Native vegetation of the South East Forests region, Eden, New South Wales

David A. Keith and Michael Bedward

Abstract

Keith, David A. and Bedward, Michael, (NSW National Parks and Wildlife Service, PO Box 1967, Hurstville NSW Australia 2220) 1999. Native vegetation of the South East Forests region, Eden New South Wales. Cunninghamia *6(1): 001–218*. Terrestrial, freshwater and estuarine native vegetation of the Eden region was classified into 79 floristic assemblages and mapped at 1: 100 000 scale. Assemblages were derived from multivariate analysis of 1604 quantitative vegetation samples. Mapping was carried out using a hybrid decision tree-expert system approach based on quantitative relationships between floristic assemblages and spatial variables (land cover pattern, substrate, climatic variables and terrain variables) and qualitative expert knowledge derived from field experience. The use of vegetation-environment relationships and sampling of remnants allowed prediction of vegetation patterns prior to European clearing. The map was validated using three procedures: qualitative checking by experts; reliability mapping using sampling intensity; and accuracy quantification using independent sample data. The map units were described using comprehensive profiles of diagnostic species, structural features, habitat characteristics and sample distributions.

The 79 floristic assemblages include rainforests, mesic eucalypt forests, dry grassy eucalypt forests of the coastal rainshadow valleys, hinterland and tableland, dry shrubby eucalypt forests, grasslands, heathlands, scrubs and wetlands. Variation in climate and geological substrate influence vegetation patterns at regional scales, while variation in topography, local soil moisture and nutrient status and disturbance regimes influence vegetation patterns at local scales. Sixty-eight per cent of the region retained a cover of native vegetation in 1994. Processes threatening various portions of the remainder include further habitat loss from clearing, high-frequency disturbances and certain other disturbance regimes, overgrazing, habitat degradation due to nutrification, dumping and vandalism, and feral animal activity. Past depletion of habitat has been highly biased. Some grassy assemblages on fertile flat terrain are depleted by more than 90%, while some forests with shrubby understories in steep infertile terrain retain close to their original extent. The former assemblages are distributed principally as remnants on privately owned land, while the latter occur in remote areas of public land. Representation in conservation reserves is also biased against grassy assemblages in fertile flat terrain, as well as some other assemblages with restricted distributions. Opportunities for conservation of these assemblages are now very limited and rely on integrated planning, reservation and cooperative management with emphasis on private land.

For Tommy Keith (1918–1999). Best friend.

Introduction

In far south-eastern New South Wales coastal wilderness and rugged forested mountains are juxtaposed with undulating pastoral country in coastal valleys and subalpine plains. The region falls centrally within Australia's unique temperate eucalypt forest biome (Beadle 1981, Ovington 1983).

Ferdinand von Mueller, director of the National Herbarium of Victoria, was one of the earliest botanical explorers of the South East Forests in 1860. Mueller's ventures to Twofold Bay and the upper Genoa River were preceded by earlier expeditions to the Monaro Tableland by Cunningham and Lhotsky (Benson 1994, Andrews 1998). Knowledge of the regional flora developed opportunistically over a century with numerous collecting trips by botanists based in Sydney and Melbourne and, more recently, Canberra. With the development of nature conservation as a land use, a number of vegetation surveys were carried out to provide resource inventories for reserve management (Breckwoldt 1979, Gilmour 1983, Outhred 1986, Lane et al. 1998) and management of National Estate values within production forest (Fanning & Rice 1989, Fanning & Mills 1989, 1990, 1991, Fanning & Fatchen 1990, Binns & Kavanagh 1990a, b, Fanning & Clark 1991). Hitherto neglected remnant vegetation within fragmented, largely freehold agricultural landscapes of the Bega valley and associated areas was surveyed by Keith (1995) and Miles & Stone (unpubl.), while targeted surveys addressed specialised habitats including rainforest (Floyd 1982), coastal sand dunes (Clarke 1989) and saltmarsh (Clarke unpubl.).

Vegetation maps derived from aerial photograph interpretation and field reconnaissance were produced for some of the areas addressed by local surveys (e.g. Breckwoldt 1979, Gilmour 1983). Mapping of forest types (Baur 1989) was also carried out in selected areas of production forest (State Forests of NSW, unpublished maps). Vegetation surveys and small-scale vegetation maps are available for East Gippsland to the south (Forbes et al. 1982, Parkes et al. 1984, Woodgate et al. 1994), areas further north on the NSW south coast (Austin & Sheaffe 1976, Austin 1978, CSIRO 1996) and the Monaro Tableland to the west (Costin 1954).

Formation of a regional overview of the biota became an important goal with the need for environmental impact assessment of woodchipping operations (Harris-Daishowa 1986, Forestry Commission of NSW 1988) and increasing emphasis on the representativeness of regional reserve systems (Austin & Margules 1986). This began with compilation of a preliminary species list for the region (Binns 1987) and a quantitative synthesis of regional vegetation patterns (Keith & Sanders 1990). In the absence of detailed vegetation mapping across the region, surrogate maps based on modelled forest types (Skidmore 1989, Forestry Commission of NSW 1988), land systems (Keith & Sanders 1990) and environmental domains (Richards et al. 1990) were developed to provide a basis for environmental impact assessment and regional land use decisions.

A formal framework for resolving potential conflicts between competing land uses was adopted through the endorsement of Australia's National Forest Policy Statement (Commonwealth of Australia 1992). The policy provides for Regional Forest

Agreements (RFAs) between Commonwealth and State governments that will address planning and management for both a comprehensive, adequate and representative system of conservation reserves and ecologically sustainable use of forest resources (Anon. 1998). The agreements are to be negotiated using the outcomes of comprehensive regional assessments of environmental, heritage, economic and social values of the forests. A detailed regional map representing the distributions of plant and animal habitats is an essential requisite for the assessment of environmental and heritage values. Guidelines for the assessment suggest that map units, termed 'forest ecosystems' should preferably 'be discriminated at a resolution requiring a map-standard scale of 1:100 000… [and] defined in terms of floristic composition in combination with substrate and position within the landscape' (JANIS 1996).

The purpose of this study was to develop a regional land classification and map that effectively represents species distributions. Consistent with JANIS (1996), we adopted an approach based on floristic composition and its relationship with environmental variables. Although initially intended to provide the central component of an information base on biodiversity for the Eden Comprehensive Regional Assessment, classification and mapping were carried out mindful of previous work and broader needs in environmental planning, assessment and management beyond the Eden Regional Forest Agreement. The work presented here is the fourth revision (version 4.0) of a vegetation survey and map that has previously been available in published and unpublished forms (Keith & Sanders 1990, Keith et al. 1995, Keith & Bedward 1998). Revisions to the map since version 3.0 (Keith & Bedward 1998), which was used in the Eden Comprehensive Regional Assessment, relate primarily to areas of privately owned land and some rainforest and scrub assemblages.

Study Area

The study area coincides with the Eden Native Forest Management Area (State Forests of NSW 1994) in the south-eastern corner of New South Wales between Bermagui and Numeralla in the north and Cape Howe and Craigie in the south (Fig. 1). The area comprises 800 000 ha between latitudes 36°22' and 37°30'S and longitudes 149°00' and 150°05'E and is bounded by the Tasman Sea to the east, the Victorian border to the south, the Monaro Tableland to the west and an arbitrary line following watercourses, roads and landforms in the north. The Bega and Towamba Rivers and their tributaries respectively drain most of the region to the east, while the Genoa and Wallagaraugh Rivers run to the south, the Bombala and McLaughlin Rivers run to the south-west and the Numeralla and Kybean Rivers run north-west into the Murray River basin.

Landscape

Keith and Sanders (1990) described broad geomorphological and vegetation patterns in the region using land systems. A narrow coastal plain dominated by sand and gravel deposits of Tertiary and Holocene age supports heath, scrub and dry forest vegetation punctuated by coastal lagoons, estuaries and swamps. A low and broken coastal range rises to about 300 m elevation, although this height is well exceeded by individual mountains including Mumbulla Mountain (775 m), Burragate Peak (879 m),

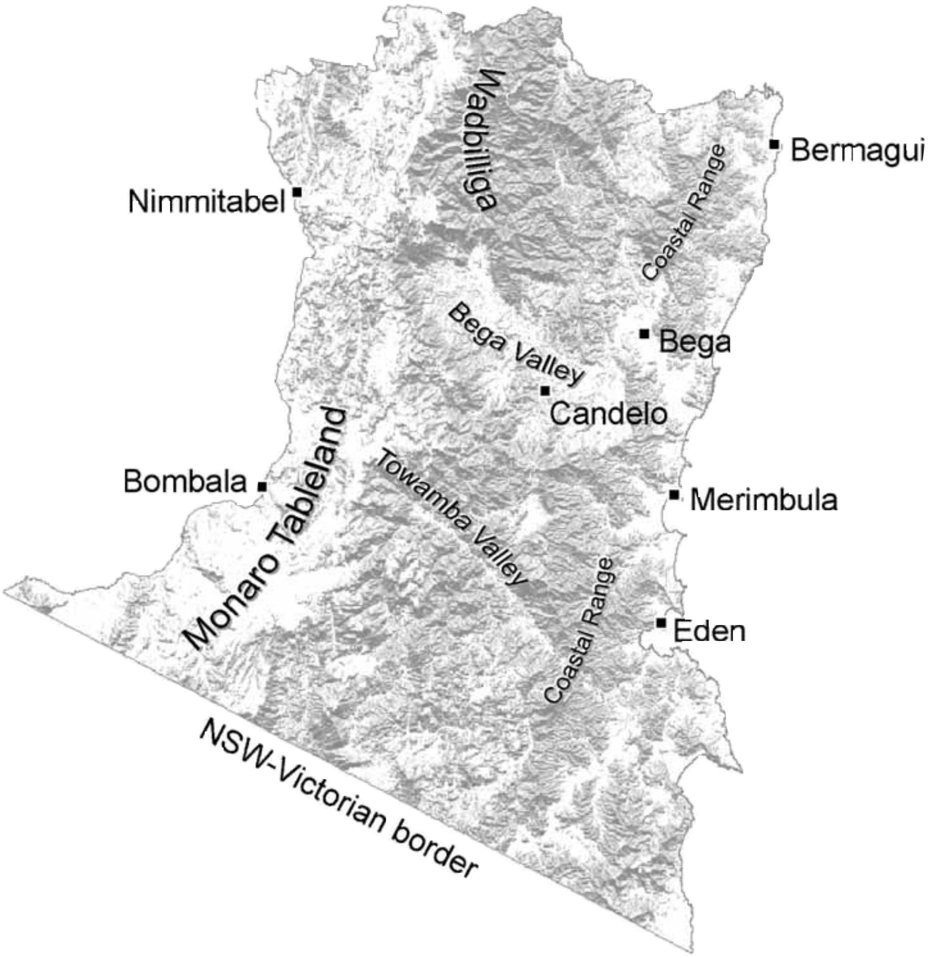

Fig. 1. South East Forests study area based on the Eden Forest Management Area.

Mt Imlay (888 m) and Mt Nadgee (542 m). The coastal range is comprised mainly of Ordovician and Devonian siltstones and sandstones subject to varying degrees of metamorphism. Devonian granitoid intrusions outcrop at Mumbulla Mountain (tonalite) in the north and around Mt Nadgee (adamellite) in the south, while an alkali intrusion of monzonite and related rock types outcrops on Burragate Peak (Beams & Hough 1984). Localised outcrops of Devonian rhyolite and basalt occur around Nethercote, west of Pambula. The coastal range is dominated by dry shrubby eucalypt forests with mesic eucalypt forests and numerous small patches of rainforest in sheltered gullies.

Further west, the coastal range gives way to an undulating hinterland dominated by the Bega Batholith, a complex of Devonian acid volcanics including mainly adamellite and granadiorite with smaller outcrops of granite, quartz diorite, leucogranite, tonalite and gabbro (Beams & Hough 1984). Small outcrops of Ordovician metamorphosed mudstones occur throughout. The rainshadow valleys of the Bega and Towamba Rivers and Narira Creek are a feature of the hinterland. Dry grassy eucalypt forests dominate these valleys, while forests of the remaining hinterland (e.g. in the Wallagaraugh catchment) have a greater but variable shrub component (Keith & Sanders 1990).

The western parts of the rainshadow valleys are bounded by a steep granitoid escarpment that exceeds 900 m elevation at its highest point west of Bemboka. The dry lower slopes support grassy eucalypt forest, while sheltered gullies and elevated slopes receiving orographic moisture support mesic eucalypt forest and small patches of rainforest. The escarpment rises to a mountain range, generally 700–1000 m elevation, on the edge of the tableland. This range joins the Great Dividing Range east of Nimmitabel in the north and exceeds 1200 m elevation still further north at Kydra. The tableland range is dominated by granitoid geology with localised outcrops of Ordovician metamorphosed mudstones (e.g. on Wog Wog Mountain) and Tertiary basalt at Mt Darragh, Bull Mountain and Brown Mountain. Mesic eucalypt forests are the principal vegetation cover, with dry shrubby eucalypt forests occurring on more exposed slopes and ridgetops. The tableland range dissipates in the south where several isolated mountains and plateaux punctuate the terrain. These include Nalbaugh Plateau-Wog Wog Mountain, Letts Mountain, Mt Poole, Mt Waalimma, Mt Tennyson and Nungatta and Yambulla Mountains. The latter peaks form part of a dissected Devonian sandstone plateau dominated by dry shrubby eucalypt forest.

North of the Bega valley, the tableland range adjoins an extensive area of highly dissected terrain derived from Devonian metamorphosed siltstones and sandstones. This landscape is dominated by dry shrubby eucalypt forest with mesic eucalypt forest and small patches of rainforest confined to the most sheltered gorges, and heath atop the most exposed high-elevation ridges.

In the west, the tableland range declines and adjoins an extensive elevated plain, the Monaro Tableland. An extensive belt of Tertiary basalt extends along the western boundary of the study area north from Bombala. Metamorphosed siltstones, mainly of Ordovician age but some of Silurian and Devonian age, cover much of the remaining area, with some areas of Devonian granitoid rocks. Volcanic substrates support grassy eucalypt woodlands with grassland on large low-lying areas of basalt, while metamorphosed sediments support eucalypt woodlands with a mixed grass and shrub understorey. Exposed hills close to the tableland range support localised patches of heath, while bogs form on poorly drained flats.

Climate

Mean annual precipitation varies from 800–900 m on the coastal strip and generally increases orographically inland to the summits of the coastal ranges. Precipitation exceeds 1000 mm on the tableland range and is likely to exceed 1300 mm on mountain summits such as Mt Imlay and Wog Wog Mountain. Rainshadow effects prevail in the Bega and Towamba valleys where mean annual precipitation falls below 700 mm. The Monaro Tableland is also in a rainshadow zone where the driest parts of the region near Numeralla and Bombala receive less than 600 mm annual precipitation. Preciptation is weakly seasonal in the region with late summer months likely to be wetter than late winter months.

On the coast mean daily maximum temperatures reach 25°C in February on the coast at Merimbula, while mean daily minima are 4°C in July (Commonwealth of Australia 1988). Temperature ranges increase further inland, with equivalent means for Bega being 27° and 1°C, respectively, and frost occurs on average 30 days per year. The tablelands are generally cooler all year round, Nimmitabel having a daily maximum temperature of 23°C in February and a mean daily minimum of -2°C and nearly 100 frost days (Commonwealth of Australia 1988).

Land use and management

Numerous archaeological sites within the region suggest aboriginal occupation in the region over some tens of thousands of years (e.g. Byrne 1983). Aboriginal people interacted with their environment through hunting, gathering and burning, although the extent and ways in which they influenced fire regimes are subject to speculation and debate (Benson & Redpath 1997).

European settlement began in the region in the late 1820s as squatters occupied land for grazing in the Bega and Towamba valleys (Codrington 1979, Byrne 1983, Andrews 1998) and on the Monaro Tableland (Benson 1994, Andrews 1998). By the time of Lambie's census in 1839, a population of more than 100 pastoralists and their workers and families had become established both on the coast and on the tableland (Andrews 1998). The environmental impact of pastoralism was initially slow, although native forest was cleared in localised patches within large grazing runs, and localised erosion and introduced species were recorded as early as 1830 (Lunney & Leary 1988). Agricultural land uses intensified after 1860 with conversion to freehold title and growth of the dairy industry in coastal valleys. By the first decade of the twentieth century most of the native vegetation in the Bega valley had been cleared. Clearing of the small remaining patches of native vegetation in the coastal valleys and on the tableland continued at a slow rate to the present day (Lunney & Leary 1988, Keith 1995), with a total of 32 per cent (c. 260 000 ha) of the region being cleared by 1994 (analysis of Landsat TM image).

Pastoral activities vary across the region. Intensive dairying is limited to the more productive lower parts of the Bega valley, beef cattle grazing predominates in other freehold parts of the Bega and Towamba valleys, as well as on small crown and State Forest leases scattered across the hinterland and tableland, while sheep grazing is the dominant pastoral activity on the Monaro Tableland.

In contrast to the coastal valleys and the tableland, the surrounding 'hill country' has retained a greater extent of its native vegetation cover and remains largely in public ownership. There are about 400 000 ha of naturally vegetated public land, accounting for about half of the region. Hardwood (eucalypt) forestry is a major industry in this part of region, although sawn timber production commenced initially in the Bega valley in tandem with land clearance for agriculture (Lunney & Leary 1988). Sleeper cutting accounted for a large part of timber production from 1900 until after World War II when demand for building materials increased and made sawlog extraction more economically viable (Lunney & Leary 1988).

Selective logging continued in the most accessible parts of the region until the development of a pulpwood industry in 1969. The new industry resulted in a significant change in forest management with the introduction of integrated logging (SFNSW 1994). Under this system a high proportion of standing biomass is removed for both sawlogs and pulpwood in alternate coupes (10–200 ha patches) across the production forest landscape on a rotation of 50–80 years. Thinning operations are carried out within the regrowth forest at intervals of two to four decades.

Development of a softwood sawlog industry based on plantations of *Pinus radiata* paralleled the development of the pulpwood industry. Some 35 000 ha of plantations were established over marginal grazing lands and native forest during the 1970s and 1980s, largely in the Bombala and Pericoe areas in the west and south, respectively.

Mineral extraction is a minor land use within the region. Goldfields at Yambulla, Pambula and Wolumla were mined last century and the first two of these are now recognised as cultural heritage sites. A small industry extracting pyrophyllite from rhyolite outcrops west of Pambula has operated in recent decades.

Nature conservation was established as a formal land use within the region with the dedication of Nadgee Nature Reserve in the far south east of the region in 1962. Additions to the reserve system in the late 1960s and 1970s focussed on mountainous wilderness areas. Further additions in 1990 and 1996 and the Eden Regional Forest Agreement (1998) reflected a change in emphasis toward balanced representation of different habitats in the region (Margules & Stein 1989, Bedward et al. 1992a). Conservation within reserves entails management of fire regimes, rare and threatened species, pest species and recreational visitors. Reserves are supplemented by increasing off-reserve conservation through management of production forests, community programs and voluntary agreements with private landholders, and planning regulations administered by state agencies and local government.

Tourism has grown rapidly within the last two decades and is focussed primarily on coastal locations, heritage sites and bushland. The development of tourism is reflected in the expansion of coastal townships, particularly Merimbula and Tathra and the intensified use of the coast for recreation.

Disturbance regimes

Eden's climate supports occasional high intensity forest fires, particularly in wetter parts of the region, while drier parts of the region may experience more frequent fires of lower intensity (Keith & Sanders 1990). Dendrochronological studies of fire scars (Banks 1990) and charcoal deposition patterns in peat profiles (Polach & Singh 1980) suggest possible changes in the fire regime with patterns of human occupation and land use. Some of these changes involve a general increase in fire frequency corresponding with European settlement (Banks 1990) and are consistent with inferences drawn elsewhere in eastern Australia (Benson & Redpath 1997). At two study sites in the upper Tantawangalo catchment, fire frequency increased in several episodes between 1830 and the early part of this century, then decreased after 1970. Overall average return times were 8 and 14 years, respectively, in dry and wet eucalypt forest sites (Banks 1990). Many of these fires are likely to have been low intensity events associated with native pasture management and timber-getting. Major fires were recorded within the region during 1988, 1983, 1980, 1972, 1968, 1964, 1954, 1952, 1939 and 1926 (SFNSW 1994). In these years, the estimated areas burnt varied between 10 000 and 80 000 ha, up to 10 per cent of the region (SFNSW 1994). Although such fires recur somewhere in the region every 2–13 years, the average return time of major wildfires is likely to be much longer than 20 years because successive fires did not always overlap, even allowing for small but intense events recorded in local parts of the region in other years (Lunney & Leary 1988, Banks 1990).

In recent years, intensive management systems in wood production forests include logging, regeneration fires and hazard reduction fires (SFNSW 1994). These disturbances are superimposed upon unplanned components of the fire regime and interact in potentially complex ways (Bradstock et al. 1995). Current management regimes in production forest includes low-intensity hazard reduction burning on a 4–7 year rotation and up to 3 years prior to logging. Logging and high-intensity regeneration burns are planned to be implemented every 50–80 years. All fires are excluded for c. 15 years after logging. Several thinning operations may be implemented at 20–40 year intervals in between intensive logging events. Integrated logging is also carried out within privately owned forests, though generally with fewer management controls.

Methods

Classification and mapping approach

Map units are widely recognised in conservation biology as potential ‘surrogates’ or ‘coarse filters’ for biodiversity (Austin & Margules 1986, Noss 1987). The use of floristic assemblages as biodiversity surrogates (JANIS 1996) is supported *a priori* by the fact that vascular flora accounts for a significant portion of the total biodiversity of a site and that plant species individually or collectively provide essential habitat resources for many other organisms. However, a range of empirical approaches suggest that the extent to which alternative map bases correctly predict species distributions remains uncertain (e.g. Burgman 1988, Bedward et al. 1992b, Pressey & Bedward 1991, Ferrier & Watson 1997, Oliver et al. 1998, Panzer & Swartz 1998). Some of these studies suggest that the predictive capability of maps may be quite poor in certain areas or for certain biotic groups (Ferrier & Watson 1997, Oliver et al. 1998). Nevertheless, there is some evidence that floristic assemblages are either better predictors of species distributions (e.g. Pressey & Bedward 1991, Ferrier & Watson 1997) or no worse than alternative classifications and maps (e.g. Burgman 1988, Ferrier & Watson 1997), even though the range of different map bases examined is limited.

Furthermore, some substantial methodological sampling issues remain to be overcome in empirical studies of map surrogacy (e.g. Ferrier & Watson 1997).

In this study we have developed a classification based on floristic composition using an approach illustrated in Fig. 2. We used quantitative analyses of field samples to interpret and classify compositional patterns and then carried out mapping as an independent step using environmental relationships and remote data (e.g. Keith 1994, Brooker & Margules 1996). This contrasts with traditional mapping approaches, which place primary emphasis on remote sensing for both the definition and mapping of vegetation classes (e.g. Keith & Benson 1988, Baur 1989, Sun et al. 1996). Quantitative field samples offer greater accuracy and precision in the measurement of floristic composition than remote data combined with qualitative field reconnaissance especially, though not only, for understorey species which account for more than 90 per cent of floristic diversity in this region. Quantitative samples also lend themselves to explicit multivariate analysis, which may detect patterns that escape recognition by traditional intuitive methods. Mapping was carried out using explicit decision rules to interpolate the distributions of floristic classes from point samples using relationships between the classes and environmental and remote structural variables that were available as spatial data layers (Fig. 2). The separation of mapping as an independent step based on explicit data-dependent decision rules maximises mapping consistency and reduces the role of non-repeatable intuitive classification and mapping decisions.

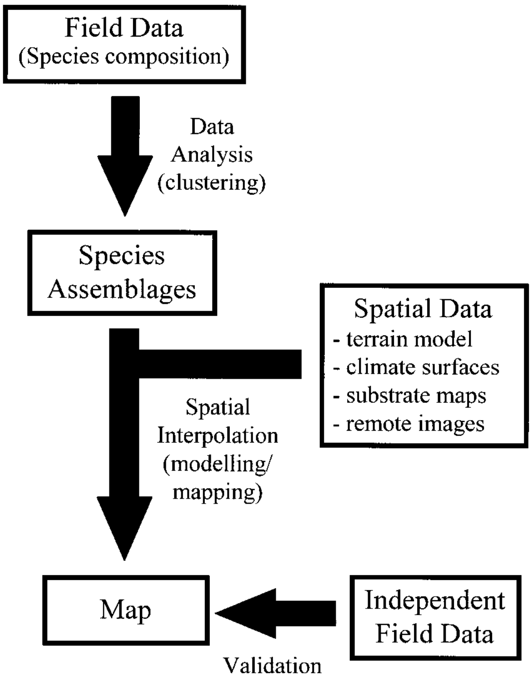

Fig. 2. Approach to vegetation classification and mapping based on field samples.

Vegetation data

Sample stratification

Sampling was stratified by parent material, elevation and terrain. The samples were gathered over a period from 1987 to 1997. Sample stratification was refined iteratively over this period with field sampling targeted to fill gaps. The progressive evaluation of sampling gaps also took into consideration suitable data available from other sources (see below). The final sample stratification was based on eight classes of parent material, seven classes of altitude, two classes of slope and three classes of aspect on steep slopes (Table 1). The distributions of sampling strata were mapped by intersection of relevant spatial data layers in a geographic information system (Eastman 1993). This was used in fieldwork planning and, in conjunction with a recent digital Landsat coverage, allowed the naturally vegetated extent of each stratum to be calculated. As expected, the distribution of strata in the study area was highly skewed with 100 of 224 possible strata not represented within the study area and only 17 of the remaining 124 strata accounting for more than 50% of the naturally vegetated area.

One hundred and two of the 124 sampling strata with extant vegetation were sampled (Table 1). The remaining unsampled strata represented environments covering less than 0.02% of native vegetation in the region, suggesting that sampling had a qualitative coverage of regional environmental variation. The most widespread strata were covered by larger numbers of samples (Table 1, Fig. 3).

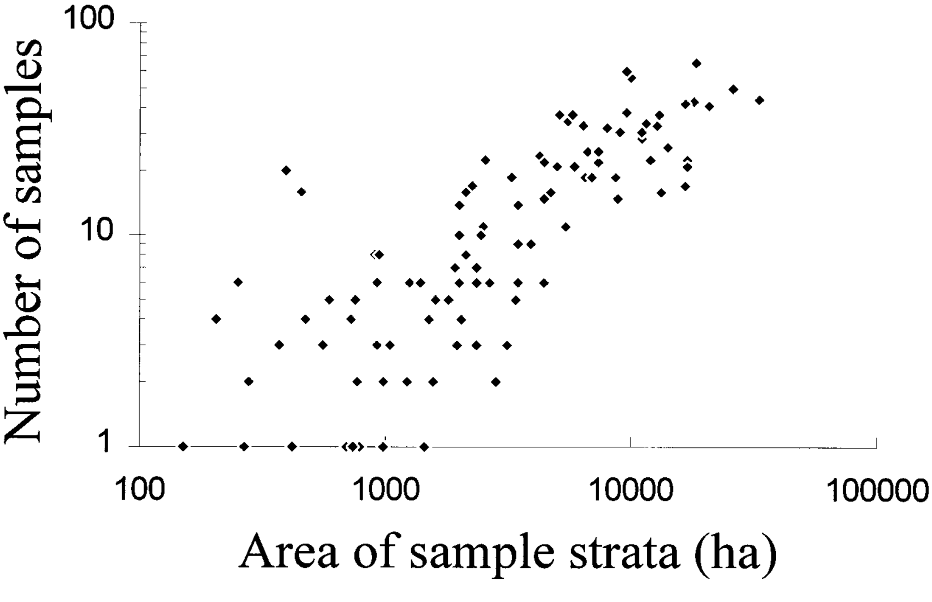

Fig. 3. Numbers of samples in sampling strata of varying extent (excluding cleared land).

Table 1. Sample stratification by classes of substrate, terrain and elevation. Data are number of samples and area (extant) under native vegetation (ha). Terrain classes: flat, slope ≤ 5°; north, slope > 5° and aspect < 30° or > 300°; intermediate, slope > 5° and aspect 30–120° or 210–300°; south, slope > 5° and aspect 120–210°. Elevation in metres above sea level.

Substrate/terrain	Elevation	0–150	151–300	301–450	451–600	601–750	751–900	> 900	Total
Riverine alluvium									
flat	#samples	14	-	2	-	-	-	1	17
	extant area	2002	0	279	0	0	0	87	2616
north	#samples	1	-	-	-	-	-	-	1
	extant area	776	0	0	0	0	0	0	855
intermediate	#samples	5	-	0	-	-	-	-	5
	extant area	1601	0	101	0	0	0	0	1913
south	#samples	1	-	-	-	-	-	-	1
	extant area	695	0	0	0	0	0	0	924
Coastal sand									
flat	#samples	25	-	-	-	-	-	-	25
	extant area	390	0	0	0	0	0	0	390
north	#samples	5	-	-	-	-	-	-	5
	extant area	202	0	0	0	0	0	0	202
intermediate	#samples	18	-	-	-	-	-	-	18
	extant area	454	0	0	0	0	0	0	454
south	#samples	7	-	-	-	-	-	-	7
	extant area	248	0	0	0	0	0	0	248
Tertiary alluvium									
flat	#samples	16	1	-	-	-	1	-	18
	extant area	13376	140	0	0	0	150	0	13864
north	#samples	0	0	-	-	-	-	-	0
	extant area	2045	33	0	0	0	0	0	2161
intermediate	#samples	9	-	-	-	-	-	-	9
	extant area	3894	0	0	0	0	0	0	4147
south	#samples	4	0	-	-	-	-	-	4
	extant area	2032	17	0	0	0	0	0	2091
Sedimentary (low quartz)									
flat	#samples	6	3	0	-	-	0	10	19
	extant area	1995	370	151	0	0	174	2461	5206
north	#samples	1	6	3	5	1	0	3	19
	extant area	974	928	925	759	739	821	2360	7506
intermediate	#samples	7	16	7	2	4	3	11	50
	extant area	2377	2105	1927	1570	1510	1970	5463	16923
south	#samples	2	8	8	2	0	0	8	28
	extant area	1219	901	937	760	767	909	2141	7633
Sedimentary (high quartz)									
flat	#samples	17	5	3	4	1	14	2	46
	extant area	16623	3427	1036	468	419	3438	982	26392
north	#samples	23	29	19	6	2	6	5	90
	extant area	17070	11071	6398	4403	2805	2646	1789	46183

Table 1. cont.

Substrate/terrain	Elevation	0–150	151–300	301–450	451–600	601–750	751–900	> 900	Total
intermediate	#samples	44	41	33	31	19	19	22	209
	extant area	33239	20982	12781	8942	6558	6961	4423	93886
south	#samples	21	23	25	16	9	6	10	110
	extant area	17074	11983	6704	4692	3464	3481	1982	49381
Rhyolite									
flat	#samples	6	0	-	-	-	-	-	6
	extant area	2363	73	0	0	0	0	0	2439
north	#samples	0	0	-	-	-	-	-	0
	extant area	1291	160	0	0	0	0	0	1452
intermediate	#samples	3	0	-	-	-	-	-	3
	extant area	3155	442	0	0	0	0	0	3598
south	#samples	1	0	-	-	-	-	-	1
	extant area	1440	142	0	0	0	0	0	1584
Granitoid volcanics									
flat	#samples	19	22	31	35	23	33	42	205
	extant area	3286	7397	11185	5523	2571	6357	16673	52992
north	#samples	11	19	34	32	24	15	21	156
	extant area	2521	8643	11613	7963	4292	4404	5869	45304
intermediate	#samples	21	43	49	66	55	59	26	319
	extant area	4982	18241	26008	18612	10007	9611	14232	101692
south	#samples	17	15	37	38	37	37	25	206
	extant area	2254	8841	13117	9572	5743	5092	7379	51997
Basalt									
flat	#samples	0	-	-	-	-	5	6	12
	extant area	112	0	0	0	0	587	1244	2040
north	#samples	0	0	-	-	-	0	3	3
	extant area	381	203	0	0	0	144	551	1321
intermediate	#samples	0	0	-	-	-	0	6	6
	extant area	420	453	0	0	0	534	1392	2932
south	#samples	0	0	-	-	-	2	4	6
	extant area	183	170	0	0	0	266	722	1438
Total #samples		**304**	**230**	**253**	**237**	**176**	**199**	**205**	**1604**
Total extant area		**140676**	**96866**	**93491**	**63460**	**39353**	**48020**	**69897**	**551763**

Field sampling methods

Vegetation was sampled in a total of 1032 0.04 ha quadrats, a standard size used by the National Herbarium of NSW, National Parks and Wildlife Service and State Forests of NSW in surveys of the coast and tablelands. These were generally square (20 × 20 m) except for some samples on linear landscape features such as beach dunes or riparian alluvium. Where these features were narrower than 20 m, quadrat dimensions were adjusted to ensure landform homogeneity within an area of 0.04 ha. All vascular plant taxa were recorded and allocated cover-abundance estimates on a six-point Braun-

Blanquet scale (Poore 1955). Plant identifications were verified where necessary by checking specimens at the National Herbarium. Records that could not be fully verified (due to inadequate specimens) were excluded from further analysis. Quadrats were searched as fully as possible, however some geophytic and ephemeral species may have escaped detection, depending on the presence of identifiable above-ground organs at the time of sampling. It seems unlikely that these omissions would affect analyses significantly because seasonal geophytes and ephemeral species occur at low frequencies usually at low local abundance in this region.

The height and projective foliage cover were estimated for up to four vertical vegetation strata if present: tree; small tree or tall shrub; shrub; and groundcover. The local terrain was described by measuring slope, aspect and horizon azimuths on eight points of the compass and by qualitative description of landform. Additional notes were made on soil texture and drainage, and evidence of recent disturbance (including fire, logging and physical damage).

Evaluation of additional data

In addition to the 1032 samples described above, a large volume of additional data were available from numerous surveys of local management areas (e.g. Gilmour 1983, Binns & Kavanagh 1990a) and regional surveys of particular habitats (e.g. Floyd 1982, Clarke 1989). These additional data were gathered using a range of different sampling methods which, in some cases, may preclude them from valid analysis with other data. Inclusion of incompatible data within a single analysis may cause results to be influenced more by methodological artefacts than florisitic similarities. Reduction of data to a level of detail that is common to all samples is a potential solution to some of these problems. For example, if some proportion of available samples lacked species abundance estimates or if different abundance measures were applied in different data sets, then all samples could be reduced to species presence/absence data for a common analysis. Differences in abundance measures therefore could not influence results. However, we rejected this approach because we believed variation in species abundance could be important in detecting significant vegetation patterns and because a large number of samples with reasonable coverage of the study area had a common abundance measure (Braun-Blanquet cover abundance). Instead, we set data evaluation criteria to exclude unsuitable samples from analysis.

As a minimal requirement, samples were required to be located on the Australian Map Grid with a precision of at least 100 m. In addition, the following sampling criteria were applied:

(I) Area of plot within the range 0.04–0.1 ha;
(II) Complete list of vascular plant species within the plot;
(III) Species abundances estimated on the six-point Braun-Blanquet cover-abundance scale.

The limits suggested in Criterion I were supported by trial data analyses in which the outcome of cluster analysis was not sensitive to variation in sample size between 0.04 and 0.1 ha. All samples met Criterion I except those of Floyd (1982), Gilmour (1983), Garven (1984), Benson (1994) and Clarke (unpubl.). The dimensions of plots were not recorded in the first three of these surveys (Table 2), however, it is likely that most of Gilmour's (1983) samples fell within the 0.04–1.0 ha range (Gilmour, pers. comm.). The surveys of Benson (1994) and Clarke (unpubl.) used quadrats smaller than 0.04 ha.

With the exception of NPWS (unpubl. 1986) tree survey data, all samples met Criterion II (Table 2). However, it is likely that a few inconspicuous species may have been overlooked in some samples, particularly geophytes which may be absent above ground during certain seasons or years. In a few samples, species richness appeared to be low, particularly for less tractable taxa such as Poaceae, relative to other samples in similar locations and habitats. Most of these samples were linked to particular observers suggesting that some species may have been consistently overlooked. These samples were excluded to ensure precautionary maintenance of data quality.

A large number of samples failed to meet Criterion III (Table 2) because they had species presence/absence data only (e.g. Breckwoldt 1979, SFNSW unpubl.). Another large set of samples had abundance measures other than Braun-Blanquet cover-abundance (Table 2). Examples include qualitative species abundance classes (e.g. Floyd 1982, Gilmour 1983), species frequency scores based on nested quadrats (Outhred 1986), and surveys in which species were assigned multiple abundance estimates for respective strata but no overall estimate for the plot (e.g. Fanning & Mills 1990). In a few cases where raw cover values were estimated for each species (e.g. Dodson et al. 1988), these were converted to Braun-Blanquet cover-abundance scores. Extensive exploratory analyses were carried out to determine whether samples that failed to meet Criterion III could be allocated to the vegetation classes defined by analysis of cover-abundance data of other samples. The exploratory analyses involved the identification of indicator species from presence/absence data in the additional samples. The details of these analyses will not be reported here, but they generally failed to allocate presence/absence samples to classes with an acceptable level of certainty.

Of 2400 additional samples evaluated, 614 met the locational precision criterion and all three sampling criteria (Table 2). With one exception, samples that failed to meet the data evaluation criteria were in areas that were well covered by other samples. The exception involved the extensive area of dissected terrain in Wadbilliga and Bemboka National Parks. Only 30 samples in this area met all criteria while a further 173 samples (Outhred 1986) met all criteria except Criterion III. These 173 samples were included in a supplementary data analysis to provide an adequate description of vegetation patterns in this part of the region.

Botanical nomenclature

Botanical nomenclature was reviewed and standardised across all data sets. There were many instances in which two or more synonyms were applied to the same taxon in different data sets and these were updated to reflect currently accepted nomenclature (Harden 1990–93, and subsequent revisions). In other cases, some observers specified a subspecific or varietal taxon, while others did not. If these species were represented in the region only by a single subspecies or variety, the records were

Table 2. Additional vegetation data evaluated. Data sets marked * met all data evaluation criteria (see text).

Reference	Location surveyed	Number of samples	Species recorded	Plot size (ha)	Abundance measure
Benson 1994	Monaro grasslands	5	All vascular	0.01	Braun-Blanquet
Binns & Kavanagh 1990a*	Nalbaugh SF	62	All vascular	0.1	Braun-Blanquet
Binns & Kavanagh 1990b*	Nullica SF	91	All vascular	0.1	Braun-Blanquet
Breckwoldt 1979	Bermagui NR, Goura NR, Mimosa Rocks NP, Wallaga Lake NP	385	All vascular	0.1	Presence/absence
Clarke 1989*	NSW Coastal dunes	84	All vascular	0.04	Braun-Blanquet
Clarke unpubl.	Southern NSW saltmarsh	141	All vascular	0.0025	Braun-Blanquet
Dodson et al. 1988*	Tantawangalo catchment	30	All vascular	0.1	% Cover
Fanning & Clark 1991*	Jingera, Nullica SF	66	All vascular	0.1	Braun-Blanquet
Fanning & Fatchen 1990*	Wog Wog Ck	113	All vascular	0.1	Braun-Blanquet
Fanning & Mills 1989	South Rockton, Bondi SF	71	All vascular	0.1	Frequency index
Fanning & Mills 1990	Myanba Ck	107	All vascular	0.1	Qualitative index
Fanning & Mills 1991	Stockyard Ck	66	All vascular	0.1	Qualitative index
Floyd 1982	Eden rainforests	11	All vascular	undefined	Qualitative index
Garvin 1984	Ben Boyd (South) NP	26	All vascular	undefined	Qualitative index
Gilmour 1983	Nadgee NR	65	All vascular	undefined	Qualitative index
Lane et al. 1998*	Bermagui NR, Biamanga NP, Goura NR, Wallaga Lake NP	73	All vascular	0.1	Braun-Blanquet
Outhred 1986	Wadbilliga NP	173	All vascular	0.1	Frequency score
NPWS unpubl. 1986	South east NSW	183	Trees	0.1	Presence/absence
State Forests* (NSW)	Coolangubra Escarpment FR	22	All vascular	0.1	Braun-Blanquet
State Forests* (NSW)	Illawambra FR	21	All vascular	0.1	Braun-Blanquet
State Forests* (NSW)	Mt Poole FR	24	All vascular	0.1	Braun-Blanquet
State Forests* (NSW)	Waalimma FR	22	All vascular	0.1	Braun-Blanquet
State Forests* (NSW)	Yambulla FR	6	All vascular	0.1	Braun-Blanquet
State Forests (NSW)	Yambulla catchments	558	All vascular	0.1	Presence/absence

updated by adding the appropriate epithet. For species with more than one subspecific or varietal taxon in the region, the unresolved records were deleted if these were few in number relative to resolved records, or otherwise all of the records were reduced to the species level. A regional species list was compiled from the sample data and supplemented by additional records from the literature (e.g. Binns 1987) and herbarium collections (see Keith et al. 1999).

Cluster analyses and definition of floristic assemblages

A preliminary cluster analysis was carried out on a core set of 1066 samples for an interim forest assessment (Keith et al. 1995). The analyses were carried out using PATN computer programs (Belbin 1994) and were similar to those used in an earlier study by Keith & Sanders (1990). Compositional dissimilarity among samples was calculated using the symmetric version of the Kulzcynski coefficient applied to unstandardised cover-abundance data (Faith et al. 1987). An unweighted pair-group arithmetic averaging (UPGMA) clustering strategy was applied to the resulting association matrix (Belbin and McDonald 1993) to derive a hierarchical classification. Homogeneity analysis (Bedward et al. 1992b), a technique that measures the extent to which group splitting yields improvements in overall homogeneity of all groups based on inter-sample dissimilarities, was applied to the hierarchical classification. The trend of diminishing gains in homogeneity was used to identify a level in the hierarchy (dendrogram) from which lineages were to be interpreted for the definition of floristic groups. These lineages were interpreted at successively lower levels in the hierarchy by assessing differences between sister groups (Keith & Sanders 1990) with respect to diagnostic species, vegetation structure and physical attributes (elevation, aspect, parent material, distribution). Interpretation using these attributes is consistent with JANIS' (1996) criteria for forest ecosystem definition, viz. 'units should be defined in terms of floristic composition in combination with substrate and position in the landscape.' Floristic groups were recognised when further splitting failed to discernibly resolve variation in any of these factors. The number of groups in the classification was therefore limited by the identification of prominent differences in species composition, vegetation structure and physical habitat.

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

The classification was modified and refined with new data that became available after the interim forest assessment. As stated previously, the collection of new data was directed to fill gaps identified by iterative assessment of the sample stratification. Further analyses were conducted on an expanded data set to assign new samples to floristic groups in the existing classification and, where new variation was apparent, define additional groups. Consensus between four analyses was used to establish relationships between new samples and the classification groups defined by analysis of the core data (Table 3). These included further cluster and nearest neighbour analyses as described previously, group centroid analyses and indicator species allocation analyses. Group centroid analyses were carried out using ALOC (Belbin 1987, 1994) to determine the five nearest group centroids to each new sample. Indicator species allocation analyses allocated new samples to classification units using the dendrogram as a decision rule structure for the presence or absence of species (Bedward & Keith unpubl.). The method delivers an indeterminate result for samples with no informative species or where different species give conflicting information on group membership.

Where cluster analysis agglomerated new samples into discrete dendrogram lineages, these were assessed against sister lineages and new floristic groups were recognised as described previously. The remainder of new samples were assigned to existing floristic groups using rules to assess consensus among the four alternative allocation analyses (Table 3). Four hundred and six of the 614 new samples met one or more of the consensus rules and were added to the core set of 1066 samples. Conversely, 208 of the new samples failed to meet any of the consensus rules indicating significant conflict between the four allocation analyses. In these cases, the new samples could not reliably be assigned to a floristic group and were excluded from further analysis to avoid the introduction of methodological artefacts into the results.

To address a significant gap in sample stratification, it was necessary to carry out supplementary analyses including samples from Outhred's (1986) survey of Wadbilliga National Park. Species abundance was estimated in these samples using a frequency index (Table 2) that was analytically incompatible with Braun-Blanquet cover-abundance estimates. In the supplementary analyses all data were reduced to presence/absence format and subject to cluster analysis and lineage interpretation as described previously. Lineage interpretation resulted in recognition of some new floristic groups recorded only in the Wadbilliga survey. The new groups accounted for 91 of Outhred's (1986) 173 samples. The remaining new Wadbilliga samples were then either assigned to existing floristic groups by consensus among the four allocation analyses (Table 3), accounting for a further 41 samples or excluded from further analysis if they could not be reliably assigned (41 samples). Thus, the total number of samples assigned to floristic groups was 1604, including 132 from the Wadbilliga data set.

Table 3. Consensus rules for assignment of new samples to existing floristic groups.

A new sample was assigned to an existing floristic group (Group x) if any of the following conditions were met:

1 Three or more of its five nearest neighbours belong to Group x;

2 Allocated to Group x by cluster analysis AND at least one of five nearest neighbours belongs to Group x AND closest centroid is Group x;

3 Allocated to Group x by cluster analysis AND at least one of five nearest neighbours in Group x AND indicator species analysis suggests exclusive membership of Group x;

4 Allocated to Group x by cluster analysis AND at least two of five nearest neighbour belong to Group x AND second closest centroid is Group x;

5 Allocated to Group x by cluster analysis AND at least two of five nearest neighbours belong to Group x AND indicator species analysis suggests membership of Group x and no more than three other groups.

Description of Floristic Assemblages

Floristic assemblages were assigned vernacular names to impart to readers a mental picture of the vegetation and its habitat or distribution. Names were composed of up to four parts. The last part of the name describes vegetation structure (e.g. rainforest, forest, woodland, scrub, heath, swamp, grassland). Other parts of the name may include a place name (e.g. Wadbilliga, Waalimma, Eden) or landform (e.g. coastal, hinterland, tableland) and/or terms describing understorey strata (e.g. layered, wet fern, dry grass, dry shrub). Where possible, comparisons were drawn with similar types of vegetation described in adjacent regions (e.g. Austin 1978, Forbes et al. 1982, Woodgate et al. 1994).

Each floristic assemblage was described using summaries of the sample data to produce profiles of species composition, vegetation structure and physical habitat. Diagnostic species were identified for each floristic group in a fidelity analysis of the final set of 1604 samples described above. Diagnostic species were defined by the extent to which their occurrence at regional and local scales discriminated the target assemblage from residual vegetation (pooled samples of all other assemblages) as shown in Table 4 (after Westhoff & van der Maarel 1978). Species' occurrences at regional scales were represented by their frequency among quadrats, while their local abundances were represented by median cover-abundance within quadrats. For a few assemblages not represented among the 1604 samples (i.e. groups confined to the Wadbilliga area, grassland and saltmarsh) it was necessary to carry out additional analyses on data that did not meet the criteria for inclusion in a combined analysis (Benson 1994, Outhred 1986, Clarke unpubl.).

Three categories of species were defined (Table 4): positive diagnostic species (those more likely to occur within the target floristic assemblage than in all others); negative diagnostic species (those unlikely to occur within the target assemblage but generally abundant elsewhere); and frequent species (those common or dominant in the target assemblage, but also likely to be common in others). All tree species recorded were listed in the descriptions of each floristic assemblage for context, irrespective of whether they met any of the three diagnostic criteria.

Table 4. Definitions of diagnostic species (modified from Westhoff & van der Maarel 1978). C/A refers to median Braun-Blanquet cover-abundance value (after Poore 1955).

		Residual Assemblages		
		Frequency < 0.5 AND C/A ≥ 2	Frequency ≥ 0.5 OR C/A < 2	Frequency $= 0$
Target Assemblages	Frequency ≥ 0.5 AND C/A ≥ 2	Frequent	Positive diagnostic	Positive diagnostic
	Frequency < 0.5 OR C/A < 2	Negative diagnostic	Uninformative	Positive diagnostic
	Frequency $= 0$	Negative diagnostic	Uninformative	-

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

The physical habitat of each floristic assemblage was characterised by calculating summary statistics for terrain variables, precipitation and parent material from the sample data. These summaries included: the frequency of occurrence on nine classes of parent material (Holocene coastal sands, Holocene riverine alluvium, Tertiary alluvium, Devonian high-quartz sedimentaries, Ordovician high-quartz sedimentaries, Devonian rhyolite, low quartz sedimentaries, Devonian granitoids and Tertiary and Devonian basalt); frequency of occurrence in four aspect classes (flat, north, west or east, and south); mean and interquartile ranges of altitude, slope and mean annual precipitation (latter calculated from modelled data, Table 5).

Gradient Analysis

Gradient analysis was carried out to gain an understanding of environmental relationships that may be useful predictors of the spatial distribution of floristic assemblages. A semi-strong hybrid multidimensional scaling ordination (Belbin 1991) was applied to the set of 1604 samples to examine relationships between floristic composition and environmental gradients. An association matrix was calculated using the symmetric form of the Kulzcynski coefficient, as for the cluster analysis described previously. Ratio regression was applied to association values less than 0.9, while ordinal regression was applied to values above this cut point. Ordinations were derived from 10 random starting configurations and a maximum of 50 iterations were allowed unless earlier termination was accepted when reductions in stress between successive iterations fell below 0.005. Ordinations were applied in an increasing number of dimensions to determine a parsimonious solution with comparatively low stress in a small, manageable number of dimensions. Vectors representing 19 terrain, substrate and climatic variables (Table 5) were fitted to the parsimonious ordination and their rank correlations with floristic trends were calculated. The variables used were: altitude; slope, two aspect indices, topographic roughness and position indices at three neighbourhood sizes each, local topographic position index, wetness index, solar radiation index, annual preciptation, precipitation of the driest and wettest months, mean maximum and minimum temperatures of the hottest and coldest months, respectively, and substrate nutrient index. The nutrient index was derived by arranging classes of parent material into an ordinal sequence, starting with the least fertile as follows: Holocene coastal sands; Tertiary alluvium, Devonian high quartz sedimentaries; Devonian rhyolite; Ordovician high quartz sedimentaries; Devonian granitoids; low quartz sedimentaries; Holocene riverine alluvium; and Tertiary/Devonian basalts.

Environmental and remote spatial data

A set of spatial data layers were rasterised to 25 m square grid cells for use in vegetation modelling. Terrain variables were derived from a 25 m grid digital elevation model supplied by the NSW Land Information Centre (Table 5).

Table 5. Spatial data layers used in mapping.

Spatial Variable	**Description**
Terrain	
Altitude	Elevation above sea level (metres)
Slope	Inclination from horizontal (degrees)
Aspect	Deviation from grid north perpendicular to slope (degrees)
Sine Aspect Index	Continuous index (0–100) calculated as 100 times sine of half aspect value in degrees (flat sites allocated missing values)
Ordinal Aspect Index	Categorical index of aspect (0: flat, 1: 301–30°, 2: 211–300°, 3: 31–120°, 4: 121–210°)
Solar Radiation Index	Continuous index representing topographic exposure to solar radiation calculated from slope, aspect, horizon azimuth and latitude. Varies below 100 for sheltered sites and above 100 for exposed sites
Wetness Index	Continuous index representing the volume of water draining to a given point in the landscape (after Moore et al. 1993)
Local Topographic Position (S)	Continuous index (0–100) representing proportional distance between local ridge (100) and local gully (0) (after Skidmore 1990)
Neighbourhood Topographic Position (250 m)	Difference between altitude of a central grid cell and mean altitude of surrounding cells within a 250 × 250 m neighbourhood
Neighbourhood Topographic Position (500 m)	Difference between the altitude of a central grid cell and mean altitude of surrounding cells within a 500 × 500 m neighbourhood
Neighbourhood Topographic Position (1000 m)	Difference between the altitude of a central grid cell and mean altitude of surrounding cells within a 1000 × 1000 m neighbourhood
Neighbourhood Topographic Roughness (250 m)	Standard deviation of altitude within a neighbourhood of 250 × 250 m
Neighbourhood Topographic Roughness (500 m)	Standard deviation of altitude within a neighbourhood of 500 x 500 m
Neighbourhood Topographic Roughness (1000 m)	Standard deviation of altitude within a neighbourhood of 1000 × 1000 m
Climate	
Annual Rainfall	Mean total yearly rainfall (mm)
Rainfall of Wettest Month	Maximum mean monthly rainfall (mm)
Rainfall of Driest Month	Minimum mean monthly rainfall (mm)
Minimum Temperature of Coldest Month	Mean minimum monthly temperature (°C)
Maximum Temperature of Hottest Month	Mean maximum monthly temperature (°C)
Substrate	
7-class Parent Material	Major geological formations
28-class Parent Material	Dominant lithologies
106-class Parent Material	Lithological classes
Land cover	
Vegetation Structure	Major vegetation formations (excluding temperate rainforest) determined from aerial photos
Temperate Rainforest	Rainforest determined from aerial photos
Forest Types	Baur (1989) types and mosaics interpreted from aerial photos
Extant Native Vegetation Cover	Presence of extant native vegetation determined from Landsat TM
Location	
Distance from Coast	Shortest distance from coast (metres)
Easting	Australian map grid
Northing	Australian map grid

The derived variables represented topographic position, relief, shelter and soil moisture at varying spatial scales.

Climatic surfaces (Table 5) were derived using ESOCLIM (Hutchinson 1989). The sparse distribution of weather stations within the region, and consequent scarcity of weather data, precluded quantitative evaluation of the climatic surfaces. Modelled temperature surfaces were very closely related to altitude and patterns due to local frost hollows were likely to be under-represented. Similarly, rainfall surfaces possibly underestimated regional orographic effects, although intuitively expected patterns were evident.

Spatial data for parent material supplied by the Bureau of Resource Sciences were based on a revision of earlier maps by Barnes & Herzberger (1975) and Beams & Hough (1984) and recent field observations. The classification was modified to distinguish coastal sands from other Holocene alluvium; Lochiel Basalt from associated Devonian lithologies; and Genoa Sandstone beds from other Devonian sediments (Barnes & Herzberger 1975). The final classification included 106 lithological units within the Eden region. Related units were lumped according to dominant lithology into 28 classes and these were lumped further into 7 major formations to provide three hierarchical spatial coverages of substrate (Table 5).

A GIS coverage differentiating native vegetation from cleared land and plantations of exotic species was prepared by manual interpretation of a Landsat TM image taken in 1989 and a map of existing plantations. This coverage was used as training data for a spectral classification of a Landsat TM image taken in 1994. It was assumed, consistent with field observations, that negligible land clearance occurred between 1994 and 1998.

A GIS coverage differentiating major structural types of native vegetation was prepared by manual interpretation of 1:25 000 scale black and white aerial photographs flown in 1963 (Table 5). For small parts of the area where these were unavailable photographs flown in 1979 and 1990 were used. Mapped occurrences of various structural types were checked using the sample data and observations gathered during field traverse. A separate coverage of rainforest was prepared from colour aerial photographs flown in 1994 as part of the Eden CRA old growth mapping study.

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

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

Spatial Interpolation and Mapping

A hybrid decision tree/expert system technique was selected as the preferred approach for modelling the spatial distribution of the 79 floristic groups (map units). This technique describes the distribution of map units using decision rules that comprise a series of quantitative statements about spatial variables connected by conjunctions. The distribution of each map unit may be described by one or more mutually exclusive rules. Reasons for choice of this method include:

- the method is explicit and repeatable relative to intuitively based mapping techniques;
- the method is free from statistical constraints and assumptions about the structure of the data;
- the method is efficient because sets of decision rules are developed simultaneously for all map units, rather than individually; and
- the method allows for intervention by experts in an explicit manner through the choice and design of decision rules.

This latter capability is a major strength because it provides a framework for incorporating non-formal expert knowledge into the map. This kind of knowledge is difficult to build into statistical models, which traditionally rely upon quantitative sample data (e.g. Austin et al. 1984). While intuitive mapping allows qualitative knowledge to be incorporated, this generally occurs in the absence of an explicit framework (e.g. Keith & Benson 1988) such as that offered by a decision rule approach.

The main disadvantage of decision tree models relative to parametric models (e.g. generalised linear and additive models) is that they utilise fewer and fewer samples as more variables are fitted. Consequently, inadequate sampling of environmental space may be more limiting, at least superficially, for decision tree models. Statistical models rely upon environmental relationship established across the data set as a whole and consequently these are called upon to make predictions where sampling intensity is low. Comparative studies on the prediction of distributions of individual species suggest that generalised linear models and generalised additive models return slightly more accurate predictions than decision tree models (Ferrier & Watson 1997). However, these trials excluded expert intervention, a major strength of the approach employed here. In a comparative species modelling study, Elith et al. (1998) concluded that expert knowledge is likely to be useful, at least in the selection of appropriate variables for modelling. However, no comparative studies have yet been carried out on the modelling of multi-species assemblages.

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

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

A decision-tree model of floristic groups in the Eden region was developed using 1450 of the 1604 allocated samples. Use of these samples assumed that no substantial vegetation changes occurred during the sampling period (1987–1997). Significant regional-scale spatial variables (parent material, rainfall and temperature) were selected at early stages of tree construction, while attention turned to local-scale variables (e.g. terrain) to discriminate smaller groups of samples representing different map units. The model was developed iteratively by checking distributions predicted by particular sets of rules and adjusting tree structure as necessary (see below). Terminal nodes were allocated to the map unit represented by the greatest number of samples. Where there was a tie, expert knowledge was applied to choose a suitable option.

The final set of decision rules was applied to the full set of spatial data layers (Table 5) to allocate all 25 m grid cells in the study area to a map unit. Several small polygons remained unassigned to map units because some of the finest-scale (106–class) geological units were not sampled within the relevant climatic and terrain envelope. These polygons were assigned to a map unit either by using data on a related geological class or by assigning cells to the same map unit as their nearest assigned neighbour. The model output was then smoothed to remove small artefactual features. The resulting map represented the pre-1750 distribution of floristic groups, a baseline required for the Comprehensive Regional Assessment (JANIS 1996). This was cut using the Landsat coverage of extant native vegetation cover (Table 5) to derive the extant distributions of map units.

Map validation

Three complementary approaches were used in map validation: qualitative checking, description of map reliability and quantitative accuracy assessment. Qualitative checking procedures were incorporated into the development of the map. The decision-tree model was broken down into manageable components for proofing. The checking process was carried out by an experienced field botanist (DK) and consisted of the following steps.

(1) A small number of rules (5–12) were extracted from the model and implemented on the spatial data to display the distribution of respective map units.

(2) The mapped distributions were examined in relation to the regional distribution of their samples.

(3) The fine-scale distributions of map units were examined with reference to topographic maps to determine whether appropriate landscape relationships were reflected (e.g. that sheltered gullies generally support either similar or more mesic vegetation than adjacent ridges, but not less mesic vegetation).

(4) The sources of all identified anomalies were traced to particular nodes in the decision tree and the sample data were examined to explore alternative rule pathways below the node identified.

(5) The model and map were revised and proofing steps 1–5 were repeated until all identified anomalies were resolved.

When model development was well advanced, further refinements were sought from two other experienced field botanists (Doug Binns, State Forests of NSW; Jackie Miles, consultant, Brogo).

Sampling density was used to describe map reliability across the study area. The 1450 samples used to construct the decision tree model were used to calculate the number of samples within a 5 km^2 radius of each 100 m grid cell. Sampling density was calculated by dividing the number of samples by the area of extant native vegetation in each circular neighbourhood. Six classes of sampling density were defined in terms of the number of samples per square kilometre of extant native vegetation. The distribution of these classes was mapped in all parts of the study area supporting extant native vegetation.

One hundred and fifty-four (approximately 10%) of the 1604 samples selected for data analysis were withheld from modelling for accuracy quantification. These validation samples were used to test model predictions against independent observations at varying spatial scales relevant to map usage. These spatial scales were represented by spatial neighbourhoods of varying size around the validation samples. Validation samples were selected at random from all map units excluding those with less than 20 samples so as not to unduly constrain modelling options for these less common units.

The principal aim of accuracy quantification was to determine the likelihood that selection of an area to represent a given floristic assemblage in a reserve actually contained the assemblage predicted on the map. Planning units used for reserve selection in the Eden Comprehensive Regional Assessment varied in size from approximately 20 ha to 240 ha with a median size around 100 ha. Validation samples were thus compared to mapped units within circular neighbourhoods with the following radii and area to determine error rates at spatial scales relevant to map usage: 100 m (3 ha); 200 m (12 ha); 300 m (28 ha); 400 m (50 ha); 500 m (79 ha); 600 m (112 ha); 700 m (153 ha); 800 m (201 ha); 900 m (253 ha); and 1 000 m (314 ha). The percentages of correct and incorrect matches were recorded as an estimate of map accuracy and statistical errors were calculated from the binomial distribution.

Results

Classification and description of floristic assemblages

The hierarchical classification derived from cluster analysis is summarised in a simplified dendrogram (Fig. 4). Thirty-three dendrogram lineages were identified for further interpretation using homogeneity analysis. A number of these lineages were not split further, while others were resolved into several floristic assemblages that were related to qualitatively different habitats defined by substrate and position in the landscape. The following example shows how complex variation in one dendrogram lineage was resolved into six floristic groups (refer to first six groups in Fig. 4).

The parent lineage contains 90 samples with a diverse range of dry forest species. Samples encompass altitudinal range of 15–915 m on a range of granitoid, sandstone, mudstone and alluvial parent materials, across all aspects on flat and dissected terrain. Samples are distributed throughout the coast and southern parts of hinterland and tableland range.

The first split segregated a group of samples restricted to sandstone on steep northern and western aspects of Mt Imlay, Nungatta Mountain and Bondi Gulf at 330–750m elevation. Samples indicate a forest less than 20 m tall dominated by *Eucalyptus agglomerata* and prominent ground stratum. Further splitting failed to resolve substantial variation within this group. It was therefore recognised and mapped (map unit 50 in Fig. 4).

The second split resulted in two further groups. The first of these included samples distributed widely on coastal ranges and inland mountains which, when split again, yielded one subgroup dominated by *Eucalyptus sieberi* and largely confined to tonalite lithology in the Mumbulla Mountain area, and another subgroup dominated by *Eucalyptus agglomerata*, *Eucalyptus sieberi* and *Allocasuarina littoralis* that was more widespread on sedimentary lithologies of coastal and hinterland ranges. Further splitting failed to resolve substantial variation within these subgroups which were recognised and mapped (map units 48 and 49, respectively, in Fig. 4).

The remaining sample groups in the lineage were resolved into three map units in a similar manner. They were: 46A (low forest dominated by *Eucalyptus consideniana* restricted to granitoids and Tertiary alluvium in the Timbillica area); 46B (taller forest dominated by *Corymbia gummifer*a and *E. sieberi* confined to sediments and Tertiary alluvium on the coastal strip); and 47 (taller forest dominated by *Angophora floribunda* and *E. sieberi* confined to sediments south of Pambula).

Alternative interpretations of the hierarchy yielding greater and fewer map units were considered in the manner described above. A total of 79 map units were recognised in the vegetation classification. These included 61 floristic groups that were interpreted from the 33 dendrogram lineages identified initially using homogeneity analysis. Six additional assemblages were recognised in the supplementary analysis of presence/absence data including samples from Wadbilliga National Park. A further nine units including eight estuarine wetlands and one grassland were recognised independently of the numerical analyses and described either using available

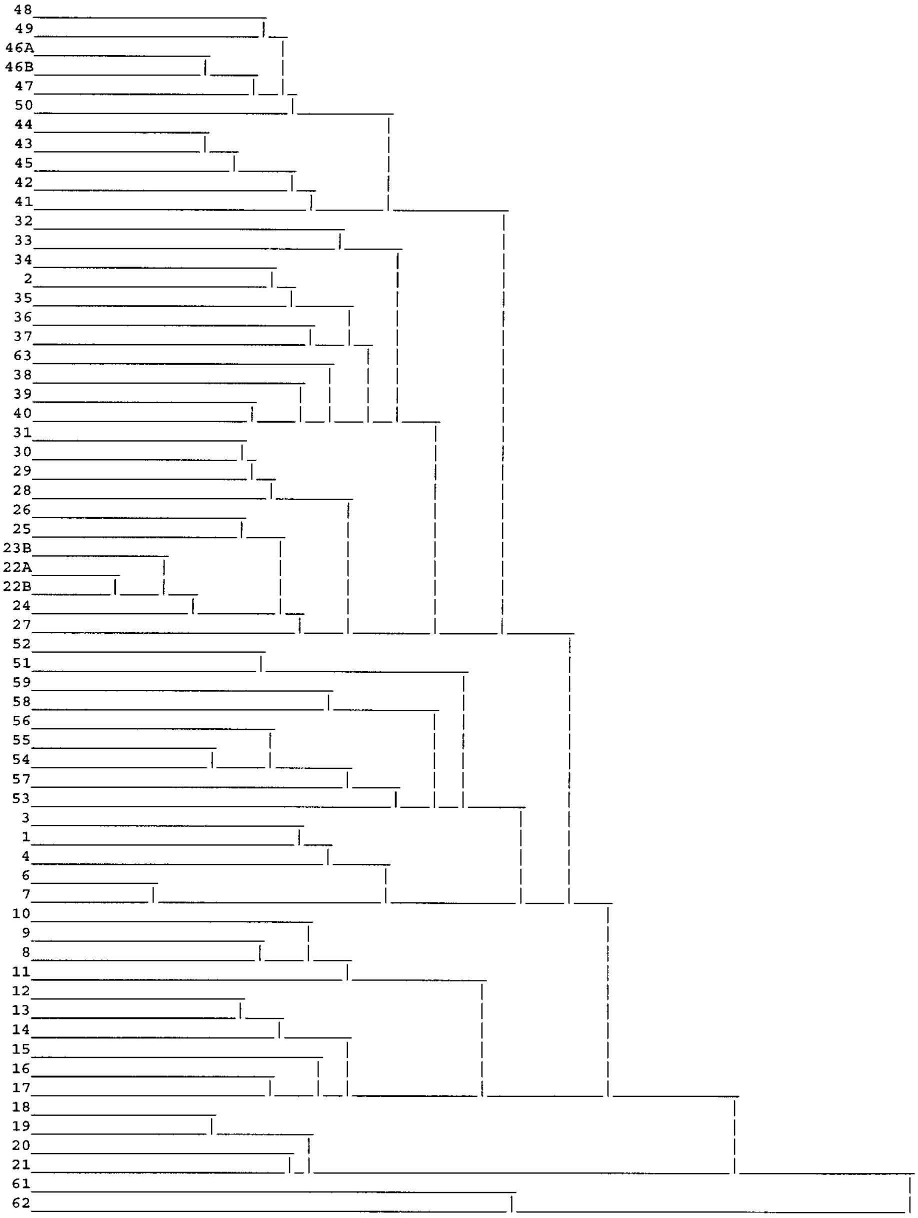

Fig. 4. Simplified dendrogram showing floristic relationships based on samples with Braun-Blanquet cover-abundance estimates.

qualitative observations from the field or the literature, or using available quantitative data that were unsuitable for inclusion in the cluster analyses (e.g. Benson 1994, Clarke unpubl.)

The Appendix describes the floristic composition, vegetation structure, physical habitat and distribution of samples for each map unit. Four of the 79 map units (67–70) were restricted to estuaries below low tide mark (sea grass meadows). A further four units (63–66) were estuarine wetlands associated with the high tide mark. Of the remainder, 47 map units were forests dominated by eucalypts, six were rainforests or scrubs with rainforest affinities, 10 were shrublands or heathlands, 3 were swamps and 2 were grasslands. The 47 types of eucalypt forest varied from tall forests with mesophyllous shrub, fern or herbaceous understories, to intermediate and dry forests with grassy or sclerophyllous shrub understories.

There was close correspondence between the current floristic classification and that based on an earlier analysis of a smaller data set (369 samples, Keith & Sanders 1990). Thirty-four floristic assemblages were related on a 1:1 basis to units defined in the earlier study (Table 6). In five cases two (map units 5 and 6, 16 and 17, 44 and 45, 46A and 46B) or three (e.g. map units 11, 12 and 15) of the currently recognised assemblages corresponded to a single unit in the earlier classification (Table 6). The additional data now available allowed resolution of poorly sampled vegetation classes that were not previously recognised. Conversely, three of the currently recognised assemblages (map units 26, 35 and 56) corresponded with two previously recognised units. In these cases, additional sampling suggested there was greater overlap between the units in the earlier classification than previously recognised. Three of Keith and Sanders' (1990) communities were originally defined in the absence of quantitative data and were resolved as follows: Community 18 in the Bega and Towamba valleys (resolved into map units 18–21); Community 19 on the Monaro Tableland (resolved into map units 22–24); and Community 41, the estuarine complex (resolved into map units 63–70). Eleven assemblages had locally restricted distributions and were not previously sampled (map units 2–4, 28, 29, 39, 40, 52, 54, 60 and 62). The remaining seven previously unrecognised units (22B, W1–W6) were introduced to describe vegetation in the Wadbilliga-Numeralla area which was not included in the previous study (Table 6).

Regional flora and species richness

A total of 1522 vascular indigenous plant taxa were represented by confirmed records in the region (Keith et al. 1999). A further 136 taxa were recorded, but require confirmation. Some previous records were determined to be erroneous identifications, while a number of others remain doubtful. Three hundred and seventy-five introduced plant taxa were recorded, but this is likely to underestimate the regional alien flora because highly disturbed habitats that are favourable to such species, such as pastures and wastelands, were under-represented in sampling (Keith et al. 1999).

Species richness of terrestrial vegetation varied from 2 to 81 per 0.04 ha, with a regional mean of 30 and inter-quartile range of 23–40. There was considerable variation in species richness between floristic assemblages (Table 7). The most species-

Table 6. Correspondence between floristic assemblages described in this study with those described by Keith and Sanders (1990).

This study	Keith & Sanders(1990)
1	1
2	not sampled
3	not sampled
4	not sampled
5	2(I)
6	2(I)
7	2(II)
8	3
9	4
10	5
11	not sampled but referable to 6
12	6
13	9(I)
14	9(II)
15	6
16	7
17	7
18	not sampled but referable to 18
19	not sampled but referable to 18
20	not sampled but referable to 18
21	not sampled but referable to 18
22A	not sampled but referable to 19
22B	outside study area
23A	not sampled but referable to 19
23B	not sampled but referable to 19
24	38
25	20
26	37, 21
27	13
28	not sampled but referable to 14
29	not sampled but affinities with 7 and 22
30	17
31	14
32	30
33	26(II)
34	12
35	16, 15
36	32
37	10
38	11
39	not sampled but referable to
11	
40	not sampled
41	23
42	27
43	22
44	24
45	24
46A	28
46B	28
47	29
48	26(I)
49	26(I)
50	20
51	25
52	not sampled but referable to 25
53	35
54	not sampled but referable to 33
55	33
56	34, 36
57	39
58	8
59	40
60	not sampled
61	31
62	not sampled
63	not sampled but referable to 41
64	not sampled but referable to 41
65	not sampled but referable to 41
66	not sampled but referable to 41
67	not sampled but referable to 41
68	not sampled but referable to 41
69	not sampled but referable to 41
70	not sampled but referable to 41
W1	outside study area
W2	outside study area
W3	outside study area
W4	outside study area
W5	outside study area
W6	outside study area

rich assemblages (map units 19 and 34) were semi-mesic assemblages with a high diversity of both shrubs and herbs contributing on average to more than 45 species per 0.04 ha. Other species-rich assemblages with more than 40 species per 0.04 ha (map units 13, 17, 18 and 30) generally had large numbers of herb species in the ground stratum but fewer shrub species. Mesic eucalypt forests (map units 11–19) and dry grassy eucalypt forests of the coastal valleys (map units 20–21) and hinterland (map units 27–31 and 35) had species richness consistently above 32 species per 0.04 ha (Table 7). Some intermediate forests (map units 34 and 37) and dry shrubby forests at low elevation (map units 46A and 46B) also had richness values in this range. These low elevation assemblages excepted, dry shrubby eucalypt forests (map units 25, 41–50) generally have 20–30 species per 0.04 ha. In low rainfall areas, the dry shrubby forests on quartz-rich sediments (map units 25, 50, W1–W5) and dry grassy forests and woodlands on the tableland had low levels of species richness (16–24 species per 0.04 ha, and 11 per 0.01 ha for Map Unit 23A). Rainforests (map units 1, 5–8), layered forests (map units 2, 3, 9 and 10) and heathlands (map units 53–56 and 61) had variable levels of species richness, the coastal assemblages generally having more species than the elevated montane assemblages (Table 7). Freshwater swamps (map units 57–60) had moderate richness levels, while estuarine wetlands (map units 63–70) and beach strand (map unit 62) generally had very few species.

Gradient Analysis

Four ordination axes were required to summarise regional floristic variation parsimoniously (stress values of 0.33, 0.26 and 0.20 were returned for configurations in 2, 3 and 4 dimensions, respectively). Altitude had the highest correlation with floristic composition, while minimum temperature of the coldest month, annual rainfall and rainfall of the driest month were also strongly correlated with composition (Table 8). These relationships reflect regional scale patterns in vegetation. The variables may be expected to correlate strongly with each other (Fig. 5), given orographic influences on rainfall and adiabatic lapse related to altitude, even though rainshadows and frost hollows may cause subregional deviations from general altitudinal relationships. A suite of topographic variables including neighbourhood indices at all three scales and slope were moderately correlated with floristic composition (Table 8), as was substrate nutrient index. These relationships reflect primarily local-scale patterns in vegetation. While the topographic variables were correlated to varying degrees with each other, substrate nutrient index was largely unrelated to all other environmental variables examined (Fig. 5). There may be additional relationships between floristic composition and substrate that were not adequately represented by the simple ordinal nutrient index. Variables representing the finest scale variation in topography (e.g. aspect indices, radiation, local topographic position and wetness) were the least correlated with floristic composition. This may be due in part to the poor representation of complex fine scale relationships in a large data set reduced to 4 dimensional space.

Table 7. Native species richness of major vegetation formations at scales ≤ 0.1 ha.

Floristic assemblage	Species richness mean	se	n	Sample area (ha)
1	28	5	6	0.04
2	32	3	5	0.04
3	27	3	13	0.04
4	8	2	3	0.04
5	47	-	1	0.04
6	31	2	13	0.04
7	28	3	10	0.04
8	17	2	5	0.04
9	21	2	11	0.04
10	29	1	80	0.04
11	31	1	18	0.04
12	33	2	31	0.04
13	40	1	70	0.04
14	33	2	36	0.04
15	33	1	132	0.04
16	35	1	32	0.04
17	43	3	19	0.042
18	42	2	16	0.04
19	48	2	38	0.04
20	39	1	48	0.04
21	35	3	28	0.04
22A	16	1	5	0.04
22B	13	3	3	0.04
23A	11	2	5	0.01
23B	17	3	14	0.04
24	26	2	20	0.04
25	22	1	10	0.04
26	32	2	34	0.04
27	38	2	5	0.04
28	34	2	10	0.1
29	39	3	17	0.1
30	42	2	17	0.04
31	38	1	54	0.04
32	31	2	42	0.04
33	27	1	55	0.04
34	46	3	24	0.04

Floristic assemblage	Floristic mean	Species richness se	n	Sample area (ha)
35	37	1	51	0.04
36	22	2	6	0.04
37	35	2	17	0.04
38	22	14	3	0.04
39	37	7	5	0.0
40	27	9	4	0.04
41	21	1	28	0.04
42	30	1	64	0.04
43	34	2	13	0.04
44	30	1	29	0.04
45	29	3	23	0.04
46A	36	0	24	0.04
46B	35	2	19	0.04
47	26	1	19	0.04
48	28	2	19	0.04
49	28	1	48	0.04
50	21	3	5	0.04
51	34	4	14	0.1
52	24	2	8	0.1
53	17	2	21	0.04
54	37	3	6	0.04
55	35	4	8	0.04
56	29	4	5	0.04
57	28	4	9	0.04
58	30	4	14	0.04
59	29	4	7	0.04
60	39	7	3	0.04
61	17	1	41	0.04
62	5	1	30	0.04
63	22	2	4	0.04
64	4	0	141	0.0025
W1	18	1	28	0.05
W2	20	1	15	0.05
W3	20	2	13	0.05
W4	24	2	6	0.05
W5	32	1	22	0.05
W6	33	3	7	0.05

Table 8. Rank correlations of floristic vectors fitted to 4-dimensional ordination space with the environmental variables they represent. Abbreviations for variables refer to Fig. 5.

Environmental Variable	Abbreviation	Correlation
Altitude	Alt	0.657
Minimum Temperature of Coldest Month	Min.T	0.587
Annual rainfall	Ann.R	0.559
Rainfall of Driest Month	Min.R	0.545
Neighbourhood Topographic Roughness (500 m)	Rug.500	0.386
Neighbourhood Topographic Roughness (1000 m)	Rug.1000	0.385
Neighbourhood Topographic Roughness (250 m)	Rug.250	0.384
Slope	Slp	0.371
Rainfall of Wettest Month	Max.R	0.363
Substrate Nutrient Index	Sub	0.335
Maximum Temperature of Hottest Month	Max.T	0.335
Neighbourhood Topographic Position (500 m)	Top.500	0.306
Neighbourhood Topographic Position (1000 m)	Top.1000	0.292
Sine Aspect Index	Asp.s	0.263
Neighbourhood Topographic Position (250 m)	Top.250	0.240
Solar Radiation Index	Rad	0.237
Wetness Index	Wet	0.207
Local Topographic Position	Top.1	0.174
Ordinal Aspect Index	Asp.o	0.127

Vegetation model and map

A hierarchical set of 470 decision rules was developed iteratively to describe the distribution of the 79 map units. Each map unit had between one and 31 rules describing its distribution. The highest order node in the decision tree (Fig. 6) was split according to major structural formations identified from aerial photopattern (rainforest, eucalypt forest, scrub, riparian vegetation, heath, grassland, treeless swamp and estuarine vegetation). Rainforest units were distinguished from one another using classes of aerial photopattern and rule thresholds for rainfall and elevation. The eucalypt forest node was split according to 8-class parent material and each parent material node was in turn segregated using the most informative regional-scale variables (Fig. 6). These included: mean rainfall of the driest month for granitoid substrates, the most widespread parent material in the region; elevation for high-quartz sedimentary rocks; finer scale geological units for basalt and low-quartz sedimentary rocks; and geographic trends for alluvial substrates. Lower order statements in rules describing the distribution of eucalypt-dominated map units were, in most cases, based on local terrain, substrate and eucalypt aerial photopattern. Three scrub map units were distinguished by aerial photopattern and parent material, while aerial photopattern and mean annual rainfall (Fig. 6) distinguished the three riparian units. Heathlands and grassland were segregated using elevation and aerial photopattern, while estuarine units were distinguished on the basis of aerial photopattern.

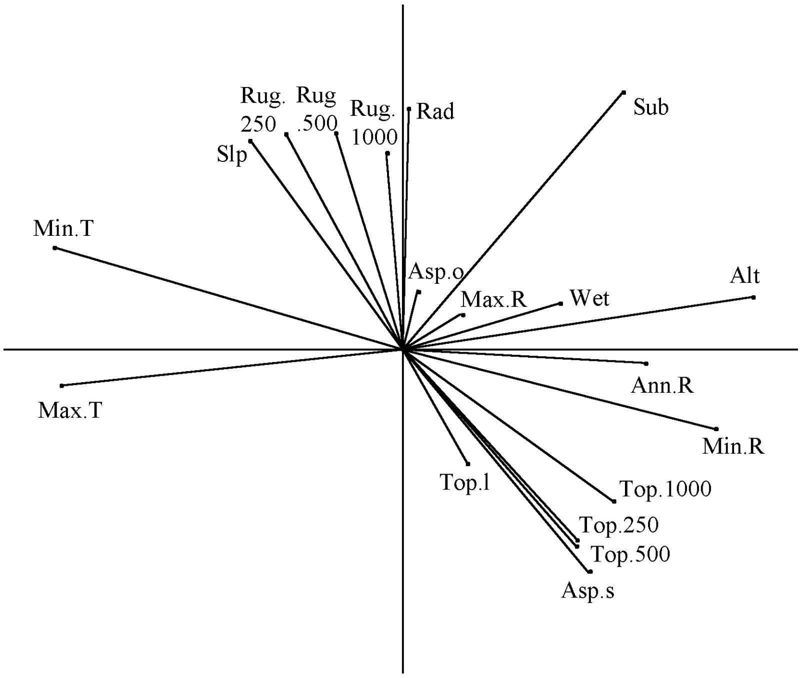

Fig. 5. First two axes of 4-dimensional ordination showing vectors representing environmental gradients in floristic composition. Refer to Table 8 for key to abbreviations.

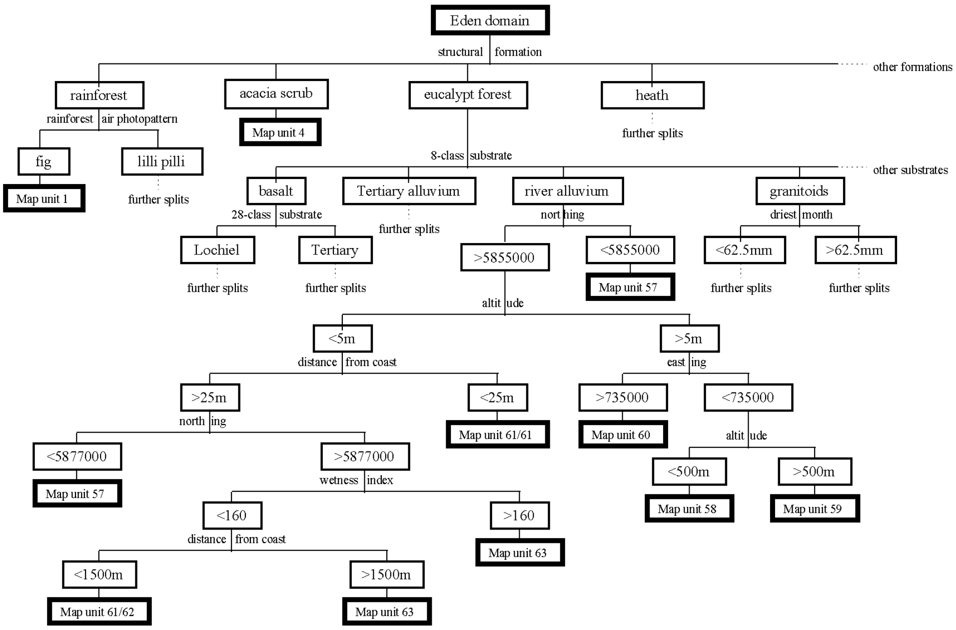

Fig 6. Principal nodes and branches in the decision tree model.

The spatial variables that were most frequently invoked in decision rules were major structural formations (aerial photopattern) and 8-class parent material (Table 9), reflecting their position high in the hierarchy of the decision tree (Fig. 6). Other variables invoked frequently in rules included elevation, mean annual precipitation, mean precipitation of the driest and wettest month, 28-class parent material, mean maximum temperature of the warmest month and topographic position within a 5 x 5 cell neighbourhood (Table 9). Slope, aspect indices and forest type were seldom invoked in decision rules. The frequency with which environmental variables were invoked in decision rules generally reflected the strength of their correlation with floristic composition (Table 8 cf. Table 9). Parent material (8 classes) had a high frequency in decision rules, but a lower ranking correlation with floristic composition. This may reflect the loss of information which occurred with the ordinal transformation of substrate classes that was necessary for vector fitting. Table 10 gives some examples to illustrate different rules used in mapping.

Table 9. Frequency with which spatial variables were invoked in decision rules.

Spatial Variable	% decision rules with variable
Terrain	
Altitude	84
Slope	4
Sine Aspect Index	1
Ordinal Aspect Index	1
Solar Radiation Index	19
Wetness Index	18
Local Topographic Position (S)	6
Neighbourhood Topographic Position (250 m)	22
Neighbourhood Topographic Position (500 m)	11
Neighbourhood Topographic Position (1000 m)	20
Neighbourhood Topographic Roughness (250 m)	13
Neighbourhood Topographic Roughness (500 m)	7
Neighbourhood Topographic Roughness (1000 m)	19
Climate	
Annual Rainfall	64
Rainfall of Wettest Month	57
Rainfall of Driest Month	66
Minimum Temperature of Coldest Month	36
Maximum Temperature of Hottest Month	16
Substrate	
8-class Parent Material	93
28-class Parent Material	48
106-class Parent Material	17
Land cover	
Vegetation Structure	100
Forest Types	1
Location	
Distance from Coast	10
Easting	10
Northing	15

Table 10. Example decision rules.

IF Vegetation Formation = eucalypt forest
    AND Parent Material (8 class) = basalt
    AND Parent Material (28 class) = Devonian basalt
    AND Annual rain ≤ 900 mm
THEN map unit = 19

IF Vegetation Formation = eucalypt forest
    AND Parent Material (8 class) = granitoids
    AND Driest month <= 62.5 mm
    AND Altitude ≤ 435 m
    AND Driest month > 50.5 mm
    AND Roughness (1000 m) ≤ 36.5 m
    AND Driest month ≤ 56.5 mm
    AND Parent Material (28 class) = Gabo adamellite OR Wallagaraugh adamellite
    AND Annual rain ≤ 922.5 mm
    AND Roughness (250 m) ≤ 5.5 m
THEN map unit = 26

IF Vegetation Formation = eucalypt forest
    AND Parent Material (8 class) = granitoids
    AND Driest month ≤ 62.5 mm
    AND Altitude ≤ 435 m
    AND Driest month > 50.5 mm
    AND Roughness(1000 m) ≤ 36.5 m
    AND Driest month ≤ 56.5 mm
    AND Parent Material (28 class) = Gabo adamellite OR Wallagaraugh adamellite
    AND Annual rain ≤ 922.5 mm
    AND Roughness (250 m) > 5.5 m
THEN map unit = 46A

IF Vegetation Formation = eucalypt forest
    AND Parent Material (8 class) = granitoids
    AND Driest month ≤ 62.5 mm
    AND Altitude ≤ 435 m
    AND Driest month > 50.5 mm
    AND Roughness (1000 m) ≤ 36.5 m
    AND Driest month > 56.5 mm
    AND Parent Material (106 class) = Dgbb OR Dgic OR Dgkk OR Dgpp OR Dgur
    AND Topographic position (250 m) ≤ 72.5 m
    AND Topographic position (500 m) ≤ 98.5 m
THEN map unit = 17

IF Vegetation Formation = eucalypt forest

Table 10. cont.

AND Parent Material (8 class) = granitoids
AND Driest month £ 62.5 mm
AND Altitude > 435 m
AND Altitude ≤ 796 m
AND Annual rain > 954 mm
AND Parent Material (28 class) = granodiorite
AND Altitude ≤ 643.5 m
AND Parent Material (106 class) = Dgdy OR Dgkk
AND Altitude > 492 m
AND Wetness index > 126
THEN map unit = 13

IF Vegetation Formation = eucalypt forest
AND Parent Material(8 class) = high quartz sediments OR rhyolite
AND Altitude ≤ 372.5 m
AND Annual rain ≤ 911.5 mm
AND Topographic position (1000 m) ≤ 149.5 m
AND Parent Material (28 class) = Adaminaby sandstone OR rhyolite
AND Driest month > 52.5 mm
AND Maximum temperature > 25.5°C
AND Wetness index > 141
THEN map unit = 13

IF Vegetation Formation = eucalypt forest
AND Parent Material (8 class) = low quartz sediments
AND Parent Material (106 class) = Db
AND Driest month ≤ 58.5 mm
AND Maximum temperature ≤ 25.1°C
AND Topographic position (250 m) ≤ 76 m
AND Solar radiation index ≤ 115
THEN map unit = 13

IF Vegetation Formation = eucalypt forest
AND Parent Material(8 class) = tertiary alluvium
AND Easting > 725000
AND Maximum temperature ≤ 23.6°C
AND Wetness index > 156.5
THEN map unit = 37

The decision rules were implemented on the spatial data layers to produce the vegetation map (inside back cover). Floristic assemblages 61 and 62 were mapped as a mosaic because stands of assemblage 62 were restricted to narrow beach strands and too small to map separately from adjoining stands of assemblage 61 at a scale of 25 m pixels. The map was printed at 1:100 000 scale and is available digitally at 25 m pixel scale on licence (GIS manager, NSW National Parks and Wildlife Service).

Distribution, extent, depletion and reservation of floristic assemblages

Maps in the Appendix show the location of samples assigned to each floristic assemblage and the distribution of their map units excluding areas cleared before 1994 are shown on the vegetation map (inside back cover). Rainforests are scattered in small patches throughout the coastal and tableland ranges, but rarely occur in low relief parts of the hinterland and tableland (Fig. 7g). Mesic eucalypt forests are widespread on the tableland range, more scattered on the coast and hinterland and absent from the rainshadow areas of the lowland valleys and Monaro Tableland (Fig. 7a). Intermediate eucalypt forests occur mainly on the coastal ranges (Fig. 7b). Warm temperate dry grassy eucalypt forests occupy the lowland rainshadow valleys (Fig. 7f), while related forests occur in the hinterland (Fig. 7e). Cool temperate dry grassy forests and woodlands and treeless grasslands (Fig. 7d) occupy the low relief rainshadow areas of the Monaro Tableland. Dry shrubby eucalypt forests are widespread in the coastal region and hinterland, but become more scattered on the tableland range and they are very rare in the rainshadow areas of lowland valleys and the tableland (Fig. 7c). Heathlands and scrubs are restricted to small areas on exposed coastal and tableland sites or specialised habitats in the hinterland such as riparian zones or rocky outcrops (Fig. 7i). Wetlands are also restricted to small patches, either in estuaries, on floodplains or broad headwater valleys in the southern coast and hinterland, and the eastern edge of the Monaro Tableland (Fig. 7h).

The predicted pre-1750 extent of floristic assemblages varies from more than 40 000 ha (map units 13, 15, 19 and 24) to less than 100 ha (units 1, 5, 51, 65, 66 and 69). The latter include rainforests, scrub on rocky outcrops and estuarine wetlands (Table 11). Habitat loss due to vegetation clearing has affected floristic assemblages unevenly. By 1994 some floristic assemblages had been depleted by more than 90%, while others remain at close to their original extent (Table 11). The floristic assemblages most depleted by clearing are in the Bega and Towamba valleys (18, 19, 20, 21, 39 & 40), on the Monaro Tableland (22A, 22B, 23A, 23B, 24 & 59) and along the coastal strip (36 & 60). The remaining area of these units is largely on private or leasehold land (Table 11). Reservation status was also highly biased (Table 11, Fig. 8). Floristic assemblages typically inhabiting steep, infertile terrain (e.g. map units 25, 49, 50, W1–W6) had high proportional reservation, while those found in low relief, fertile terrain had very low proportional reservation (e.g. 20, 21, 22A, 22B, 60).

Map validation

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

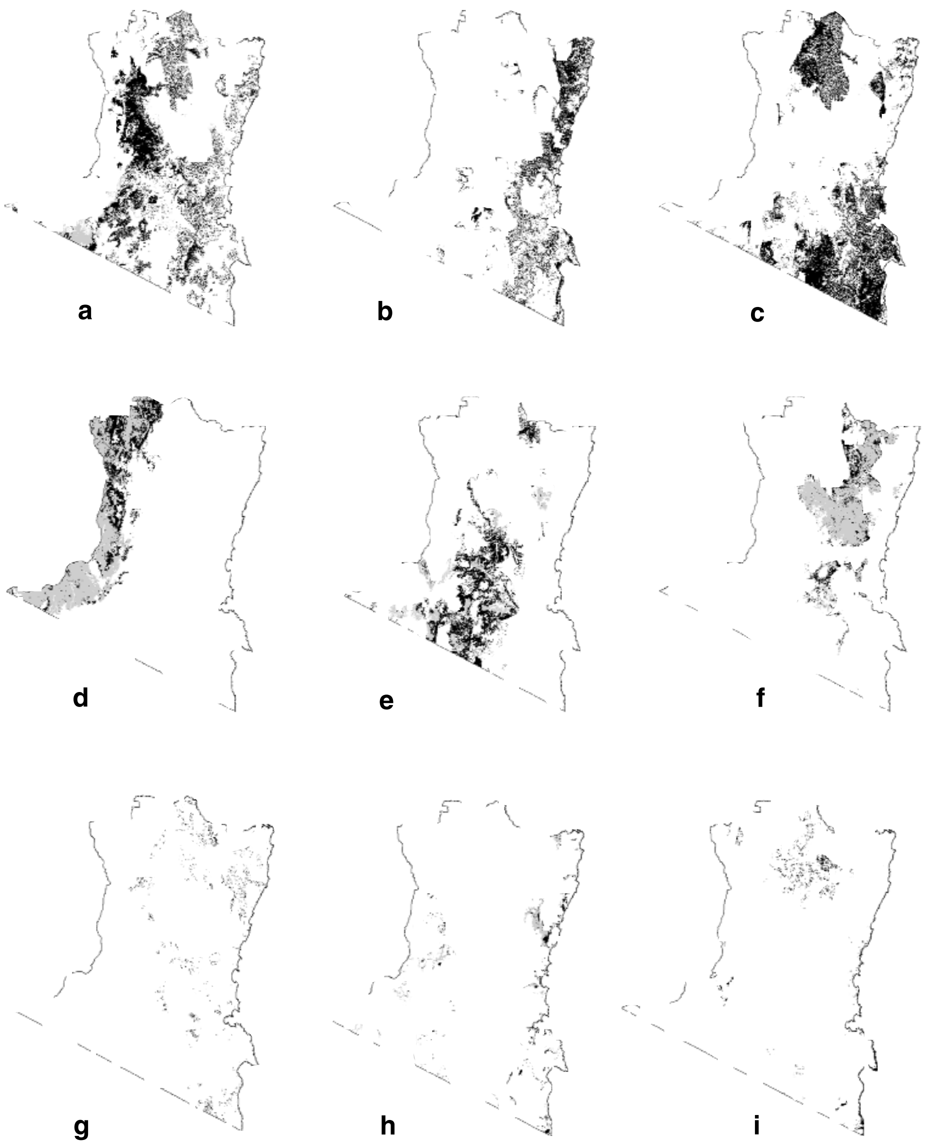

Fig. 7. Extant (black) and former (grey) distributions of a) mesic eucalypt forests (map units 9–17), b) intermediate dry forests (map units 2, 3, 32–34, 36, 37 and W6), c) dry shrubby forests (map units 25, 41–50, W1–W3 and W5), d) dry grassy tableland assemblages (map units 22–24 and W4), e) dry grassy hinterland forests (map units 26–31 and 35), f) dry grassy coastal valley forests (map units 18–21), g) rainforests (map units 1, 5–8), h) wetlands (map units 38–40, 57–60 and 63–70), and i) scrubs and heathlands (map units 4, 51–56, 61 and 62).

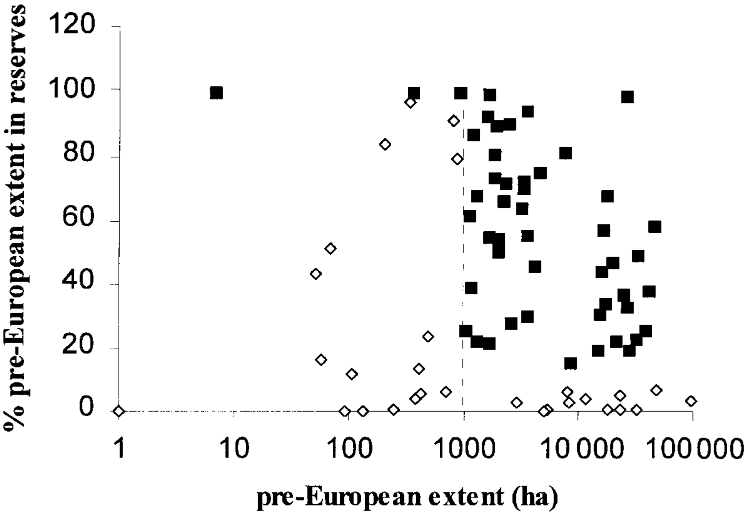

Fig. 8. Representation of map units in conservation reserves (Nature Reserves, National Parks and Flora Reserves). Broken line represents the JANIS (1996) threshold discriminating the general target for reservation of 15% of pre-european extent from the special target of 100% for rare units less than 1000 ha in pre-european extent. Open symbols show assemblages that do not meet relevant target, filled symbols show assemblages that do meet target.

Mean sampling density within a 5 km radius varied from less than 0.1 samples.km^{-2} extant native vegetation to more than 7 samples.km^{-2}. Sampling density was lowest (< 0.2 samples.km^{-2}) in: tableland remnants near Kybean and Craigie; inaccessable wilderness in the upper Brogo River catchment; and areas of State Forest south and north-east of Narrabarba, and in the upper Genoa River area adacent to the Victorian border (Fig. 9). The highest levels of sampling density (> 1 sample.km^{-2}) were in National Parks on the tableland range in the Coolangubra-Nalbaugh and upper Tantawangalo Creek areas, the Egan Peaks-Yowaka area west of Pambula; around Mt Waalimma near the Victorian border; and in privately owned remnant vegetation in the Bega valley (Fig. 9).

The 154 samples withheld from modelling for accuracy quantification represented map units 13, 14, 15, 31, 32, 33, 34, 37, 42, 46A, 46B, 47, 49, 53, 61, 62, W1 and W6. Overall map accuracy varied from 72% within 100 m to 96% within 1 km (Fig. 10). At the average spatial scale of planning units used in the Comprehensive Regional Assessment (100 ha forestry coupes and subcatchments), overall map accuracy was 93%. Thus, based on the 154 validation samples, there was a 93% chance that a planning unit selected to represent a particular map unit actually contained some of that map unit. Gains in accuracy increased at a decreasing rate with increasing neighbourhood size. The most accurately mapped assemblages included map units 35, 42, 53 and 61, while map unit 13 was the least accurately mapped. Many of the less widespread map units excluded from validation were modelled principally using aerial photograph interpreted spatial layers (e.g. rainforests, heaths, swamps). It was thus assumed that these units were mapped with reasonable reliability.

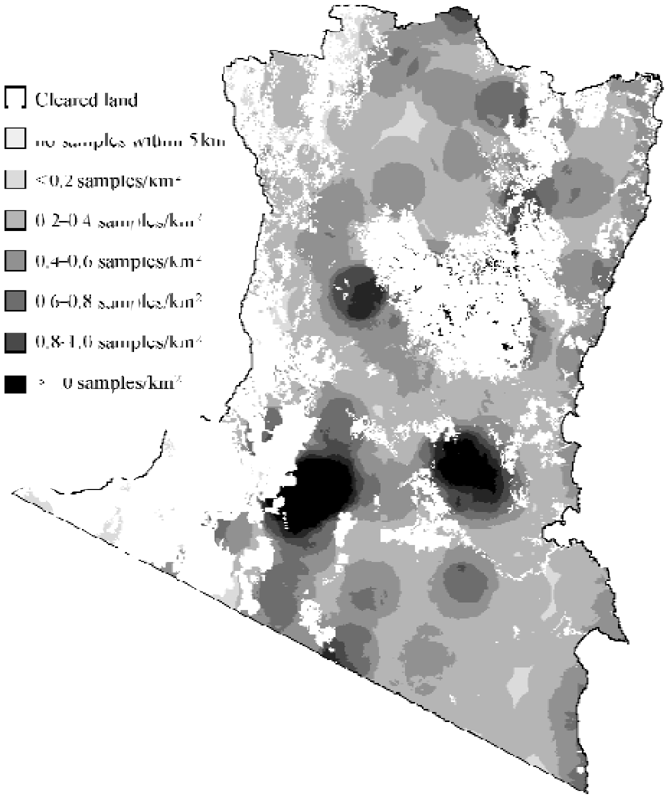

Fig. 9. Map reliability as represented by the mean number of samples per square kilometre of extant native vegetation within circular neighbourhoods of 5 km radius.

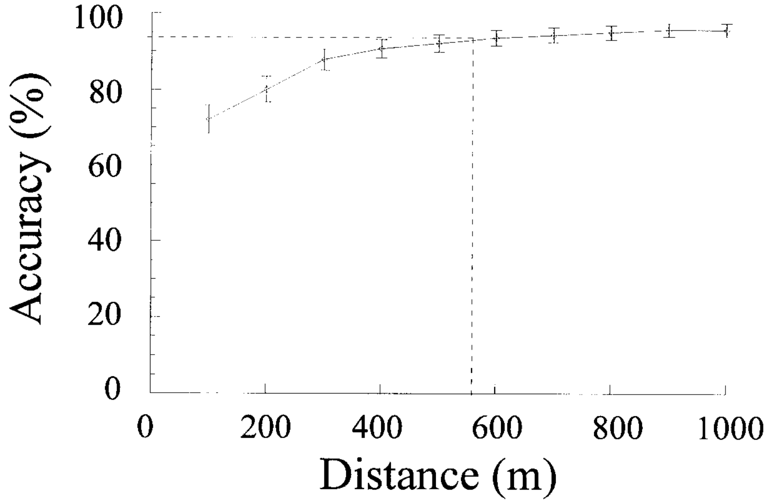

Fig. 10. Accuracy assessment of the vegetation map at varying spatial scales. Accuracy is the percentage of samples for which the floristic assemblage matched a mapped unit within varying distances of its location. Error bars are standard errors of the binomial distribution. Dotted line indicates the average spatial scale of planning units used in the Comprehensive Regional Assessment (100 ha).

Table 11. Pre-1750 extent of floristic map units, their depletion and representation on various land tenure classes as of 1st April 1999.

Floristic Assemblage	Pre1750 extent (ha)	Extant area 1994 (ha)	% depleted	National Parks & Nature Reserves (ha)	Flora Reserves (ha)	State Forest (ha)	State Forest plant-ation	Reserved Crown Land (ha)	Other Crown Land (ha)	Leased Crown Land (ha)	Private Land (ha)
1 Dry Rainforest	70	63	9	36	0	0	0	0	0	3	24
2 Myanba Dry Scrub Forest	334	334	0	323	0	0	0	0	0	0	10
3 Rocky Tops Dry Scrub Forest	1205	1205	0	1043	0	136	2	4	0	0	22
4 Acacia Scrub	3623	3585	1	3416	0	0	0	0	1	0	168
5 Bunga Head Rainforest	7	7	0	7	0	0	0	0	0	0	0
6 Coastal Warm Temperate RF	4160	4143	0	1910	169	1626	3	19	1	0	415
7 Hinterland Warm Temperate RF	1883	1878	0	1521	48	184	0	6	5	0	115
8 Cool Temperate Rainforest	874	844	3	696	20	94	0	0	0	1	35
9 High Mountain Wet Layered Forest	2267	1815	20	1489	124	131	0	0	8	0	63
10 Mountain Wet Layered Forest	20183	18091	10	9444	15	5138	32	148	21	245	3048
11 Tantawangalo Wet Shrub Forest	809	808	0	741	0	59	0	4	0	0	4
12 Mountain Wet Fern Forest	2322	2279	2	1666	22	508	8	12	0	1	64
13 Hinterland Wet Fern Forest	45986	43190	6	26677	555	8980	38	200	79	100	6562
14 Hinterland Wet Shrub Forest	27252	26169	4	8885	150	12860	0	364	74	17	3820
15 Mountain Wet Herb Forest	41575	30895	26	15612	560	10365	296	108	35	78	3841
16 Basalt Wet Herb Forest	14961	12263	18	3537	27	3100	149	104	39	295	5011
17 Flats Wet Herb Forest	3572	2949	17	1070	34	379	60	20	0	1	1385
18 Brogo Wet Vine Forest	8705	5046	42	1348	29	101	0	1	1	11	3555
19 Bega Wet Shrub Forest	48885	17959	63	3336	17	1026	133	37	31	37	13342

Table 11. cont.

Floristic Assemblage	**Pre1750 extent (ha)**	**Extant area 1994 (ha)**	**% depleted**	**National Parks & Nature Reserves (ha)**	**Flora Reserves (ha)**	**State Forest (ha)**	**State Forest plant-ation**	**Reserved Crown Land (ha)**	**Other Crown Land (ha)**	**Leased Crown Land (ha)**	**Private Land (ha)**
20 Bega Dry Grass Forest	32639	4429	86	275	0	20	25	27	3	12	4066
21 Candelo Dry Grass Forest	18015	1578	91	93	0	0	0	2	2	0	1481
22A Monaro Dry Grass Forest	11860	8222	31	527	0	17	0	88	5	643	6942
22B Numeralla Dry Shrub Woodland	5408	3611	33	1450	0	0	1	133	100	630	1298
23A Monaro Grassland	5096	311	94	0	0	0	0	0	0	1	310
23B Monaro Basalt Grass Woodland	23473	3395	86	109	0	82	234	107	0	32	2831
24 Subalpine Dry Shrub Forest	94924	26520	72	3589	8	1616	443	214	93	2546	18011
25 Sandstone Dry Shrub Forest	1140	821	28	697	28	95	0	0	0	0	0
26 Tableland Dry Shrub Forest	28011	16080	43	5424	284	6733	99	56	0	231	3252
27 Waalimma Dry Grass Forest	1324	1324	0	294	0	1031	0	0	0	0	0
28 Wog Wog Dry Grass Forest	1304	922	29	881	1	13	3	0	0	0	23
29 Nalbaugh Dry Grass Forest	2597	1937	25	711	2	875	78	3	0	12	256
30 Wallagaraugh Dry Grass Forest	1663	914	45	356	7	311	13	1	0	0	226
31 Hinterland Dry Grass Forest	33040	27700	16	16161	119	6275	281	113	0	50	4700
32 Coastal Foothills Dry Shrub Forest	24738	23614	5	9069	45	9123	0	729	147	25	4475
33 Coastal Range Dry Shrub Forest	16498	16336	1	9379	221	5614	19	15	32	5	1051
34 Coastal Gully Shrub Forest	17576	15289	13	5963	0	3913	0	201	109	46	5057
35 Escarpment Dry Grass Forest	38487	24423	37	9653	35	979	418	443	19	109	12768
36 Dune Dry Shrub Forest	1055	646	39	319	0	4	0	47	19	0	256
37 Lowland Gully Shrub Forest	15520	14685	5	4797	486	7699	0	81	21	6	1595

Floristic Assemblage	Pre1750 extent (ha)	Extant area 1994 (ha)	% depleted	National Parks & Nature Reserves (ha)	Flora Reserves (ha)	State Forest (ha)	State Forest plant-ation	Reserved Crown Land (ha)	Other Crown Land (ha)	Leased Crown Land (ha)	Private Land (ha)
38 Southern Riparian Scrub	490	441	10	116	168	42	9	0	0	0	106
39 Northern Riparian Scrub	693	447	35	44	0	2	6	0	2	2	393
40 Riverine Forest	249	197	21	1	0	1	0	0	0	0	195
41 Mountain Intermediate Shrub Forest	1878	1877	0	1376	196	243	0	3	0	6	54
42 Inland Intermediate Shrub Forest	21918	21429	2	4791	959	14952	1	11	22	2	692
43 Mountain Sandstone Shrub Forest	2497	2484	1	2249	17	63	0	0	0	0	154
44 Foothills Dry Shrub Forest	3337	3152	6	2322	28	689	67	0	0	0	45
45 Mountain Dry Shrub Forest	2040	1930	5	1023	71	464	17	0	0	1	354
46A Timbillica Dry Shrub Forest	22922	22797	1	1167	2345	18720	13	11	0	0	542
46B Lowland Dry Shrub Forest	16461	15428	6	7355	3	5165	8	447	100	0	2350
47 Eden Dry Shrub Forest	17892	17246	4	12145	250	3740	16	99	69	1	927
48 Mumbulla Dry Shrub Forest	4617	4576	1	3492	0	796	0	69	1	0	217
49 Coastal Dry Shrub Forest	32846	32240	2	7382	1063	20254	0	55	61	1	3423
50 Genoa Dry Shrub Forest	3697	3022	18	2037	37	737	11	0	0	1	200
51 Rhyolite Rock Scrub	51	51	0	22	19	7	0	0	0	0	3
52 Mountain Rock Scrub	202	202	0	170	17	9	1	0	0	0	6
53 Montane Heath	3248	3025	7	2391	0	3	19	60	10	121	420
54 Mt Nadgee Heath	371	371	0	371	0	0	0	0	0	0	0
55 Coastal Lowland Heath	1618	1582	2	1493	0	7	0	0	4	0	78
56 Hinterland Heath	385	385	0	16	68	286	0	0	0	0	15

Table 11. cont.

Floristic Assemblage	**Pre1750 extent (ha)**	**Extant area 1994 (ha)**	**% depleted**	**National Parks & Nature Reserves (ha)**	**Flora Reserves (ha)**	**State Forest (ha)**	**State Forest plant-ation**	**Reserved Crown Land (ha)**	**Other Crown Land (ha)**	**Leased Crown Land (ha)**	**Private Land (ha)**
57 Lowland Swamp	1662	1589	4	912	146	407	0	2	0	3	118
58 Swamp Forest	1190	1056	11	463	4	539	9	1	0	0	39
59 Sub-Alpine Bog	8188	1897	77	492	1	259	40	14	17	62	1013
60 Floodplain Wetlands	8537	2774	68	267	0	239	0	185	123	10	1951
61&62 Coastal Scrub & Beach Strand	2015	1358	33	1091	0	0	0	52	61	0	154
63 Estuarine Wetland Scrub	2970	956	68	123	0	15	0	55	21	3	738
64 Saltmarsh	411	295	28	62	0	4	0	33	49	15	133
65 River Mangrove	1	1	19	0	0	0	0	0	0	0	1
66 Grey Mangrove	92	60	35	13	0	1	0	1	0	0	45
67 Seagrass Meadow *(Halophila)*	108	108	-	13	0	3	0	0	0	0	15
68 Seagrass Meadow *(Posidonia)*	130	130	-	0	0	0	0	1	0	0	7
69 Seagrass Meadow *(Ruppia)*	56	56	-	10	0	2	0	0	0	0	20
70 Seagrass Meadow *(Zostera)*	423	423	-	24	0	5	0	4	1	0	74
W1 Wadbilliga Dry Shrub Forest	27347	27336	0	26913	0	65	0	0	109	39	211
W2 Wadbilliga Range Shrub Forest	933	933	0	933	0	0	0	0	0	0	0
W3 Wadbilliga Heath Forest	1683	1683	0	1671	0	0	0	0	0	2	10
W4 Kydra Flats Grass Forest	3386	3098	9	2434	0	106	0	48	51	108	350
W5 Wadbilliga Gorge Dry Forest	7938	7423	6	6446	0	3	0	0	6	0	968
W6 Wadbilliga River Valley Forest	1952	1947	0	1754	0	0	0	0	0	0	194
Total	809476	552284	32	246083	8398	156916	2554	4439	1550	5511	126295

Discussion

Biogeographic and environmental relationships of vegetation

The Eden region is centrally placed in Australia's unique eucalypt forest biome in a zone of climatic transition where subtropical and warm and cool temperate floras are juxtaposed (Beadle 1981, Keith & Sanders 1990). Subtropical elements of the regional flora are largely confined to a coastal strip extending north from Bega and represented on a continental scale by Nix's (1982) Torresian bioclimatic zone. The diminution of the subtropical flora with latitude is illustrated by numerous plant species, including many characteristic of rainforest habitats, reaching their southern limits of distribution in the Eden region (Keith 1990, Keith & Ashby 1992). Broad-scale latitudinal trends in species composition have been documented in both rainforests (Webb et al. 1984) and heathlands (Specht 1979). Turnover in eucalypt species composition occurs in relation to gradients of temperature and rainfall across south-east New South Wales (Austin et al. 1984).

The majority of the Eden region supports a temperate flora and is represented on a continental scale by Nix's (1982) Bassian bioclimatic zone, which becomes increasingly restricted to the tablelands further north. The temperate flora contains many plant taxa with southern Gondwanan origins (Keith & Sanders 1990). The cool temperate component of this flora is characterised by mesic elements strongly represented in floristic assemblages 8–17 and W4. Some widespread characteristic species include *Eucalyptus fastigata, E. obliqua, E. cypellocarpa, Bedfordia arborescens, Olearia argophylla, Blechnum nudum, Polystichum proliferum* and *Stellaria flaccida*. Their structural features include tall straight eucalypt dominants (except Cool Temperate Rainforest) and dense understories comprising various mixtures of ferns, mesophyllous shrubs and forbs. Subcanopies of small mesophyllous trees are essentially unique features of this group of assemblages. These mesic assemblages are widespread on elevated parts of the region that experience both high rainfall and cool temperatures (Fig. 7). Eight (map units 8–12, 15, 16 and W4) of these 11 mesic assemblages occur principally above 500 m elevation, while the two that are widespread below 400 m elevation (map units 13 and 14) are restricted to topographically sheltered sites in coastal and hinterland parts of the region.

A very different cool temperate flora inhabits elevated parts of the region that experience cool temperatures but low rainfall. This climatic regime typifies the Monaro Tableland, an extensive low-relief inclined plateau in a rainshadow that stretches from the escarpment range westward beyond the study area to the Australian alps (Costin 1954). The most widespread floristic assemblages here are dry grassy eucalypt forests and woodlands (map units 22–24, Fig. 7). Widespread characteristic species include *Eucalyptus pauciflora, E. dives, E. dalrympleana, E. viminalis, Poa sieberiana, Themeda australis* and *Asperula conferta*. Structurally these dry cool temperate assemblages comprise an open canopy of small eucalypts (except in Monaro Grassland) with an open or non-existent shrub stratum and continuous ground stratum dominated by grasses with interstitial herbs. Similar vegetation formations occupy elevated rainshadows of the Great Dividing Range as far north as the New England Tableland and south at lower elevations in Victoria and the Tasmanian midlands (e.g. Fensham 1989). All of these regions have been exploited for their pastoral resources.

A predominantly dry warm temperate flora dominates the coast and hinterland. The driest parts of this zone are the large rainshadow valleys of the Bega and Towamba Rivers, which are dominated by dry grassy eucalypt forests (map units 18–21). Widespread characteristic species include *Eucalyptus tereticornis, E. baueriana, E. melliodora, Eragrostis leptostachya, Dichanthium sericeum, Themeda australis* and *Desmodium brachypodum*. The dominant eucalypts may form a tall but open canopy above an open stratum of smaller *Acacia* trees. The shrub stratum is variable, but most developed on sites with either higher rainfall or greater topographic shelter (map units 18 and 19). A continuous cover of grasses and interstitial herbs dominates the ground stratum. Distance from the coast and cold air drainage result in low winter temperatures, even though summer maxima may be high. Consequently, some elements of the dry cool temperate flora (e.g. *E. pauciflora, E. dives*) occur sporadically in the coastal rainshadow valleys (e.g. near Candelo and Wolumla). Similar rainshadow valleys are scattered to the north (e.g. Araluen valley, Cumberland Plain, Hunter valley), although their occurrence is limited further south, with the Gippsland Lakes district being the most physiographically similar valley. All of these regions have also been exploited for their pastoral resources.

Beyond the rainshadow valleys, the coast and hinterland are dominated by a variety of shrubby eucalypt forests, although mesic eucalypt forests (map units 13 and 14) and warm temperate rainforests (units 6 and 7) occupy the most sheltered parts of the landscape. Typical widespread species of the warm temperate shrubby eucalypt forests include *Eucalyptus sieberi, E. globoidea, Corymbia gummifera, Platysace lanceolata, Epacris impressa, Leucopogon lanceolatus, Pultenaea daphnoides, Lepidosperma laterale* and *Lomandra multiflora*. Although all these assemblages share a sclerophyllous shrub stratum, their structural characteristics are variable. The tallest of the shrubby eucalypt forests (map units 32– 34, 37, 41, 42 and W2) occupy open gullies and less exposed slopes on the coastal ranges and hinterland. They may also occupy elevated sites on coastal ranges or mountain slopes where rainfall is high relative to most of the coast and hinterland. *Eucalyptus obliqua* and *E. muelleriana* are frequently among the most abundant canopy species with *E. sieberi*, while the shrub stratum may be dominated by Asteraceous and Fabaceous genera such as *Ozothamnus, Cassinia, Acacia, Daviesia* and *Pultenaea*. Ridges and more exposed slopes, especially on quartz-rich, low fertility substrates, support shorter forests dominated by *E. sieberi*, either in pure stands or with *E. agglomerata, E. consideniana, E. globoidea* or *C. gummifera*. Their prominent, open shrub strata are dominated by scleromorphs such as *Lomatia ilicifolia, Epacris impressa, Leucopogon lanceolatus*, *Podolobium ilicifolium* and *Platysace lanceolata* and a sparse groundcover of scleromorphic graminoids (map units 36, 43–50, W1, W3 and W5). Lower relief terrain in the hinterland supports dry eucalypt forest assemblages in which a grassy ground stratum may attain greater cover than the shrub strata (map units 25–31 and 35). Characteristic species here include *E. globoidea, E. maidenii, E. angophoroides, Poa meionectes*, *Senecio* sp. E and *Hibbertia obtusifolia.*

Variation in topography and soils superimposes local vegetation patterns on coarse scale climatic trends. The nutrient and moisture statuses of soils interact to produce complex environmental relationships with vegetation in the Eden region (Keith & Sanders 1990). Soil nutrient status varies between lithological substrates and across the catenary profile (Kelly & Turner 1978, Turner et al. 1978). Soil moisture varies with regional precipitation patterns, topographic exposure and terrain flows (Keith & Sanders 1990). In general, sheltered mesic sites with relatively high soil fertility support rainforest. Mesic eucalypt forests are found on moister, more fertile soils than sclerophyllous eucalypt forests, while sclerophyllous forests with grassy understories are generally associated with more fertile soils than those with shrub-dominated understories (Keith & Sanders 1990). These general relationships are well known in other parts of eastern Australia (e.g. Beadle 1954, Costin 1954, Keith 1994, Le Brocque & Buckney 1997).

Many of the region’s floristic assemblages are restricted to localised habitats defined by specialised topographic and soil conditions. These include: rainforests restricted to relatively fertile soils in very sheltered gullies (map units 5–8) or upper slopes (map unit 1); riparian scrubs and forest restricted to narrow bands of river alluvium (map units 38–40); scrubs restricted to skeletal soils on rocky outcrops (map units 51 and 52); heathlands restricted to exposed slopes on quartz-rich low-fertility soils (map units 53–56); freshwater swamps restricted to periodically waterlogged soils (map units 57–60); scrub and grassland restricted to maritime sands (map units 61 and 62); and estuarine wetlands restricted to inter-tidal and sub-tidal zones (map units 63–70). Some vegetation patterns are related to the distribution of parent materials. For example, two of the mesic eucalypt forest assemblages (map units 13 and 14) are found in similar climatic and topographic habitats, but one is found primarily on granitoid substrates and the other is found primarily on metasedimentary substrates. Some parent materials support distinctive groups of floristic assemblages (e.g. map units 16, 22A and 22B are primarily restricted to basalt), while several assemblages have high fidelity to one type of parent material (e.g. map units 4, 51, 62).

Recurring landscape fires influence spatial patterns in vegetation through time. It seems likely that fires are at least partly responsible for the restriction of rainforest and related scrubs (map units 1–8) to small patches in the landscape (Floyd 1990). General models of the dynamics of temperate wet sclerophyll forests suggest several successional pathways are possible under alternative fire regimes, with fire exclusion eventually leading to rainforest development and high frequency fire regimes leading to the elimination of eucalypts and dominance of shrubs (Ashton 1981, Noble & Slatyer 1981). Models and empirical studies of heathland and upland swamps similarly suggest elimination of certain functional groups of plant species under sustained high and low frequency fire regimes, respectively (Keith 1991, Keith & Bradstock 1994, Bradstock et al. 1997). Shifts in floristic composition including local extinctions may occur in response to fire regimes. However, the spatial patterns in composition attributable to disturbance history are generally smaller than those attributable to physical environmental factors such as soil texture and moisture, at least in the short term (Bradstock et al. 1997).

Conservation

Eucalypt forests are physiognomically, structurally and floristically unique to Australia (Beadle 1981, Ovington 1983). Other temperate forested regions of the world support rainforests, deciduous forests or coniferous forests (Ovington 1983). The Eden region has a diverse range of eucalypt forests and is placed centrally in the east Australian eucalypt forest belt that spans 15° latitude from south-east Queensland to south-east Tasmania. Alpha species richness values for mesic and dry grassy eucalypt forests in Eden are among the highest in the world recorded for temperate forests (e.g. Whittaker & Woodwell 1969, Glen-Lewin 1975, Peet 1978, Kirkpatrick 1984, Cawe & McKenzie 1989, Wardell-Johnson et al. 1989, Fensham 1989). Sclerophyllous shrubby forests and heathlands exhibit intermediate species richness in the Eden region compared with those elsewhere (Whittaker 1979, Gimingham et al. 1979, George et al. 1979, Rice & Westoby 1983, Cowling 1983, Keith 1994). At landscape scale, the Eden region has a large native flora relative to forested regions of similar size at similar latitudes, but the flora is small compared to southern mediterranean regions and some eucalypt forests regions further north (Keith et al. 1999).

Threatening Processes

A range of threatening processes influence the conservation status of vegetation in the region (Appendix). These include habitat loss, certain disturbance regimes, overgrazing, nutrification, habitat degradation due to human misuse and feral animal activity. Continuing habitat loss due to clearing affects vegetation close to developing coastal resort centres, dry grassy eucalypt forests in agricultural zones and other forest assemblages on the margins of these zones. Clearing and subsequent land use change usually results in irreversible loss of native vegetation and is almost entirely restricted to private tenures. Small-scale clearing occurs on public land for the construction of public facilities and access. Although the rate of clearing has slowed substantially since the early 20th century, losses are spread unevenly (Table 11) and the continuing loss of small vegetation remnants in the region is reducing some types of vegetation to very small proportions of their original extent. Some regrowth of native vegetation has occurred in marginal agricultural districts, but there are few examples where such vegetation has attained a structure and composition that closely resembles uncleared vegetation. In concert with feral predators, continuing habitat loss is correlated with several regional extinctions of fauna (Lunney & Leary 1988).

Disturbance regimes involving fires and logging may threaten populations of certain species depending on how the timing and type of disturbance events interact with their life history (Whelan 1995, Williams et al. 1995, Keith 1996). Logging is not carried out in conservation reserves, but fires may occur across all land tenures. Rainforests are especially susceptible to intense wildfires which may result in major changes in structure and composition (Ashton & Frankenberg 1976, Floyd 1990) or elimination, as apparently occurred on Mt Darragh in 1942 (F. Carey pers. comm.). These effects may be exacerbated under higher fire frequency. In eucalypt forests, woodlands, scrubs and heathlands high frequency disturbance regimes may cause declines and local extinctions of some woody plant species. This effect is most conspicuous in species that depend on seed for regeneration (obligate seeders), but declines in resprouters may occur if high frequencies are sustained over several disturbance cycles (Keith 1996, Keith & Tozer 1997). Declines or elimination of certain eucalypts (particularly ashes) may occur if intervals between successive disturbances that kill standing trees are less than 20 years (Ashton 1981). Interactions between species, such as competitive effects of dense vegetative regrowth on seedling recruitment may exacerbate these effects. The existence of large stands of *Acacia dealbata* with sparse emergents of *Eucalyptus fastigata* and *E. nitens* near Nunnock River and Wog Wog Mountain lend tacit support for such fire effects within the region. Introduction of logging and associated soil disturbance and burning practices into the disturbance regime of production forests may cause additional effects (e.g. Dickinson & Kirkpatrick 1987). These disturbance regimes may result in increased relative abundance of fecund species such as *Eucalyptus sieberi* that establish rapidly and in greater numbers in exposed conditions relative to their competitors (Bridges 1983). Conversely, comparative studies on *Dicksonia antarctica* and associated epiphytes (Ough & Ross 1992) have shown that populations of other species may decline if plants are killed by logging treatments and require undisturbed conditions for establishment. Logging may also exacerbate the competitve elimination of some slower growing woody species, as their seedlings are deprived of light and perhaps other resources by fast-growing thicket-forming species such as some fern species and *Senecio linearifolius*. Although the densities of these opportunists may eventually decline, they may be replaced by taller, more persistent dense canopies such as *Bedfordia arborescens*. The role of these interactions in the failure of eucalypt regeneration in logged areas of mesic forest warrants further investigation.

Domestic cattle, sheep, feral and domestic goats and rabbits graze native vegetation, as do native herbivores. The impacts are likely to be greatest in remnants of grassland and dry grassy eucalypt forests and woodlands in and around the main pastoral districts (Bega and Towamba valleys and the Monaro Tableland). Grazing affects native plant species differentially according to interactions between their palatability, growth form and regeneration capacity. One of the most palatable native pasture species, *Themeda australis*, proliferates when grazing is excluded, particularly in response to summer rain, but may be eliminated under continued heavy grazing regimes (Vickery 1961). Forbs with erect growth forms are more prone to declines under grazing than those with rosette or prostrate growth forms, apparently because of the greater exposure of their buds to herbivory (McIntyre et al. 1995). However, grazing is one of several mechanisms that create gaps in grass canopies, which are an important requisite for seedling establishment in many species (Lunt 1991, Morgan 1997). These species may vary in the extent to which they exploit different kinds of gaps. In some cases this may provide opportunities for establishment of alien plant species, particularly if these are less palatable than native competitors. Nutrient enrichment, either through animal dung or direct pasture improvement may confer further advantages on alien species. Heavy grazing may exacerbate rates of soil erosion by increasing the exposure of soils to rainsplash and runoff as well as wind (Costin 1954). Such effects may be particularly evident after prolonged drought when regrowth capacity is diminished.

Nutrification may be associated with drift and runoff from pasture improvement or with more localised urban and rural developments. The impacts are usually expressed in the replacement of some native plant species with mesophyllous herbs, grasses and shrubs, many of which are introduced (e.g. Clements 1983). Scleromorphic shrubs are the most susceptible species to nutrification, either through direct toxicity effects or because they are eliminated by competitors with superior growth responses. Competitive relationships under varying nutrient regimes may also result in shifts in the relative abundance of native species. Groves et al. (1973), for example, found that *Poa labillardieri* showed a greater response to increased soil phosphorus and nitrogen than *Themeda australis*. The habitats most susceptible to nutrification include vegetation remnants in and around urban and rural developments and improved pastures, as well as riparian habitats and wetlands exposed to water runoff from these areas. Benson (1994), for example, observed higher levels of weed invasion along drainage lines in a *Poa labillardieri* tall tussock assemblage than in other Monaro grassland habitats.

Dumping and vandalism causes localised but significant habitat degradation near inhabited areas such as urban and rural centres and popular recreation sites. These threats are most significant for populations of rare plant species or floristic assemblages whose occurrences are concentrated in areas close to habitation (e.g. map units 36 and 61). Feral pigs are also associated with localised habitat degradation. Their intensive foraging activities cause major soil disturbance and varying levels of weed invasion, particularly in topographic flats in the south-west of the region. These sites support restricted floristic assemblages (map units 17, 30 and 58) and are likely to be important habitat resources for some native fauna. On parts of the Monaro Tableland, trampling by stock may have similar impacts on the soft organic soils of subalpine bogs (map unit 59).

Reservation and management

Management of conservation reserves is an important means of mitigating processes that threaten biodiversity. The reservation status of floristic assemblages was highly biased (Table 11, Fig. 8). Assemblages typically inhabiting steep, infertile terrain (e.g. map units 25, 41, 43, 47, 50, W1–W6) have more than two-thirds of their original extent represented in conservation reserves (Nature Reserves, National Parks and Flora Reserves). In contrast, assemblages found in low relief, fertile terrain have very low proportional reservation (e.g. Map Units 18, 19, 20, 21, 23A, 23B and 60). This kind of reservation bias has been demonstrated in other regions of New South Wales (Braithwaite et al. 1993, Pressey et al. 1996) and is apparently a world-wide phenomenon.

Many floristic assemblages have a relatively high proportion of their predicted pre-European occurrence represented in reserves. However, for assemblages with naturally restricted or highly depleted distributions, these proportions may amount to small areas and complete representation is considered a desireable goal for the conservation of biota within these units (JANIS 1996). Although a full appraisal of floristic assemblages in relation to criteria for a comprehensive, adequate and representative reserve system (JANIS 1996) is beyond the scope of this paper, two of the eight biodiversity conservation criteria are represented in Fig. 8. These criteria require that at least 15% of the pre-European extent of ecosystems be represented in reserves and that 100% of rare ecosystems (i.e. current area < 1000 ha) be represented in reserves. Nearly two-thirds of the map units currently meet these targets (Fig. 8). Most of those that do not are rare and some are below high tide mark, although a number of widespread assemblages (map units 18–24 and 60) have very low proportions (0–10%) of their distribution represented in reserves (Table 11). The poorly reserved assemblages are among the most species-rich in the region (Table 7), the most depleted by past clearing (Table 11) and the most threatened by continuing processes (Appendix). These features suggest that the conservation of map units 18–24 and 60 should be a very high priority. However, their fragmented distribution largely on freehold and leasehold lands and the degraded state of many stands impose substantial challenges for effective conservation. In some cases (e.g. map units 20, 21, 23A, 23B, 60), levels of depletion are so great that JANIS (1996) targets are unattainable unless an extensive restoration of cleared areas currently in production is implemented.

Acquisition of private lands for inclusion in the public reserve network will be limited by cost, but a high priority must be given to the few opportunities to formally reserve the most threatened assemblages. Although some significant unprotected stands of threatened assemblages remain adjacent to existing reserves, these stands are often transitional and do not represent the full range of variation within the respective units. Complementary off-reserve conservation measures are essential if loss and degradation of these vegetation types is to be mitigated. These measures include: community conservation projects; Voluntary Conservation Agreements (legally binding agreements between landholders and the state government to protect native habitat); private purchase and management of land for conservation; implementation of a regional vegetation management plan under the NSW Native Vegetation Management Act (1996); and declaration of critical habitat for threatened species and ecological communities under the NSW Threatened Species Conservation Act (1995). The last two mechanisms stem from recent legislation and are yet to be implemented in the Eden region. However, there has been evidence of progress on other measures since 1990. Recent examples include: the implementation of fauna and flora surveys in the Bega valley (Whelan & Hibberd 1992, Keith 1995); the operation of a vegetation management advisory service for farmers during 1995–1997 (J. Miles, pers. comm.); implementation of two Voluntary Conservation Agreements to protect stands of map units 19 and 21, respectively; and the purchase and management of a land parcel containing stands of map units 1 and 18 by the Bush Heritage Fund in 1996.

While protection from further habitat loss is a principal concern on private land, public land is largely exempt from clearing activities. Here, management of the disturbance regime is a major factor mediating the persistence of native plants and animals. On the public land estate most of the area outside reserves is managed for wood production. Within production forest there is a system of management zones that provide varying levels of protection from logging. In some of these zones (unproductive forest, scenic protection, flora protection, wildlife corridors and filter strips) logging is excluded or regulated at reduced intensity. Outside special management zones, protocols exist for the protection of certain habitats. Several naturally restricted floristic assemblages including some widely scattered in small stands are dependent on these measures to supplement low levels of representation in formal reserves (e.g. map units 17, 27, 30, 38 and 56), although in some cases the contribution is small. Within reserves, conservation is implemented primarily through the management of fire and visitor access, as well as rehabilitation works targeted at degraded locations.

Field identification of floristic assemblages

Floristic assemblages may be identified in the field by the co-occurrence of positive diagnostic species listed in the descriptions (Appendix). Positive diagnostic species are those that have high fidelity to a particular assemblage, i.e. high frequency and abundance relative to occurrences elsewhere (Table 4). Diagnostic species may be common or uncommon within their respective assemblages, but are always less common elsewhere. Examples include *Eucalyptus fraxinoides* and *E. ovata*, positive diagnostics for map units 41 and 58, respectively (Appendix). A species may be quite common in a particular assemblage, but may not be diagnostic of that unit if it is at least as common in several other units. These relatively ubiquitous species (e.g. *Eucalyptus sieberi*, *E. cypellocarpa*, Appendix) are less informative about the identity of a floristic assemblage at a given site.

The greater the number of diagnostic species identified in a particular stand, the more reliably a particular stand may be attributed to one of the floristic assemblages. The likelihood of membership of a stand to any given assemblage could be assessed statistically by using species frequency values to calculate the probability of finding a given combination of species in that assemblage. The probabilities of membership to alternative assemblages could thus be compared. If structural and habitat characteristics and stand location fall within the ranges specified for a particular assemblage (Appendix), this may be further evidence in support of a particular identification. Conversely, the presence of negative diagnostics and mismatches of other species, structural characteristics, habitat and distribution may be used to eliminate other possibilities from contention. Depending on available diagnostic species, definitive identification of vegetation at a given site may sometimes require sampling of full floristic composition and analysis with procedures such as those listed in Table 3. Although keys to floristic assemblages could be constructed (e.g. Outhred et al. 1985), we considered these to be inappropriate tools for field identification because they fail to consider variability within and between assemblages.

The continuous nature of variability in vegetation (Austin 1987) means that there will often be difficulty in assigning stands to classes, irrespective of how classes are defined. Furthermore, the classification and map of 79 vegetation units is a conservative representation of vegetation diversity for a coastal region of this size. Finer-scale analysis and recognition of more units at local scales could resolve some of the variability within units, particularly eucalypt forest assemblages. A finer-scale analysis will often be appropriate for assessments, planning and management of vegetation in local areas.

Map Accuracy

A range of factors is likely to influence the accuracy of the vegetation map. These include the comprehensiveness and evenness of sampling, characteristics of the vegetation classification, the accuracy of spatial data layers and the structure of the spatial model.

The comprehensiveness and evenness of sampling could be improved with additional sampling targeted at gaps (Table 1, Fig. 3, Fig. 9). The use of additional data from other surveys resulted in some areas being sampled at higher intensity than most other parts of the region. It may be expected that these areas are the most reliably mapped parts of the region (Fig. 9). Our recent sampling targeted at hitherto poorly surveyed areas (the Bega valley, Wallagaraugh catchment, Nungatta-upper Genoa area, Monaro Tableland and Numeralla area) would have improved map reliability and accuracy in those parts of the region. The least intensively sampled areas remaining include the dissected wilderness of the upper Brogo River (Wadbilliga National Park), parts of Nadgee, East Boyd and western Bondi State Forests, parts of the Monaro Tableland and a small part of the upper Towamba valley. However, notwithstanding possible refinements, the Eden region is now one of the most comprehensively surveyed regions in Australia and priorities for vegetation survey should lie elsewhere.

The characteristics of vegetation classifications should be driven largely by their purpose. Alternative vegetation classifications are possible, but it remains to be seen how different methods of classification and mapping affect the performance of alternative vegetation maps as surrogates for biodiversity. Nevertheless, the integration of quantitative field samples into the methodologies of both classification and mapping, and the relative stability of the classification since the earlier analysis by Keith & Sanders (1990) despite the inclusion of four times as many samples, suggest that the current classification and map are a robust representation of vegetation diversity in the region.

Inaccuracy in the spatial data layers may be responsible for some errors in vegetation mapping. During field work a number of small unmapped outcrops of various geological substrates (mainly basalt and metasediments) were discovered. While these were corrected on the digital substrate map before its use in modelling, other errors may await detection. Derived topographic variables such as slope, aspect, horizon azimuths (used in calculating radiation index) and wetness index are likely to deviate from field values more than raw altitude values because of their sensitivity to fine-scale topographic features. Climatic surfaces are possibly the least reliable of the spatial variables because of the sparse and uneven distribution of weather stations to calibrate predictions. Predicted mean temperatures and precipitation values are also sensitive to variation in observation periods between stations. Local climatic phenomena such as frost hollows may well have been under-represented in the climatic surfaces. We attempted to minimise these sources of error by using values from the spatial data layers to develop environmental relationships for mapping, rather than values measured or calculated from the field.

A wide range of models could be developed to provide an equally good fit to the sample data, but these may perform differently when evaluated against independent data. Procedures such as generalised linear models and generalised additive models have proved useful in the construction of distributional models for individual species (e.g. Austin et al. 1984, CSIRO 1996, Ferrier & Watson 1997, Elith et al. 1998). We chose a decision tree model structure because, although these may return slightly less accurate predictions from quantitative data, they have flexibility allowing the incorporation of qualitative expert knowledge into the mapping process. Arguably, alternative modelling approaches may have yielded a product of similar accuracy. Within a decision tree framework, many alternative structures offering a reasonable fit to the data are possible. With more time and more iterations in map checking, it may be possible to build a map that returns greater accuracy when evaluated against independent data.

The three approaches to map validation employed here (qualitative checking, description of map reliability and accuracy quantification) offer an overall measure of potential limitations discussed above. Qualitative checking is essential to correct the most simple and conspicuous inaccuracies that may arise in mapping. A description of map reliability alerts users to those areas subject to least survey effort, as well as providing some guidance for future sampling work. Accuracy quantification gives a minimal estimate of the likelihood that planning units of a given size actually contain a map unit that they may be selected to represent for some natural resource planning purpose. Validation is a much neglected component of mapping and is currently the subject of further research.

Acknowledgements

Fieldwork was carried out over a 12-year period with the assistance of Robyn Aitkin, David Albrecht, Elizabeth Ashby, Ross Bradstock, Nicholas Carlile, Michael Doherty, Annie Etheridge, Phil Gilmour, Tim Hager, Carole Helman, Meredith Henderson, Belinda Pellow, John Porter, Bob Pressey, Cathy Prideaux, Jackie Miles, Patsy Nagle, Jonathan Sanders, Dominic Sivertsen, Jonathan Smith, Heather Stone, Mark Tozer, Merin Tozer and Cathy Wilson. Use of data contributed by John Benson, Doug Binns, Steve Clark, Peter Clarke, John Dodson, Tim Fatchen and Bob Outhred is gratefully acknowledged. Jonathan Smith and Cathy Prideaux assisted with data analyses. ‘Mr Ed’ Knowles carried out the classification of Landsat image data and gave expert advice on GIS manipulation and chaff rumination. Mark Tozer expertly designed the map layout and implemented its production. Doug Binns, Phil Gilmour and Jackie Miles provided detailed comments on various aspects of the map. Jackie Miles, Peter Myerscough and Dominic Sivertsen commented on a draft manuscript. Work carried out by Jackie Miles for Bega Valley Catchment Management Committee assisted greatly with post-CRA map revision. NSW National Parks and Wildlife Service and the Resource and Conservation Assessment Council funded the work. We thank our families for their patience and tolerance.

References

Andrews A.E.J. (1998) *Earliest Monaro and Burragorang: 1790 to 1840* (Tabletop Press: Canberra).

Anonymous (1998) *Towards an Eden Regional Forest Agreement*. (New South Wales Government and Commonwealth Government: Sydney).

Ashton D.H. (1981) Fire in tall open forests (wet sclerophyll forests). Pp. 339–368 in A. M. Gill, R.H. Groves & I.R. Noble (eds). *Fire and the Ausrtalian biota.* (Australian Academy of Science: Canberra).

Ashton D.H. & Frankenberg J. (1976) Ecological studies of *Acmena smithii* (Poir.) Merrill and Perry with special reference to Wilson's Promontory. *Australian Journal of Botany* 24: 453–487.

Austin M.P. (1978) Vegetation. Pp. 44–67 in M.P. Austin & K.D. Cocks (eds). *Land use on the south coast of New South Wales* (CSIRO: Canberra).

Austin M.P. (1987) Models for the analysis of species' response to environmental gradients. *Vegetatio* 69: 35–45.

Austin M.P., Cunningham R.B & Fleming, P.M. (1984) New approaches to direct gradient analysis using environmental scalars and statistical curve-fitting procedures. *Vegetatio* 55: 11–27.

Austin M.P. & Margules C.R. (1986) Assessing representativeness. In M. B. Usher (eds). *Wildlife conservation evaluation*, pp. 45–67 (Chapman and Hall: London).

Austin M.P. & Sheaffe J. (1976) Vegetation survey data of the south coast study area, N.S.W. *Technical Memorandum* 76/15. CSIRO, Canberra.

Banks J.C.G. (1990) *The fire history for two forest types in Glenbog State Forest, N.S.W.* Report to the Joint Scientific Committee on the South East Forests, Canberra.

Barnes R.G. & Herzberger G.A. (1975) *Bega 1:250 000 metallogenic map* (Geological Survey of New South Wales: Sydney).

Baur G.N. (1989) Forest types of New South Wales. *Research Note* 17 (Forestry Commission of New South Wales: Sydney).

Beadle N.C.W. (1954) Soil phosphate and the delimitation of plant communities in eastern Australia I. *Ecology* 35: 370–375.

Beadle N.C.W. (1981) *Vegetation of Australia* (Cambridge University Press: London).

Beams S.D. & Hough D.J. (1984) Explanatory notes to accompany geological map of the Eden forestry region, New South Wales. *Miscellaneous paper* (Forestry Commission of New South Wales: Sydney).

Bedward M., Pressey R.L. & Keith D.A. (1992a) A new approach for selecting fully representative reserve networks: addressing efficiency, reserve design and land suitability with an iterative analysis. *Biological Conservation* 62: 115–125.

Bedward M., Keith D.A. & Pressey R.L. (1992b) Homogeneity analysis: assessing the utility of classifications and maps of natural resources. *Australian Journal of Ecology* 17: 133–140.

Belbin L. (1987) The use of non-hierarchical allocation methods for clustering large sets of data. *Australian Computer Journal* 19: 32–41.

Belbin L. (1991) Semi-strong hybrid scaling, a new ordination algorithm. *Journal of Vegetation Science* 2: 491–496.

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

Belbin L. & McDonald C. (1993) Comparing three classification strategies for use in ecology. *Journal of Vegetation Science* 4: 341–348.

Benson J.S. (1994) The native grasslands of the Monaro region: southern tablelands of New South Wales. *Cunninghamia* 3: 609–650.

Benson J.S. & Jacobs S.W.L. (1994) Plant communities of the Monaro lakes. *Cunninghamia* 3: 651–676.

Benson J.S. & Redpath P.A. (1997) The nature of pre-European native vegetation in south-eastern Australia: a critique of Ryan, D.G., Ryan, J.R. and Starr, B.J. (1995) The Australian landscape-observations of explorers and early settlers. *Cunninghamia* 5: 285–328.

Binns, D.L. (1987) A preliminary list of vascular plant species for far south-eastern New South Wales. *Research paper* No. 4 (Forestry Commission of New South Wales: Sydney).

Binns D.L. & Kavanagh R.P. (1990a) Flora and fauna survey of Nalbaugh State Forest (part) Bombala district, Eden region, south-eastern New South Wales. *Forest resources series* No. 9 (Forestry Commision of New South Wales: Sydney).

Binns D.L. & Kavanagh R.P. (1990b) Flora and fauna survey, Nullica State Forest (part), Eden district, Eden region. *Forest resources series* No. 10 (Forestry Commission of New South Wales: Sydney).

Bradstock R.A., Keith D.A. & Auld T.D. (1995) Managing fire for conservation: imperatives and constraints. Pp. 323–333 in R.A. Bradstock, T.D. Auld, D.A. Keith, R.T. Kingsford, D. Lunney & D. Sivertsen (eds). *Conserving biodiversity: threats and solutions* (Surrey Beatty and Sons Pty. Ltd.: Chipping Norton).

Bradstock, R.A., Tozer, M.G. & Keith, D.A. (1997) Effects of high frequency fire on floristic composition and abundance in a fire-prone heathland near Sydney. *Australian Journal of Botany* 45: 641–655.

Braithwaite W.L., Belbin L., Ive J. & Austin M.P. (1993) Land use allocation and biological conservation in the Batemans Bay forests of New South Wales. *Australian Forestry* 56: 4–21.

Breckwoldt, R. (1979) *Vegetation survey of south coast parks and reserves*. Unpublished report to NSW National Parks and Wildlife Service.

Bridges, R.G. (1983) Integrated logging and regeneration in the silvertop ash-stringybark forests of the Eden region. *Research Paper* No. 2 (Forestry Commission of N.S.W: Sydney).

Brooker M.G. & Margules C.R. (1996) The relative conservation value of patches of remnant vegetation in the wheatbelt of Western Australia: I. Plant diversity. *Pacific Conservation Biology* 2: 268–278.

Burgman M.A. (1988) Spatial analysis of vegetation patterns in southern Western Australia: implications for reserve design. *Australian Journal of Ecology* 13: 415–429.

Byrne, D. (1983) The five forests. An archaeological and anthropological investigation. *Occasional paper* No. 2 (NSW National Parks and Wildlife Service: Sydney).

Cawe S.G. & McKenzie B. (1989) The afromontane forests of Transkei, southern Africa. II. A florisitic classification. *South African Journal of Botany* 55: 31–39.

Clarke, P.J. (1989) *Coastal dune vegetation of New South Wales*. Technical Report 89/1, Coastal Studies Unit, University of Sydney, Sydney.

Clayton-Greene K.A. & Wimbush D.J. (1988) Acacia dry scrub communities in the Byadbo area of the Snowy Mountains. *Cunninghamia* 2: 9–24.

Clements A. (1983) Suburban development and resultant changes in the vegetation of the bushland of the northern Sydney region. *Australian Journal of Ecology* 8: 307–318.

Codrington S.B. (1979) *Gold from gold: the history of dairying in the Bega Valley (*Mercury Research Press: Sydney).

Commonwealth of Australia (1988) *Climatic averages of Australia* (Commonwealth of Australia: Canberra).

Commonwealth of Australia (1992) *National forest policy statement. A new focus for Australia's forests*. Second edition (Australian Government Publishing Service: Canberra).

Costin A.B. (1954) *A study of the ecosystems of the Monaro region of New South Wales* (Soil Conservation Service of New South Wales: Sydney).

Cowling R.M. (1983) Diversity relations in Cape shrublands and other vegetation in the southeastern Cape, South Africa. *Vegetatio* 54: 103–127.

CSIRO (1996) *Pre-1750 vegetation mapping for the south coast forests area* (CSIRO Division of Wildlife and Ecology: Canberra).

Dickinson K.J.M. & Kirkpatrick J.B. (1987) Short-term effects of clearfelling and slash-burning on the richness, diversity and relative abundance of higher plant species in two types of eucalypt forest on dolerite in Tasmania. *Australian Journal of Botany* 35: 601–616.

Dodson J.R., Kodela P.G. & Myers C.A. (1988) Vegetation survey of the Tantawangalo research catchments in the Eden forestry region, New South Wales. *Forest resources series* No. 4 (Forestry Commision of New South Wales: Sydney).

Eastman J.R. (1993) *Idrisi Version 4.1* (Clark University: USA).

Elith, J., Burgman, M. & Minchin, P. (1998) *Improved protection strategies for rare plants*. Report on Project No. FB-NP22 (Environment Australia: Canberra).

Faith D.P., Minchin P.R. & Belbin L. (1987) Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio* 69: 57–66.

Fanning F.D. & Clark S.S. (1991) Flora and fauna survey of Jingo Creek catchment, Nullica State Forest, Eden region. *Forest resources series* No. 14 (Forestry Commission of New South Wales: Sydney).

Fanning F.D. & Fatchen T.J. (1990) The upper Wog Wog Creek catchment of Coolangubra and Nalbaugh State Forest, (Mines Road area) New South Wales. A fauna and flora survey. *Forest resources series* No. 12 (Forestry Commission of New South Wales: Sydney).

Fanning F.D. & Mills K. (1989) Natural resource survey of the southern portion of Rockton section, Bondi State Forest. *Forest resources series* No. 6 (Forestry Commission of New South Wales: Sydney).

Fanning F.D. & Mills K. (1990) Flora and fauna survey of the Myanba Creek catchment, Coolangubra State Forest, Eden region. *Forest resources series* No. 11 (Forestry Commission of New South Wales: Sydney).

Fanning F.D. & Mills K. (1991) The Stockyard Creek catchment of Coolangubra State Forest. A fauna and flora survey. *Forest resources series* No. 13 (Forestry Commission of New South Wales: Sydney).

Fanning F.D. & Rice B. (1989) Natural resource survey of the northern portion of Rockton section, Bondi State Forest. *Forest resources series* No. 7 (Forestry Commission of New South Wales: Sydney).

Fensham R.J. (1989) The pre-European vegetation of the Midlands, Tasmania: a florisitic and historical analysis of vegetation patterns. *Journal of Biogeography* 16: 29–45.

Ferrier S. & Watson G. (1997) *An evaluation of the effectiveness of environmental surrogates and modelling techniques in predicting the distribution of biological diversity* (Environment Australia: Canberra).

Floyd A.G. (1982) *Rainforests of the south coast of New South Wales south of Batemans Bay*. Unpublished report.

Floyd A.G. (1990) *Australian rainforests in New South Wales. Volume 2.* (Surrey Beatty and Sons: Chipping Norton).

Forbes S.J., Walsh N.J. & Gullan P.K. (1982) Vegetation of East Gippsland. *Muelleria* 5: 53–113.

Forestry Commission of New South Wales (1988) *Forestry operations in Eden management area. Environmental Impact Statement* (Forestry Commission of New South Wales: Sydney).

Garven I. (1984) *Survey of vegetation-Ben Boyd (South) National Park*. Unpublished report to NSW National Parks and Wildlife Service.

George A.S., Hopkins A.J.M. & Marchant N.G. (1979) The heathlands of Western Australia. Pp. 210–229 in R.L. Specht (ed), *Heathlands and related shrublands* (Elsevier: Amsterdam).

Gilmour P.G. (1983) *A survey of the vegetation of Nadgee Nature Reserve*. Unpublished report to NSW National Parks and Wildlife Service.

Gimingham C.H., Chapman S.B. & Webb N.R. (1979) European heathlands. Pp. 365–413 in R.L. Specht (ed.) *Heathlands and related shrublands* (Elsevier: Amsterdam).

Glenn-Lewin D.C. (1975) Plant species diversity in ravines of the southern Finger Lakes region. *Canadian Journal of Botany* 53: 1465–1472.

Groves R.H., Keraitis K. & Moore C.W.E. (1973) Relative growth of *Themeda australis* and *Poa labillardieri* in pots in response to phosphorus and nitrogen. *Australian Journal of Botany* 21: 1–11.

Harden G. (1990–1993) *Flora of New South Wales.* Volumes 1–4 (University of New South Wales Press: Kensington).

Harris-Daishowa (1986) *Draft environmental impact statement for the Eden (N.S.W.) export woodchip operation for the period 1989–2009* (Harris-Daishowa: Canberra).

Helman C.E. (1983) *Inventory analysis of southern New South Wales rainforest vegetation.* MSc thesis. University of New England.

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

JANIS (1996) *Proposed nationally agreed criteria for the establishment of a comprehensive, adequate and representative reserve system for forests in Australia*. Report of the Joint ANZECC/MCFFA National Forest Policy Implementation Subcommittee (JANIS) (Commonwealth of Australia: Canberra).

Keith D.A. (1990) Rare and biogeographically significant vascular plant species of the Eden region, south-eastern New South Wales: a listing for the 'fine filter' approach. *Proceedings of the Linnean Society of New South Wales* 112: 111–132.

Keith D.A. (1991) *Coexistence and species diversity in upland swamp vegetation.* PhD thesis. University of Sydney.

Keith D.A. (1994) Floristics, structure and diversity of natural vegetation in the O'Hares Creek catchment, south of Sydney. *Cunninghamia* 3: 543–594.

Keith D.A. (1995) Involving ecologists and local communities in survey, planning and action for conservation in a rural landscape: an example from the Bega valley, New South Wales. In D.A. Saunders, J. L. Craig & E. Mattiske (eds) *Nature Conservation 4: The role of networks* (Surrey Beatty and Sons Pty. Ltd: Chipping Norton).

Keith D.A. (1996) Fire-driven mechanisms of extinction in vascular plants: a review of empirical and theoretical evidence in Australian vegetation. *Proceedings of the Linnean Society of New South Wales* 116: 37–78.

Keith D.A. & Ashby E. (1992) Vascular plants of conservation significance in the South East Forests of New South Wales. *Occasional Paper* No. 11 (National Parks and Wildlife Service of New South Wales: Hurstville).

Keith D.A. & Bedward M. (1995) *Forest ecosystem classification and mapping for the Eden Comprehensive Regional Assessment* (New South Wales Government: Sydney. Commonwealth Government: Canberra).

Keith D.A., Bedward M. & Smith J. (1995) Vegetation of the South East Forests of New South Wales. NSW National Parks and Wildlife Service. Unpublished report.

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

Keith D.A. & Bradstock R.A. (1994) Fire and competition in Australian heath: a conceptual model and field investigations. *Journal of Vegetation Science* 5: 347–354.

Keith D.A., Miles J. & Mackenzie B. (1999) Vascular flora of the South East Forests region, Eden, New South Wales. *Cunninghamia* 6: 219–281.

Keith D.A. & Sanders J.M. (1990) Vegetation of the Eden region, south-eastern Australia: species composition, diversity and structure. *Journal of Vegetation Science* 1: 203–232.

Keith D.A. & Tozer M.G. (1997) Experimental design and resource requirements for monitoring flora in relation to fire. Pp. 274–279 in B. McKaige & R.J. Williams (eds), *Bushfire '97* (CSIRO Tropical Ecosystems Research Centre: Darwin).

Kelly J. & Turner J. (1978) Soil nutrient-vegetation relationships in the Eden area, New South Wales. *Australian Forestry* 41: 127–134.

Kirkpatrick J.B. (1984) Altitudinal and successional variation of the northern part of the West Coast range, Tasmania. *Australian Journal of Ecology* 9: 81–91.

Lane M., Semmens L. & Williams J. (1998) *Vegetation survey of south coast national parks and nature reserves*. Unpublished data, Johnstone Centre, Charles Sturt University, Albury.

Le Brocque A.F. & Buckney R.T. (1997) Multivariate relationships between floristic composition and stand structure in vegetation of Ku-ring-gai Chase National Park, New South Wales. *Australian Journal of Botany* 45: 1033–1044.

Lunney D. & Leary T. (1988) The impact on native mammals of land-use changes and exotic species in the Bega district, New South Wales, since settlement. *Australian Journal of Ecology* 13: 67–92.

Lunt I.D. (1991) Management of remnant lowland grasslands and grassy woodlands for nature conservation. *Victorian Naturalist* 108: 56–66.

Margules C. R. & Stein J. L. (1989) Patterns in the distribution of species and the selection of nature reserves: an example from the *Eucalyptus* forests in south-eastern New South Wales, Australia. *Biological Conservation* 50: 219–238.

McDougall K. & Kirkpatrick J.B. (1993) *Conservation of lowland native grasslands in south-eastern Australia* (World Wide Fund for Nature: Sydney).

McIntyre S., Lavorel S. & Tremont R.M. (1995) Plant life-history attributes: their relationship to disturbance response in herbaceaous vegetation. *Journal of Ecology* 83: 31–44.

Moore I.P.D., Gessler P.E., Nielsen G.A. & Peterson G.A. (1993) Soil attribute prediction using terrain analysis. *Soil Society of America Journal* 57: 443–452.

Morgan J.W. (1997) The effect of grassland gap size on establishment, growth and flowering of the endangered *Rutidosis leptorrhynchoides* (Asteraceae). *Journal of Applied Ecology* 34: 566–576.

Nix H.A. (1982) Environmental determinants of biogeography and evolution in Terra Australis. Pp. 47–66 in W.R. Barker & P.J. M. Greenslade (eds), *Evolution of the flora and fauna of arid Australia* (Peacock Publications: Frewville).

Noble I.R. & Slatyer R.O. (1980) The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbance. *Vegetatio* 43: 5–21.

Noble I.R. & Slatyer R.O. (1981) Concepts and models of succession in vascular plant communities subject to recurrent fire. Pp. 311–335 in Gill, A.M., Groves, R.H. & Noble, I.R. (eds), *Fire and the Australian biota* (Australian Academy of Science: Canberra).

Noss R. (1987) From plant communities to landscapes in conservation inventories: a look at the Nature Conservancy (USA). *Biological Conservation* 41: 11–47.

Oliver I., Beattie A.J. & York A. (1998) Spatial fidelity of plant, vertebrate and invertebrate assemblages in multiple-use forest in eastern Australia. *Conservation Biology* 12: 822–835.

Ough, K. & Ross, J. (1990) Floristics, fire and clear-felling in wet forests of the central highlands, Victoria. *VSP Technical Report* 11 (Department of Conservation and Environment: Melbourne).

Outhred, R. (1986) *Vegetation survey of Wadbilliga National Park*. Unpublished data, NSW National Parks and Wildlife Service.

Outhred R., Lainson R., Lamb R. & Outhred D. (1985) A floristic survey of Ku-ring-gai Chase National Park. *Cunninghamia* 1: 313–338.

Ovington J.D. (1983) *Ecosystems of the world: temperate broad-leaved evergreen forests.* (Elsevier: Amsterdam).

Panzer R. & Schwartz M.W. (1998) Effectiveness of vegetation-based approach to insect conservation. *Conservation Biology* 12: 693–702.

Parkes D., Moorees A. & Williams J. (1984) *A florisitic vegetation map of East Gippsland (1:250 000)* (Department of Conservation, Forests and Lands: Melbourne).

Peet R.K. (1978) Forest vegetation of the Colorado Front Range: patterns of species diversity. *Vegetatio* 37: 65–78.

Polach H. & Singh G. (1980) Contemporary 14C levels and their significance to sedimentary history of Bega Swamp, New South Wales. *Radiocarbon* 33: 398–409.

Poore M.E.D. (1955) The use of phytosociological methods in ecological investigations. I. The Braun-Blanquet system. *Journal of Ecology* 43: 226–244.

Pressey R.L. (1989) Wetlands of the lower Clarence floodplain, northern coastal New South Wales. *Proceedings of the Linnean Society of New South Wales* 111: 143–155.

Pressey R.L. & Bedward M. (1991) Inventory and classification of wetlands: what for and how effective? In R. Donohue & B. Phillips (eds). *Educating and managing for wetland conservation. Proceedings of the wetlands conservation and management workshop* (Australian National Parks and Wildlife Service: Canberra).

Pressey R.L., Ferrier S., Hager T.C., Woods C.A., Tully S.L. & Weinman K.M. (1996) How well protected are the forests of north-eastern New South Wales? Analysis of forest environments in relation to tenure, formal protection measures and vulnerability to clearing. *Forest Ecology and Management* 85: 311–333.

Rice B. & Westoby M. (1983) Plant species richness at the 0.1 hectare scale in Australian vegetation compared to other continents. *Vegetatio* 52: 129–140.

Richards B.N., Bridges R., Curtin R., Nix H.A., Sheppard R. & Turner J. (1990) *Biological diversity of the South East Forests* (Australian Government Publishing Service: Canberra).

SFNSW (1994) *Proposed forestry operations in Eden Management Area. Environmental Impact Statement*. State Forests of New South Wales, Sydney.

Skidmore A.K. (1989) An expert system classifies Eucalypt Forest Types using thematic mapper data and a digital terrain model. *Photogrammetric Engineering and Remote Sensing* 55: 1449–1464.

Skidmore A.K. (1990) Terrain position as mapped from a gridded digital elevation model. *International Journal of Geographic Information Systems* 4: 33–49.

Specht, R.L. (1979) The sclerophyllous (heath) vegetation of Australia: the eastern and central states. Pp. 125–210 in Specht R.L. (ed.), *Ecosystems of the World 9A: heathlands and related shrublands* (Elsevier: Amsterdam).

Sun D., Hnatiuk R.J. & Neldner V.J. (1997) Review of vegetation classification and mapping systems undertaken by major forested land management agencies in Australia. *Australian Journal of Botany* 45: 929–948.

Turner J., Kelly J. & Newman L.A. (1978) Soil nutrient-vegetation relationships in the Eden area, N.S.W. II. Vegetation-soil associations. *Australian Forestry* 41: 223–231.

Vickery J.W. (1961) *Themeda*. Gramineae. *NSW Flora Series* 19: 59–61.

Walsh N.G., Barley R.H. & Gullan, P.K. (1983) *Alpine vegetation: sites of botanical significance in the Victorian alps, excluding Bogong High Plains* (National Herbarium of Victoria: Melbourne).

Wardell-Johnson G., Inions G. & Annels A. (1989) A floristic classification of the Walpole-Nornalup National Park, Western Australia. *Forest Ecology and Management* 28: 259–279.

Webb L.J., Tracey J.G. & Williams J.T. (1984) A floristic framework for Australian rainforests. *Australian Journal of Ecology* 9: 169–198.

Westhoff V. & van der Maarel E. (1978) The Braun-Blanquet approach. Pp. 287–328 in R.H. Whittaker (ed), *Classification of plant communities.* (Junk: The Hague).

Whelan R.J. (1995) *The ecology of fire.* (Cambridge University Press: Cambridge).

Whelan R.J. & Hibberd J.K. (1992) *Mammals and habitat in the Bega valley: the importance of remnant forest on private property*. National Estate Grants Scheme (Department of Planning: Sydney).

Whittaker R.H. (1979) Appalachian balds and other North American heathlands. Pp. 427–440 in R.L. Specht (ed.), *Heathlands and related shrublands* (Elsevier: Amsterdam).

Whittaker R.H. & Woodwell G.M. (1969) Structure, production and diversity of the oak-pine forest at Brookhaven, New York. *Journal of Ecology* 57: 157–174.

Williams J.E., Whelan R.J. & Gill A.M. (1995) Fire and environmental heterogeneity in southern temperate forest ecosystems: Implications for management. *Australian Journal of Botany* 42: 125–137.

Woodgate P.W., Peel W.D., Ritman K.T., Coram J.E., Brady A., Rule A.J. & Banks J.C.G. (1994) *A study of the old-growth forests of East Gippsland*. Department of Conservation and Natural Resources, Victoria., Melbourne.

Manuscript accepted 7 January 1999