9. Swamp Forests and Sedgeland

This vegetation class comprises the swamp and swamp forests found on soils with impeded drainage, usually associated with valley bottoms and creek lines. These vegetation formations are confined to narrow wet areas usually in moderate to high rainfall areas at high elevations, on organosols which collect water from adjoining areas (Map 9 on the CD-ROM).

Vegetation class 9a, South Coast/Hinterland Swamp Forests, is found on infertile organosols overlying colluvial sandy substrates. The dominant trees are usually *Syncarpia gummifera*, *Eucalyptus robusta*, *Eucalyptus tereticornis*, *Eucalyptus longifolia* or *Corymbia gummifera*, with a tall shrub layer of *Melaleuca linearifolia* or *Melaleuca biconvexa*, *Melaleuca squarrosa* or *Leptospermum polygalifolium* subsp. *polygalifolium*. The ground layer may have either *Gahnia* spp. or *Gleichenia dicarpa* as dominant ground cover, as well as a range of sedges and forbs, depending on site conditions. This vegetation class contains a heterogeneous group of vegetation that has adapted to particular site conditions in the Jervis Bay area, usually related to different type of colluvium that has filled the creeklines or valley floors.

Fringing the eastern Southern and Central Tablelands escarpments is another heterogeneous swamp heath/low

forest group, vegetation class 9b, which occurs on sandy organosols in shallow river flats in the middle and upper Shoalhaven catchment. This is called Eastern Tablelands Swamp Heath/Low Forests. The overstorey tree dominants are usually sparse and may comprise *Eucalyptus pauciflora*, *Eucalyptus viminalis*, *Eucalyptus rubida* subsp. *rubida* or *Eucalyptus aggregata*, with *Leptospermum myrtifolium*, *Leptospermum juniperinum*, *Epacris microphyllus* subsp. *microphyllus*, as possible heath shrubs. The ground layer usually has a range of grasses and herbs, such as *Poa sieberiana* subsp. *sieberiana*, *Microlaena stipoides* var. *stipoides*, and *Gonocarpus micranthus* subsp. *micranthus*, and sedges *Schoenus apogon*, *Lepyrodia anarthria*, and *Selaginella uliginosa* subsp. *uliginosa*.

A widespread vegetation class in the South-East Highlands bioregion is vegetation class 9c, Southern Tableland Montane Wet Heaths / Swamps. This vegetation class is found in the Upper Shoalhaven and Queanbeyan River catchments on either side of the Tallaganda ranges and further to the west in the higher montane climates of northern Kosciuszko and the ACT. The vegetation groups 123, 124, 125, and 126, are confined to creek or river flats, with deep organosols in moderate to high rainfall areas between 750 and 1200 mm, occupying a diverse range of montane and lower sub-alpine environments. Typical heath shrubs include *Baeckea utilis*, *Epacris paludosa*, *Epacris brevifolius*, *Leptospermum myrtifolium* and *Hakea micrantha*. The ground cover layer may have either a dense cover of *Poa labillardieri* or *Carex gaudichaudiana*, with smaller sedges such as *Restio australis* and *Empodismus minus*. The inter-tussock space may be filled with forbs, such as *Euchiton gymnocephalus*, *Hydrocotyle peduncularis*, *Hypericum japonicum*, or *Oreomyrris eriopoda*. A closely related unit, vegetation class 9d, Southern Tablelands Swamp Grasslands, is found on soils in similar climatic zones of the South-East Highlands bioregion in the ACT and further to the north in the Oberon area. It tends to have a more dominant grassy/sedge layer of *Poa labillardieri* and *Carex appressa*, with herbs such as *Acaena novazelandiae*, as well as small sedges and rushes *Carex inversa* and *Juncus filicaulis*.

The final vegetation class in this heterogeneous formation is vegetation class 9e, Southern Tablelands Swamps / Open Woodlands, which is found mainly in central and northern Kosciuszko ranges and along narrow streams through the Tumut, Tumberumba and Woomargama districts. The soils are freer draining and are typically found in frost hollows in areas with average annual rainfall between 800 and 1200mm. The overstorey typically has *Eucalyptus pauciflora*, *Eucalyptus stellulata* and *Eucalyptus rubida*, in some of the low lying flats in the higher parts of the Kosciuszko, ACT, and Tallaganda ranges. The grass and sedge ground cover usually contains *Carex appressa* and a range of small grasses and forbs, including *Hydrocotyle laxiflora*, *Hydrocotyle peduncularis*, *Dichondra repens* and *Mentha diemenica*. In some cases this vegetation class is likely to have a more diverse heath and grassy ground layer,

which includes heath species *Leptospermum myrtifolium*, *Hakea micrantha*, *Bossiaea foliosa*, *Acrotriche serrulata*, *Mirbelia oxylloboides*, *Grevillea lanigera*, as well as *Themeda australis* and *Poa* spp., and small forbs *Acaena novazelandiae*, *Viola betonicifolia*, *Dichondra repens*, and *Asperula scoparia*.

#### 10. Vegetation on Rock Outcrops/Screes

This vegetation formation covers shrublands, woodlands, and forests on rocky outcrops and scree slopes across a wide range of climates and soil substrates in the South-East Corner, Sydney Basin, and South-West Slopes bioregions (Map 10 on the CD-ROM).

Vegetation class 10a, Sub-Alpine/Montane Rocky Heath Complex, is confined to the rocky tors and western escarpment of the Alps and has a patchy occurrence through the Scabby and Bimberi ranges of the ACT. Its dominants usually include *Kunzeamuelleri*, *Leptospermum micromyrtus*, *Leptospermum namadgiensis*, *Kunzea ericoides*, *Phebalium squamulosum* subsp. *ozothamnoides*, and *Oxylobium alpestris*.

The second vegetation class 10b, South Coast/Southern Tableland Hinterland Rocky Shrublands/Forests, covers a discrete set of vegetation groups in the classification that correspond to shrublands and rocky forests on Silurian granites in the upper Snowy River to steep rocky screes on Ordovician sediments on the mid slopes of the South Coast escarpment. In the Snowy River valley average annual rainfall varies between 600 and 700 mm per annum while along the South Coast it can be between 900 and 1000 mm per annum. There is a range of tree species adapted to these rocky exposed conditions, including *Eucalyptus smithii*, *Eucalyptus olsenii*, *Eucalyptus bauerlenii*, *Eucalyptus blaxlandi*, and *Eucalyptus fraxinoides*. Either under canopy under moderately sheltered sites or on more exposed slopes *Acacia sylvestris*, *Eriostemon trachyphyllus*, *Phebalium coxii*, may be present. An unusual group within vegetation class 10b, can be found on rhyolite outcrops in Deau and southern Budawang National Park. *Eucalyptus stenostoma* dominates the tree canopy while the shrub layer usually comprises *Allocasuarina littoralis*, *Leptospermum trinervium*, *Phebalium coxii*, *Boronia ledifolia*, *Leucopogon setiger* with a ground cover of *Patersonia* spp. The ground cover can be quite sparse on these rocky screes.

Further to the south in the Snowy River Valley, *Acacia sylvestris* shrubland form may overlap with vegetation class 10c, Lower Snowy Acacia Shrubland / Cypress Pine Forest, which has overstorey dominants of *Acacia doratoxylon*, *Callitris endlicheri*, with a similar shrub layer of *Eriostemon trachyphyllus*.

On the extreme south-western edge of the study area in the South-West Slopes bioregion, vegetation class 10d, South-West Slopes Acacia Shrublands, can be found on tops of sandstone ridges, in areas of average annual rainfall between 600 and 700 mm per annum. The shrubland usually has a

moderately dense tall shrub layer of *Acacia doratoxylon*, along with *Callitris endlicheri*, *Allocasuarina verticillata*, *Eucalyptus blakelyi* x *Eucalyptus dwyeri*, with a simplified ground cover of *Stypandra glauca*, *Gonocarpus elatius*, *Crassula sieberiana* subsp. *sieberiana*, and *Triptilodiscus pygmaeus*.

Vegetation class 10e, South-West Slopes Black Cypress Pine Forests. It is found on granitic outcrops along sections of the Murray valley between Corryong and Holbrook, and up into the lower Abercrombie river valley, north of Boorowa. Annual average rainfall varies between 600 and 700 mm per annum, which is quickly shed on the bare surfaces of these rocky outcrops. Soils are usually skeletal. Common overstorey dominants are *Eucalyptus goniocalyx*, *Eucalyptus macrorryncha*, and *Callitris endlicheri*. The understorey is usually made up of *Xanthorrhoea glauca* var. *angustissima*, *Acacia verniciflua*, *Brachyloma daphnoides*, *Dodonaea viscosa* subsp. *angustissima*, *Stypandra glauca*, *Gonocarpus elatius*, and *Lomandra filiformis* spp. *coriacea*.

The last class in this vegetation formation is 10f, Ribbon Gum Forests on Limestone, which is found on limestone outcrops in the river catchments of the Jenolan, Kowmung, lower Goodradigbee, Deau, and Yarragobilly Rivers. Unfortunately it has not been sampled. Typically it has an overstorey of *Eucalyptus viminalis*, with a shrub layer of *Bursaria spinosa* ssp. *spinosa* and *Senecio* spp., and a matt of herbs and forbs, comprising *Dichondra repens*, *Hydrocotyle laxiflora*, *Pellaea falcata* var. *falcata*, in amongst moist grasses, such as *Microlaena stipoides* var. *stipoides*.

### 11. Riparian Forests

The riparian forests mapped possibly represent a fraction of the actual and previous extent of the riparian forests in the study area. There are two principal vegetation classes shown in Map 11 on the CD-ROM, which are associated with wide rivers or streams in the study area. The first vegetation class 11a, River Oak Riparian Grass/Herb Forest, is associated with fast moving perennial streams (Keith 2004), and usually occurs on third or fourth order streams throughout the study area. The dominant tree is *Casuarina cunninghamiana*. The understorey and ground cover is typical of other moist riparian or valley bottom moist forests/woodlands (vegetation groups 48, 92, or 162) in the study area.

The other vegetation class 11b, South-West Slopes Grass/Sedge Forests, is associated with streams in the South-West Slopes bioregion and comprises two vegetation groups 43 and 162. The soils in these two vegetation groups are usually derived from colluvium or alluvium and are relatively deep and moist for most of the year. Typical overstorey dominants include *Eucalyptus camaldulensis* on major rivers and streams and *Eucalyptus blakelyi* further upstream on the minor streams and flatter valley floors with perennially moist soils. The understorey usually features *Carex appressa*, *Carex*

*inversa*, *Eleocharis* spp, *Pratia peduncularis*, and a range of forbs, grasses, and rushes adapted to temporary inundation on floodplains and on shallow riparian creeklines.

### 12. Sub-alpine Low Forests/ Woodlands

Sub-alpine low forests/woodlands are confined to the higher elevations of the New South Wales Alps between 1500 and 1650 metres (Map 12 on the CD-ROM). The formation of sub-alpine low forests comprises two vegetation classes. A northern rocky heathy type found on the Scabby and Gudgenby Ranges on granitic substrates is confined to a narrow environmental niche in the Southern ACT ranges. This is categorised as vegetation class 12a, Southern ACT Sub-alpine Snow Gum Heath Forest. The southern vegetation class 12b, Kosciuszko Sub-alpine Low Forest, is more widespread from south of Thredbo up into the ranges surrounding Nungar Plain. Vegetation class 12b is associated with organosols derived from a diverse range of parent materials, such as sandstones, cherts, granites, granodiorites, and acid volcanics. In the range of both vegetation classes average annual rainfall varies between 1300 and 2000 mm per annum.

These low forests are usually dominated by *Eucalyptus debeuzevillei* in vegetation class 12a and *Eucalyptus niphophila* and *Eucalyptus pauciflora*, in vegetation class 12b. The understorey in vegetation class 12a tends to have a denser cover of heath shrubs, including *Kunzea muelleri*, *Leptospermum micranthus*, *Leptospermum namadgiensis*, *Oxylobium alpestre*, *Kunzea ericoides*, and *Westringia lucida*. Vegetation class 12b on the other hand has a greater mixture of alpine heaths and grasses. The shrub layer is somewhat different to that in vegetation class 12a and usually comprises *Bossiaea foliosa*, *Olearia phlogopappa*, *Ozothamnus secundiflorus*, *Leucopogon montanus*, *Leucopogon hookeri*, *Hovea montana* and *Tasmania xerophila*. The dominant grass and herb plants species in the ground layer may comprise *Poa hiemata*, *Poa ensiformis*, *Oreomyrrhis eriopoda* and *Stellaria pungens*.

### 13. Alpine and Sub-alpine Complexes

Alpine and sub-alpine complexes largely fall within the bounds of the Alpine Area bioregion (Map 13 on the CD-ROM). High rainfall, low fertility soils, and cold to cool temperatures, with a high frequency of frosts in winter lead to a relatively short summer growth period. There are currently an inadequate number of vegetation samples to describe adequately this highly heterogeneous sub-alpine and alpine vegetation. The work of McDougall and Walsh (in prep.) may help to unravel the complexity of the vegetation in this vegetation formation.

Four separate vegetation classes have been identified and mapped as complexes. Vegetation class 13a, Alpine Feldmarks, is confined to the bare snow patches and bare

rocky ground at elevations above 1700 mm. Below the Alpine Feldmarks two vegetation classes 13b, Alpine/Sub-alpine Herbfields, and 13c, Alpine Bogs/Fens, dominate the more open and less well drained slopes of the Alps. In the wetter less well drained areas, vegetation class 13c, Alpine Bogs/Fens predominate. Vegetation class 13d, Sub-alpine Grasslands, is more common in the northern and eastern parts of the Alps at slightly lower elevations on grassy plains, where it can be subjected to intense frosts in winter.

#### 14. Coastal Complexes

The coastal complex vegetation is confined to the immediate surrounds of estuaries, sand-dunes, and low lying areas adjoining estuarine lakes along the South Coast. Because of the patch size and linear shape of the vegetation groups present, it is difficult to present the information at an adequate scale to differentiate the separate vegetation classes (Map 14 on the CD-ROM).

Map unit 14a, Coastal Dune Complex comprises five separate vegetation groups, which occupy distinct zones in the fore, mid, and hind-dunes. The zonation in the dunes reflects the transition from an undeveloped sandy soil in a foredune through to a well developed sandy podzol in the hind-dune. The type of plant species present in each of the distinct dunal zones reflect the soil differentiation and salt loading coming in off the sea. Details of the floristics composition of each of these vegetation groups can be found in the detailed description of each vegetation group on the accompanying CD-ROM.

In the low lying areas above the tidal zone, vegetation class 14b, Coastal Swamp Heath/Forest Complex, is found on acid sulphate soils in semi-inundated areas. Usually these areas adjoin wetlands, dominated by species such as *Phragmites communis*, and areas of open water in brackish areas of freshwater estuaries. Around the edges of saline estuaries, a complex mosaic of salt marshes and mangroves interweave in intricate patterns on mudflats, reflecting the varying impact of waterlogging and salt concentration in the soils (Keith 2004). This complex of inter-tidal estuarine vegetation is mapped as vegetation class 14c.

#### 15. Freshwater Wetlands

There are three vegetation classes of freshwater wetlands in the study area. Vegetation class 15a comprises the coastal freshwater lagoons and sand dune wetlands. Vegetation Class 15b comprises the montane lakes, such as found in the lakebeds of Lake George and Lake Bathurst. Vegetation class 15c is found in and adjoining billabongs in amongst vegetation group 43 on along the Murrumbidgee and Murray Rivers. Since none of these vegetation classes were sampled, there are no detailed vegetation descriptions. However the vegetation classes described here correspond to those in Keith (2004) where details of the characteristic species can be found.

#### Disturbance Regimes

Typical disturbance agents include fire, clearing, grazing, logging, drought, and predation by insects or diseases. These disturbance agents vary in their frequency, season, timing in relation to drought or rain, spatial extent, intensity, and likely combinations within each vegetation formation. These are referred to here as disturbance regimes and are summarised in Table 11 which is intended to be a guide to the general trends in disturbance regimes since European settlement.

The introduction of feral and domestic animals and exotic plants, combined with changed fire regimes or timber getting, have significantly altered the historical pattern of natural disturbance regimes of the grassy forested and non-forested ecosystems, with consequent changes in species diversity and structure of these grassy forests. Some of the Dry Shrub Forest and Moist Forests formations have probably had much less change to their historical pattern of disturbance processes. In the late 1800s, clearing associated with free selection on Crown Land, and timber getting in the early part of the 20<sup>th</sup> century converted extensive areas of old growth forest to pasture, potato farms, or regrowth forest. Early accounts referred to eucalypts of gigantic proportions in the Yarrowa Brush area near Robertson (Jervis 1962).

Dendrochronological studies (Banks 1982, Pulsford 1989) have suggested an increase in fire frequency in the sub-alpine forests and lower Snowy forests, associated with European use from 1870 to 1950. Frequent spring or autumn burning, associated with maintenance of 'green pick' for introduced stock, became an annual practice. This was in marked contrast to infrequent fires prior to European settlement. Research by Costin (1966) produced evidence of the negative impacts of frequent grazing and burning on water yield and sediment production. When grazing was excluded from the sub-alpine and alpine zones, there was a sudden reversal in the fire frequency on the alpine and sub-alpine vegetation in the Snowy Mountains. However from 1960–1980 the drier Montane Tableland Forests and the Dry Grass/Shrub Forests on the western footslopes of the ranges became the focus of more frequent intensive burning as a fire mitigation strategy. Since then, the NPWS have adopted a more conservative fire management in these forests, limiting burning to strategic property protection. The wildfires in a severe drought year in the 2002/2003 fire season were widespread, given the large numbers of dry lightning storm ignitions, and a dry continuous fuel cover over a wide area. Much of the forest regrowth in the sub-alpine forests is regrowing from lignotuberous resprouts and seedlings in heavily burnt areas.

Rabbit plagues between 1880 and 1950s were a regular feature until the introduction of *Myxomatosis* rabbit virus in the 1950s. These rabbit plagues also had a major impact on vegetation cover and fuel build-up, especially during droughts, and led to widespread sheet and gully erosion (Costin 1954).

Gilmour and Plumwood (1982) collated anecdotal evidence from neighbours of Budawang National Park that confirmed the frequent, chaotic, and uncontrolled pattern of burning prior to the introduction of fire permits under the 1949 Rural Fires Act of NSW. Occasional extensive hot fires were known during drought seasons such as 1913/14, 1929/30 and 1939/40. Characteristic uncontrolled spring burning on the western side of Morton, Budawang, and Deua National Parks has become much less frequent since the 1950s, with only occasional summer wildfires of smaller size than in earlier decades of the twentieth century. National parks' management from the mid 1970s has become more conservative, with burning associated with protection of life and property along national park boundaries. Occasional larger prescribed burning has occurred within parts of Deau and Wadbilliga National Parks but the gross area burnt within a ten to fifteen year period is suggesting a longer fire frequency between 25 to 40 years. Extensive and intense wildfires during El Nino drought periods could explain the lack of smaller, more numerous intervening fire events during non-drought years.

Since the introduction of exotic perennial grasses in the 1960s and 1970s, invasive perennial grasses such as Phalaris (*Phalaris aquatica*) have invaded grassy forests and woodlands adjoining improved pastures in agricultural landscapes of the South-West Slopes and South-Eastern Highlands bioregions. These grassy woodlands have lost many of their original native understorey species, and very few grassy forests in the valleys or lower slopes can be found in their original native condition on private land, on travelling stock routes, or on larger Crown Land blocks. In western lower elevations, invasive weeds, such as St Johns Wort (*Hypericum perforatum*) have spread into larger patches of grassy forests on State Forests, National Parks, and Crown Lands. Attempts to control these invasive species have been sporadic and poorly-coordinated. Fire and drought can exacerbate invasion of aggressive weeds and limited natural control agents, grazing of exotic stock, and benign neglect on public and private land, may threaten and possibly eliminate some of the more threatened natural ecosystems, particularly in the grasslands, grassy forests and woodlands.

#### *Conservation significance and threatening processes*

It is estimated that nearly 4.5 million hectares (4 447 900 hectares) of forests or woodlands covered 72% of the Southern Forests study area at the time of European settlement. The remaining 28% of vegetation was made of non-forest vegetation formations, such as tall shrublands, heaths, swamps, or grasslands (Table 12). In the last 200 years, the pre-1750 area of forests has been reduced to about three million hectares (3 120 400 hectares), about 44% of the study area, while the area of non-forest vegetation has been reduced to 428 000 hectares, about 7% of the estimated pre-1750 area. Despite these reductions however, there are still considerable areas of native vegetation, covering about 50% of the Southern Forests study area.

However the clearing and modification of native vegetation has not been uniform across the area. The vegetation formations most affected by change have been the Grassy Woodlands and Temperate Grasslands, and the Riparian and Grass/Shrub Forests. These formations are found on the more fertile and less rugged land, that provided the most suitable sites for agricultural settlement in the 19<sup>th</sup> and early 20<sup>th</sup> century. In the Shoalhaven and Kiama precincts, rainforests were cut for their timber in the 19<sup>th</sup> century, and then cleared. Considerable areas of the montane tablelands and the less productive dry grass/shrub forests were cleared for pine plantations in the Oberon and Tumut-Tumbarumba areas in the 1960s as part of Australia's commitment to self-sufficiency in wood products. The shift in population to the coast in the last 20 years has led to further clearing of significant coastal complex vegetation and the swamp forests/wet heaths, and sedgeland.

The forests in the more rugged parts have been less changed since European settlement. The least affected formations have been the high elevations Alpine/Sub-alpine Complex and the Sub-alpine Low Forests. The extent of clearing has been as low as 1–3%. Nevertheless extensive summer grazing and occasional intense fires have affected the ground-cover and soils. Severe fires at intervals between 40 and 60 years have modified the structure of the Sub-alpine Low Forests and Ash Eucalypt Forests towards a regrowth rather than an old growth form.

The Heath forests/Heathlands, as well as Vegetation on Rock Outcrops/Screes, have not been significantly cleared because of their unsuitability for agriculture or forestry, but are currently under pressures from more frequent fire regimes, particularly along the South Coast escarpment, which seems to be experiencing more frequent drought periods at the height of summer.

The production of the first vegetation map in 2000 focussed on the mapping of forest ecosystems, and did not include the mapping of extant native grasslands. The mapping of pre-1750 grasslands was undertaken to limit errors in pre-1750 forest ecosystem estimates. The 2005 version of the vegetation map now contains extant grasslands areas. Pre-1750 grassland area is estimated at 450 000 hectares, with about 12 500 hectares or about 3% remaining. The estimate of 12 500 hectares is a preliminary one, and with further field investigations, might rise to 20 000 hectares, including partially degraded natural temperate grasslands. This still represents a small fraction of pre-1750 area.

As part of the assessment of the criteria of comprehensiveness and representativeness in 1999 (JANIS 1996), experts assessed and ranked the vegetation groups. Based on the estimates of pre-1750 and extant areas, and the extent of clearing since 1750, these experts reached consensus on the rarity and vulnerability rankings of each vegetation group. The latter estimates have been since updated to reflect the 2005 version of the pre-1750 and extant vegetation map, as well as accounting for the current reserve system.

Rarity of each vegetation group was considered separately to that of vulnerability. The criterion of area less than 1000 hectares was used to identify rare vegetation groups (JANIS 1996). Because of possible errors in the estimation of pre-1750 and extant areas, this latter criterion was adjusted where local knowledge assessed some vegetation groups as being either rare or not rare. The rare vegetation groups preliminarily identified by vegetation formation: Rainforest (164, 172, 168, 197); Ash Forest (62); Grass/Shrub Forests (183); Heaths/ Heath Forests (136, 184, 200, 216); Swamp Heaths/Forests (65, 125, 126, 212); Vegetation on Rocky Outcrops (192); Alpine Complex (204, 205); Coastal Complex (195, 196); and Wetlands (188, 189, 199).

Vulnerability ranking was based on an estimated area of percentage cleared since pre-1750 (1 was considered very high vulnerability, 5 was very low). The type and significance of environmental pressures and the vulnerability of a vegetation group to those pressures were then considered. The environmental pressures considered were grazing, clearing, logging, weeds, recreational pressure, fire, urban development and hobby farming. The vegetation formation with the highest number of vulnerability class 1 or 2 scores is the Grassy Woodlands/Temperate Grasslands, with over

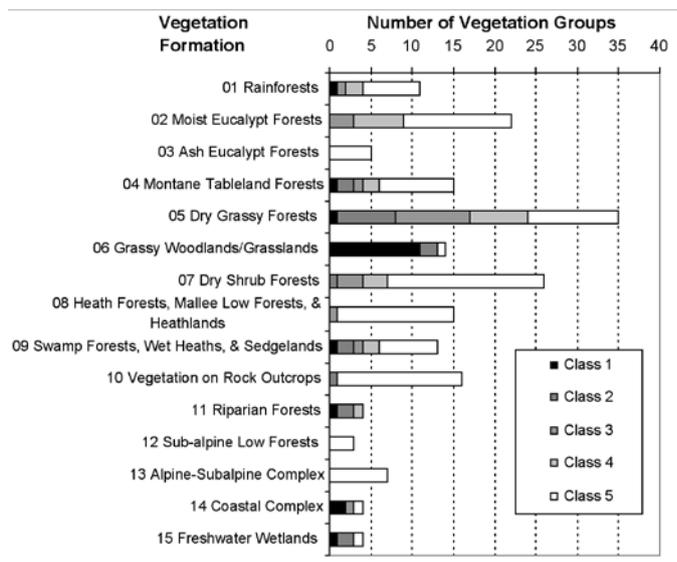


Fig.7. Vegetation formations showing vegetation groups within each vulnerability classes by vegetation formation

Table 11. Inferred historical and current disturbance regimes in the major forest formations of the Southern Forest study area

Vegetation formation	Historical disturbance regimes (pre 1820s)	Settlement period (1820–1950s)	Current regimes (1950s to present)
2. Wet Sclerophyll Forests	Very infrequent intense fires at 50–100 year intervals.	Infrequent fires at 15–30 year intervals during droughts. Selective timber cutting and some clearing. Sporadic insect defoliations.	Infrequent intense fires at 30–50 year intervals. Intensive timber harvesting. Sporadic insect defoliations.
4. Montane Tableland Forests	Infrequent moderate to high intensity fires at 20–50 intervals. Low levels of grazing.	Frequent low to moderate intensity fires at 5–10 year intervals. Timber harvesting, moderate grazing and extensive clearing for pasture.	Infrequent moderate to high intensity fires at infrequent intervals, more than 20 years. Moderate to high grazing pressures and timber harvesting.
5. Dry Grass/Shrub Forests	Infrequent moderate to high intensity fires at 12–30 year intervals. Low levels of grazing.	Frequent low to moderate intensity fires at 5–10 year intervals. Timber harvesting, moderate grazing and extensive clearing for pasture.	Infrequent moderate to high intensity fires at infrequent intervals, more than 20 years. More frequently burnt as part of prescribed burning programmes in the 1950s to early 1970s.
7. Dry Shrub Forests	Infrequent moderate to low intensity fires, at 10–20 year intervals, from late spring to late summer, low levels of grazing. Occasional high intensity fires	Frequent low to moderate intensity fires, at 5–10 year intervals, mainly in early Spring. Occasional intense summer fires at 21–40 year intervals. Selective timber cutting.	More frequent intense summer fires at 10–20 year intervals. Timber harvesting and low levels of grazing.
6. Grassy Woodlands/Grasslands	Light grazing, occasional fires of moderate intensity.	Frequent fires of varying intensity. Heavy grazing, fencing and fragmentation.	Heavy grazing, infrequent fires, weed incursion. Replacement by introduced perennial grasses.
12. Sub-alpine Low Forests / Woodlands	Occasional medium sized fires of moderate to high intensity. Very light grazing.	Frequent fires of varying intensity, with occasional high intensity fires. Heavy grazing.	Occasional intense fires during drought years. Very light grazing by native animals.

11 vegetation groups in vulnerability class 1 (Fig. 7). The next most threatened vegetation formation comprises the Riparian Forests, with four vegetation groups spread between vulnerability classes 1, 2, and 3. Both these formations are found on flatter more fertile country in the study area. The much lower representation of high vulnerability classes in the remaining vegetation formations reflect the less fertile and hillier terrain of the study area, which has been less cleared and modified in the last 200 years.

The current reserve system covers 1.5 million hectares (1 565 200 hectares) and occupies 25% of the pre-1750 area. It caters well for the least vulnerable vegetation formations in the steeper, less fertile terrain, but is still missing some of the more vulnerable vegetation formations and vegetation groups (Table 12). After applying the JANIS criteria, the total target area, comprising all vegetation groups, comes to 771 100 hectares. After deducting the area of vegetation in the current reserves, there still remains about 220 600 hectares to be conserved on private land in some form.

The priority of the recent Southern Regional Forest Agreement was to transfer land from Crown Land and State Forests to formal conservation areas such as National Parks and Nature Reserves. This process largely overlooked the more vulnerable vegetation groups in the Grassy Woodlands/Temperate Grasslands and Grassy Forests formation, which

are principally on private land on the Tablelands and Western Slopes, and reflects the current bias in the reserve system towards the less vulnerable vegetation formations. The remaining conservation target of 220 600 hectares includes 196 300 hectares in the most vulnerable vegetation formations. Given the extent of past clearing and ongoing modification of native vegetation on private lands, it may be difficult to attain the goal of a truly comprehensive, adequate, and representative (CAR) reserve system. Without some form of protection through conservation agreements and incentive schemes, vulnerable vegetation formations will most likely continue to degrade from the combined impacts of habitat fragmentation, weed infestation, and loss of native species.

## Conclusion

The approach used to map vegetation in the Southern Forests relied heavily on air photo interpretation. This is in marked contrast to the decision-tree mapping approach of Keith & Bedward (1999) in the South-East Forests region, which relied heavily on environmental variables to predict the occurrence of vegetation. Keith and Bedward could not find relationships between classified survey data and the API mapping, and so discarded the API mapping as a modelling layer. While there is a scale difference in the size of field survey samples, relative to the size of the API polygons,

**Table 12 Conservation significance of vegetation formations**

Broad Formation	Pre-1750 area (ha)	Extant area (ha)	% of total extant area	% Cleared	Area in reserves (ha)	% of pre-1750 area in reserves	JANIS target not in reserves (ha)
01 Rainforests	40 100	29 700	1%	26%	15 100	38%	1 300
02 Moist Eucalypt Forests	577 600	445 800	14%	23%	240 900	42%	1 400
03 Ash Eucalypt Forests	110 900	110 700	4%	0%	90 700	82%	100
04 Montane Tableland Forests	654 900	474 500	15%	31%	310 900	47%	9 700
05 Dry Grass/Shrub Forests	2 296 600	1 026 800	33%	56%	282 900	12%	143 300
06 Grassy Woodlands/Grasslands	1 314 800	89 600	3%	93%	39 700	3%	45 400
07 Dry Shrub Forests	620 700	481 400	16%	22%	244 100	39%	5 600
08 Heath Forests, Mallee Low Forests, & Heathlands	155 900	150 300	5%	3%	109 100	70%	100
09 Swamp Forests, Wet Heaths, & Sedgeland	51 000	30 100	1%	42%	12 100	24%	4 300
10 Vegetation on Rock Outcrops	49 600	48 300	2%	3%	29 300	59%	1 800
11 Riparian Forests	53 100	11 400	0.4%	79%	3 300	6%	2 200
12 Sub-alpine Low Forests	112 800	112 200	4%	1%	107 100	95%	0
13 Alpine-Subalpine Complex	83 300	80 400	3%	3%	76 600	92%	0
14 Coastal Complex	33 000	10 200	0.3%	68%	3 200	10%	1 600
15 Freshwater Wetlands	20 100	19 000	1%	5%	200	1%	3 800
<b>Totals</b>	<b>6 174 400</b>	<b>3 120 400</b>	<b>50%</b>		<b>1 565 200</b>	<b>25%</b>	<b>220 600</b>

the use of field knowledge and field sampling has helped to overcome some of the potential correlation issues between the two sources of mapping data. Ferrier et al. (2002) argues the case for integrating traditional vegetation mapping and environmental layers to map vegetation communities in the North-East Forests of New South Wales. This could be considered if the API mapping in the study area could be thoroughly checked for consistency in coding and modified to match more closely the environmental gradients and natural vegetation patterns.

This method of vegetation mapping has proved to be versatile, flexible, and adaptable in a consistent and more or less repeatable manner. The methods employed have some considerable advantages over mathematical modelling techniques, such as GAMS (Austin et al. 1996) or a decision tree expert system (Keith & Bedward 1999). Its advantages in mapping vegetation include:

- production using the best available GIS and field knowledge, using intuitive and interactive GIS methods; and
- rapid revision using a wide variety of site and mapping data, as well as local and regional knowledge of vegetation.

Using their combined knowledge, a botanist and an air photo interpreter can produce a draft vegetation map simply and quickly. Using the methods described in this paper, data from further validation work can be quickly incorporated into the map, using adaptive management methods to update it.

Although the method of vegetation mapping does not adhere to the rules of strict objectivity and transparency, it does incorporate a range of field survey data, field knowledge, survey and mapping data from other research and survey reports, and iterative field validation. The method allows for ready update of both the pre-1750 and extant vegetation maps, as more flora survey and improved API mapping data become available. Since the completion of the project in 2000, the original vegetation map has been extensively checked and updated for use in fire management and management plans in new RFA and existing reserves. The continued use and adaptation of the original work demonstrates a continuing use and acceptance of this work in planning and management. With further field validation on private land, this regional vegetation map could be used in State of Environment reports of vegetation condition at levels of state, regional or local government.

## Acknowledgements

I wish to acknowledge the support and direct sponsorship of the original vegetation mapping project of the southern CRA by the Department of Urban Affairs and Planning of NSW and the Commonwealth Department of Environment and Heritage. The Department of Environment and Conservation also contributed funds to the preparation of this paper for inclusion in *Cunninghamia*. I also acknowledge the support given to me by the School of Resources, Environment, and Society, at the Australian National University who enabled me to complete this paper while working concurrently on my Masters Thesis.

I am deeply indebted to the staff of the Southern CRA Unit who untiringly and professionally undertook project management, field planning, logistical and technical support. This paper is a tribute to their work. They include the following: Peter Beukers, Virginia Thomas, Jess Szigethy-Gyula, Helen Achurch, Allison Trewick, Anita Zubovic, Nicole Walkey, Mark Robey, Tanya Harrison, Naomi Robbie, Will Inveen, Malcolm Stephens, David Keith, Genevieve Wright, Peter Hesp, Rob Mezzatesta, Steve House, Brenton Marchant, Bianca Redden, Chris Beer, and Mary Grgic. I also wish to acknowledge the contribution of personnel within State Forests of NSW, including Doug Binns, Bob Bridges, and Andrew Stirling.

The study would not have been possible without external help and contractors. They include: Michael Doherty, Phil Gilmour, Mike Austin, Michael Bedward, Jackie Miles, Heather Stone, Isobel Crawford, Anne Duncan, Roger Lembit, Mark Robertson, Owen Maguire, Simon Hunter, Rob Streeter, Mark Fisher, Naomi Robbie, Will Inveen, and Matt Brookes. I wish to thank especially Phil Gilmour and Michael Doherty, who undertook a significant part of the original vegetation mapping work in the western and eastern part of the study area.

I acknowledge the provision of survey data contributed by David Keith, Doug Binns, John Benson, Frank Ingwerson, Mike Austin, Bob Outhred, Jacky Miles, Sarah Sharpe, Kevin Mills, Nicki Taws, Phil Gilmour, and Carol Helman.

Finally I wish to thank Phil Gilmour, Michael Doherty and Susan Jackson for their editorial advice and proof-reading of the manuscript. Finally the referees of this paper provided invaluable assistance and advice on the style and content.

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