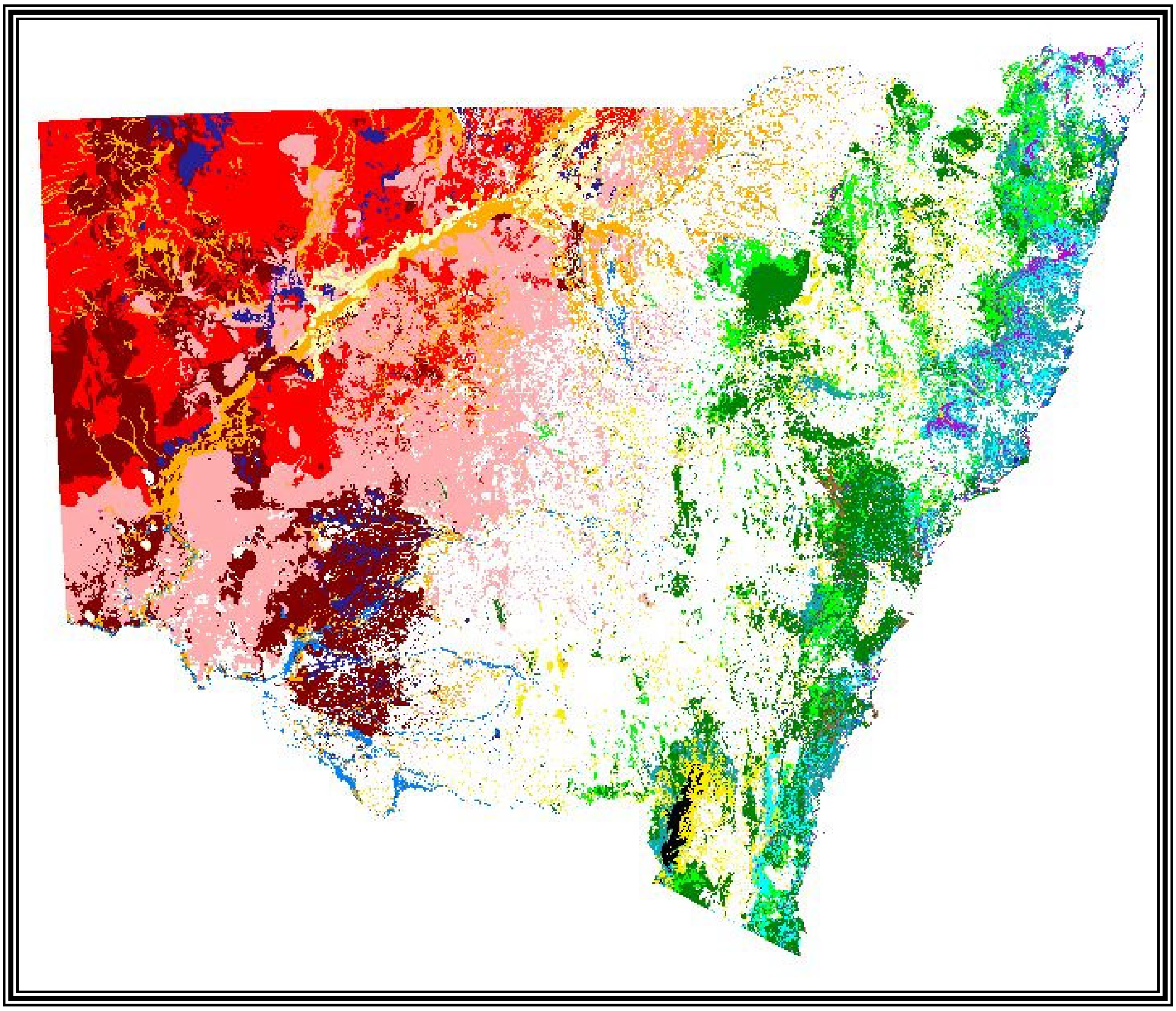

Vegetation Formations of NSW (version 3.0)

A seamless map for modelling fire spread and behaviour

Final Report to the Rural Fire Service

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Introduction

An understanding of native vegetation is essential for the informed management of bushfires for both the protection of life and property and the conservation of biodiversity. On one hand, the spread and behaviour of bushfires is influenced by the structure and composition of native vegetation that comprises the combustible fuels of an area. On the other hand, native vegetation defines a major component of habitat for plant and animal species and communities that exhibit a wide range of sensitivities to alternative fire regimes. Reliable and consistent spatial information on native vegetation is therefore essential to inform the management of bushfires, for example, by supporting predictions about fire spread and behaviour and by identifying potential locations of biodiversity components that may be sensitive to particular fire regimes. The NSW Rural Fire Service (RFS) engaged the Department of Environment, Climate Change and Water (DECCW) to compile and synthesise spatial vegetation data to help meet these needs.

The RFS has decided that vegetation formations defined by Keith (2004) initially provide a suitable framework for describing broad units of vegetation that represent characteristic fuel types across NSW. A map showing the distribution of vegetation formations is currently available (version 2.2), but the format of the data restricts the range of fire modelling applications required by RFS. In addition, since the production of version 2.2, a considerable volume of new spatial data on native vegetation has become available for various parts of NSW. The aim of this project is to produce a vector GIS layer showing the extant distributions of vegetation formations for NSW suitable for the RFS to use in its day to day fire management activities including, but not limited to, fire behaviour analysis.

The map data will meet the following agreed specifications:

- Coverage – entirety of NSW
- Resolution – maximum resolution permitted by source data (i.e. minimum polygon size in respective source data sets)
- Projection – GDA94 Lamberts conformal

Mapped polygons will have the following attributions:

- Polygon identifier
- NSW vegetation formation (as per Keith 2004, 'Ocean shores to desert dunes')
- Source map name
- Source map VIS number
- Acquisition scale
- Acquisition date (year)
- Reliability rank reflecting uncertainties in the underlying data

The new seamless vegetation map presented in this report therefore shows the extant distributions of vegetation formations throughout NSW, and provides users with information about the resolution, currency and uncertainties in the underlying data that were used to assemble the map. To assist future management and development of this information resource, we evaluate its limitations and propose recommendations for further improvements.

Methods

The NSW vegetation map (version 2.2) was revised by interpreting additional candidate maps and synthesising these into a single vector-based data set. This involved seven steps:

- developing a comprehensive 'standard' classification of vegetation formations for NSW;
- collating and standardising the projection and format of candidate source maps;
- assigning vegetation units of source maps to NSW vegetation formations;
- assessing the spatial resolution, currency and reliability of candidate source maps;
- assembling a composite map from candidate source maps to maximise reliability;
- applying a spatial mask to represent extant native vegetation;
- attributing the spatial resolution, currency and reliability of the underlying source data sets.

The classification of 16 vegetation formations and subformations described by Keith (2004) was adopted as the framework for preparation of version 3.0 of the NSW vegetation map. Other components of the methods are described below.

Candidate source maps

A set of candidate source maps covering all of NSW was compiled from the NSW Vegetation Information System (VIS) and other sources. These included 36 data sets and additional models used in the compilation of version 2.2 (Keith 2004) and additional data sets including regional-scale vegetation maps produced since 2004 and a number of local-scale vegetation maps where regional maps did not provide high-resolution or high-reliability coverage. Available resources did not permit all available data sets within the VIS to be incorporated within version 3.0 of the statewide compilation map. Therefore, a number of lower-priority data sets (mostly maps of small areas, such as individual conservation reserves, within areas covered by maps of similar quality over larger regions) were excluded from processing. In total, 105 vegetation map data sets were identified and processed as candidate source maps (Table 1). These included maps that show the extant distribution of native vegetation (i.e. including cleared areas) and others that show the reconstructed distribution of native vegetation, in which the potential vegetation type had been interpolated into cleared areas. The extant vegetation maps were tagged for later processing to prepare a mask of extant native vegetation (see below). In addition to the 105 source maps, supplementary models were constructed for seven additional areas to fill small thematic gaps in the coverage of the study area. All candidate source maps were projected into Geocentric Datum of Australia 1994 (GDA94) Lamberts Conformal Conic projection. The topology of each spatial data set was checked and corrected where errors were found.

Table 1. Source vegetation maps incorporated into the NSW map of Vegetation Formations (version 3.0).

Name	Source	VIS-ID
Albury	Priday & Mulvaney (2007)	2907
Anabranch-Mildura	Fox (1991)	1873
Balranald	Scott (1992)	3178

Name	Source	VIS-ID
Barton NR	Lembit & Skelton (1998)	837
Boginderra NR	Lembit & Skelton (1998)	848
Booligal-Hay-Deniliquin	Porteners (1993)	3179
Boorowa	Priday et al. (2002), EcoGIS (2001)	1626
Bourke Shire	Northern Floodplains Regional Planning Committee (2004c)	1661
Brewarrina Shire	Northern Floodplains Regional Planning Committee (2004b)	1659
Brigalow Belt South	Joint Vegetation Mapping Project Management Committee (2004), Beckers & Binns (2000)	1028
Burragorang	Fisher et al. (1995)	2344
Byron Shire 1998	Ecograph (1998)	6
Byron Shire 2007	Hall (2009)	3805
Central Hunter Valley	Peake (2006)	2295
Cessnock	Bell & Driscoll (2007)	184
Coastal Floodplain model	Keith & Scott (2004); Keith et al. (unpubl. data)	
Cobar	Dykes (2002)	3332
Cocopara NP	Whiting (1997)	792
Coffs Harbour	Coffs Harbour City Council (unpubl. data)	206
Coffs Harbour addition	Coffs Harbour City Council (unpubl. data)	207
Conimbla NR	Boden & Mitchell (1996)	864
Copperhannia NR	Lembit & Skelton (1998)	868
Curlewis	NPWS (unpubl. data)	803
Dapper NR	Lembit & Skelton (1998)	872
East Walgett	Peasley & Walsh (2001)	804
Estuarine macrophytes CCA	DPI (2006)	273
Estuarine vegetation	West et al. (1985)	2224
Eugowra NR	Porteners (2000)	880
Gibraltar Range NP	Hunter & Sherringham (2008)	307
Goobang NP	Porteners (1997)	1051
Gosford	Benson (1986)	2345
Gundagai	Priday (unpubl.)	2910
Guy Fawkes Addition	Hunter & Alexander (1999)	304
Guy Fawkes River NP	Austeco (1999)	302
Guyra	Benson & Ashby (2000)	234
Hunter-Macleay	Keith (unpubl. data)	N/A
Katoomba	Keith & Benson (1988)	977
Kosciuszko alpine	Wimbush & Costin (1973)	1341
Kosciuszko subalpine	Wimbush & Costin (1973)	1342
Lachlan CMA	Coote et al. (2006)	3780
Ledknapper NR	Hunter & Fallavollita (2003)	906
Ledknapper NR Glenalbyn addition	Porteners (2006)	907
Lismore City 1998	Lismore City Council (*1998)	3834
Lismore 2008	GHD (2008)	20
Little River	Seddon et al. (2002)	912
Liverpool Plains grasslands	Lang (2008)	3839
Lord Howe Island	Pickard (1983)	1068
Lower Hunter Central Coast	NPWS (2002)	2227
Lower Macquarie-Castlereagh	Kerr et al. (2003)	817
Macquarie region	Biddiscombe (1963)	818
Merriwa	McCrae & Cooper (1985)	2348
Mid Lachlan	Austin et al. (2000)	3835
Monaro	Costin (1954)	762
Monaro Grasslands	Walter & Schelling (2004)	2513
Monaro Lakes	Benson & Jacobs (1994)	2516
Moree grassland sites	Hunter & Earl (2003)	
Moree NW slopes & plains	Peasley & Walsh (2001)	822
Moree Plains Shire	White (2000)	929
Mt Canobolas SCA	Hunter (2002)	1824
Murray River riparian vegetation	Smith & Smith (1990)	827
Murray valley	Miles (2001)	1089

Name	Source	VIS-ID
Mutawintji NP	Porteners (2003)	823
Nambucca	Kendall (2003)	500
Nandewar bioregion	Wall (2006)	12
New England NP	Clarke et al. (2000)	510
New England tableland	Keith (unpubl. data)	N/A
Northeast CRA v2	NPWS (1999)	3836
Northeast CRA v3	DECC (unpubl. data, 2008)	3837
North-east Rainforests	Keith (unpubl. data)	3837
Northwest NSW	Pickard & Norris (1994)	825
NVMP Cobborah 1:250k	Ismay et al. (2004)	2101
NVMP Deniliquin 1:250k	McNellie et al. (2005)	874
NVMP Hay 1:250k	Horner et al. (2002)	2215
NVMP Inverell 1:250k	DLWC (2002a)	2129
NVMP Nth Lachlan-Bogan	Lewer et al. (2003)	1595
Penrith	Benson (1992)	2352
Plains Wanderer Habitat	Roberts & Roberts (2001)	826
Pooncarie	Porteners et al. (1997)	972
Richmond River Catchment	NPWS (unpubl. data)	3838
Riverina Grassland	McDougall (2008), Keith (unpubl. data)	
Riverina reconstructed	White et al. (2002)	974
South-east NSW	Tozer et al. (2010)	2230
Southeast Riverina	Moore (1953)	828
Southern CRA	Gellie (2005)	3840, 3841
Southern Mallee	Val (1998)	1044
St Albans	Ryan et al. (1996)	2353
Sydney	Benson & Howell (1994)	2354
Sydney Metropolitan CMA	DECCW (2009)	3817
Sydney Sandstone	Keith (unpubl. data)	N/A
Tamworth-Manilla-Cobbadah	Rolhauser et al. (2009)	3796, 3797
Torrington SCA	Clarke et al. (1998)	664
Tweed Shire	Kingston et al. (2005)	673
Upper Hunter	NPWS (unpubl. data)	N/A
Upper Shoalhaven Grasslands	Walter & Schelling (2005)	2783
Wagga	Priday & Mulvaney (2005)	1559, 1560
Walgett Shire (Western Division)	Northern Floodplains Regional Planning Committee (2004a)	1663
Wallerawang	Benson & Keith (1990)	982
Wallum	Giffith (2002)	201
Warragamba	NPWS (2003)	2380
Washpool NP West	Hunter (1998)	1573
Weddin NP	Boden & Mitchell (1996)	1013
Western Blue Mountains	DEC (2005)	2231
Wheatbelt Band A	Cox et al. (2002)	1629
Wheatbelt Band B	Sivertsen & Metcalfe (unpubl. data)	
Wheatbelt Band C	Metcalfe et al. (2003)	1602, 1604, 1606
Wheatbelt Band D	Metcalfe et al. (2003)	1608, 1610
Wheatbelt Band E	Sivertsen & Metcalfe (1995)	1613, 1616
Winburndale NP	Boden & Mitchell (1996)	1018
Wollemi NP	Bell (1998, 1999)	1849
Wombeira	Dick (1990)	1772
Yallaroi-Ashworth-Bingara-Inverell	Peacock et al. (2009)	3794, 3795
Yengo NP	DECC (2008)	1852

Assigning source map units to vegetation formations

Each vegetation map unit within each source data set was assigned to one of the 16 vegetation formations or subformations. The key to formations provided in Keith (2004) was used to determine the most commonly expressed structural form of each map unit by interpreting descriptions of map units in available documentation for each vegetation data set. This initial diagnosis was supplemented by cross-referencing other relevant information sources and knowledge derived from prior field reconnaissance. For each source map, this process produced a relational table containing a list of map units with their corresponding vegetation formation. The spatial data for each source map was then transformed to the statewide classification by joining the relational table to the attribute table of the map. An additional field was added to the attribute table to incorporate the name of the source (same for all polygons). Internal boundaries (i.e. between adjoining polygons assigned to the same vegetation formation) were then dissolved and redundant fields (including the original map unit) were deleted from the attribute table to reduce the size of the data sets that were to be merged in subsequent processing steps (see below).

Assessing candidate source maps

Four attributes relating to the reliability of candidate source maps (adapted from Keith & Simpson 2006) were compiled from the available documentation for each data set: classification skill; thematic resolution; spatial resolution; and currency.

Classification skill refers to the ability of map units to represent the salient properties of vegetation (composition, function & structure). Skill depends on the efficacy of data and other information that were used to construct the classification of map units. Five levels of classification skill were defined as follows:

I. Very high. Map units defined using quantitative analyses of floristic plot samples that meet all of the following conditions: 1) plot data collected at high density (>0.20 plots/km^2 map area) and even coverage (dispersed throughout map area, landscape types and tenure proportionate to area); 2) plots meet the minimum requirements specified in the *NSW Native Vegetation Type Standard* and record all vascular plant taxa at a time when most are likely to be detectable; 3) classification derived from interpretation of outputs from quantitative analyses to distinguish units based on species composition, with appropriate scientific justification of methods used.

II. High. As for Skill Level I (Very high skill), but plot data collected at density of 0.1-0.2 plots/km^2 map area and/or moderately even coverage of area, landscape types and tenure classes. Classification derived from quantitative or semi-quantitative analysis.

III. Intermediate. Map units defined using quantitative, semi-quantitative or qualitative classification methods. Quantitative analyses meet the following conditions: 1) plot data collected at moderate density (0.04-0.10 plots/km^2 map area) and moderately even coverage (dispersed across map area, landscape types and tenure types, but not strongly proportionate to area); 2) plots generally meet the minimum requirements specified in the *NSW Native Vegetation Type Standard,* but there is reason to suspect that appreciable numbers of vascular plant taxa were not recorded in some (>10%) plots (e.g. lower than expected species richness for some taxonomic or life form groups, survey conducted during drought conditions, numerous erroneous taxon identifications, etc.); 3) classification derived from interpretation of outputs from quantitative or semi-quantitative analyses to distinguish units based on species composition, with appropriate scientific justification of methods used. For qualitative classifications, there must be evidence that field reconnaissance was intensive (i.e. in terms of area traversed or field time) and evenly apportioned throughout the map area and across landscape types and tenures (e.g. by attributing polygons inspected), and that the classification was based on a detailed evaluation of overall species composition (cf. dominant species only).

IV. Low. Map units are quantitatively or semi-quantitatively defined but have the following limitations: 1) plot data collected at low density (0.01-0.4 plots/km^2 map area) and uneven coverage (large unsampled gaps in map area, landscape types or tenure types); 2) appreciable numbers of vascular plant taxa were not recorded in some (>25%) plots (e.g. lower than expected species richness for some taxonomic or life form groups, survey conducted during drought conditions, numerous erroneous taxon identifications, etc.); 3) analyses suffer limitations that may substantially affect outcomes of classification. Skill level IV also includes qualitatively defined classifications based on reconnaissance that provides only extensive and/or conspicuously uneven coverage of the study area.

V. Very low. Map units do not meet conditions specified for other Skill Levels I-IV. These include classifications based on very low sampling (<0.01 plot/km^2 map area) or highly biased sampling effort, qualitative classifications based on limited reconnaissance or a small subset of all vascular plant species (e.g. <70-80%) and classifications that are based essentially on vegetation proxies (e.g. spectral signatures, structural features, photopatterns, environmental variables, etc.). This category also includes subjective floristic classifications for which there is insufficient information to assess the above characteristics.

Thematic resolution refers to the detail of thematic information represented on the map - how finely the variation in vegetation is divided among map units, relative to the diversity of vegetation within the map area (i.e. fine resolution – many map units, coarse resolution – few map units). This was assessed by calculating the ratio of the number of map units in the source data set to the number of NSW vegetation classes (Keith 2004) that were represented in the data set. Thus candidate source maps with high thematic resolution had a map unit:class ratio > 3, while those with low thematic resolution had a map unit: class ratio <1.5. Some source maps with map unit:class ratio > 7 were likely to be overfitted, as the discrimination between individual map units could not be justified by the available thematic data or information.

Spatial resolution refers to the detail of spatial information represented on the map. It was assessed using the scale of imagery and other spatial data from which source maps were derived, as well as the smallest area of vegetation consistently delineated (taken as the 10th percentile of mapped polygon sizes). Thus, candidate source maps with high spatial resolution were derived from imagery finer than 1:5 000 and delineated polygons ≤0.5 ha in area, while those with low spatial resolution were based on imagery coarser than 1:50 000 and generally did not delineate polygons <20 ha in area.

Map currency refers to the age of information represented on the map. It was determined from the date of the imagery on which mapping was based. Where multiple sets of imagery were used in map preparation, the latest date of imagery that covered more than two-thirds of the relevant map area was used to determine currency.

Classification skill, thematic resolution, spatial resolution and currency each influence the reliability or conversely, the level of uncertainty, of information represented on the map. Criteria based on these attributes were used assign candidate source maps to one of five map uncertainty classes defined in Table 2. Currency data were not used to assign maps to uncertainty classes because currency was mainly applicable to changes in the extant vegetation distribution resulting from human activity (e.g. land clearing), rather than change in vegetation type. Currency was therefore assessed separately and used to identify the most recent mapping available for a given area (for preparation of an extant mask, see below). Maps were assigned to the highest class for which all three of the remaining criteria were met. For example, a source map with High classification skill, thematic resolution of 3.5, 1:30 000 imagery and 2 ha minimum polygon size, was assigned to 'moderate' map uncertainty (Class 3).

Table 2. Criteria used to assign candidate source maps to reliability classes (see text for interpretation).

Map uncertainty	Classification skill	Thematic resolution (units:class ratio)	Spatial resolution (imagery scale, polygon size)
1 Very high	Very high	Fine 3.01 – 7.0	≤1:5 000, ≤0.5 ha
2 High	High	Intermediate 2.4 – 3.0, Overfitted > 7.0	1:5 001 – 1:25 000, ≤1 ha
3 Moderate	Intermediate	Coarse 1.5 – 2.39	1:25 001 – 1:50 000, ≤5 ha
4 Low	Low	Very coarse 1.0 – 1.49	1:50 001 – 1:100 000, ≤20 ha
5 Very low	Low	Super coarse <1.0	>1:100 000, >20 ha

Assembling a composite vegetation map

Candidate source maps were initially ordered according to their respective uncertainty classes. For maps assigned to the same uncertainty class, overlapping areas were identified and examined in a Geographic Information System using SPOT5 satellite false colour imagery to view vegetation characteristics and spatial relationships. To resolve tied ranks of overlapping maps, the initial ranks based on uncertainty classes were adjusted by evaluating the raw map attribute data, the logical consistency of spatial relationships between the overlapping maps and the SPOT5 imagery, information from *a priori* field reconnaissance and further information obtained from map documentation. In some cases, different thematic features on a single source map were assigned different ranks. This segregation was implemented, for example, when features such as grasslands and wetlands were discriminated more reliably on one source map than an overlapping one, but other vegetation types were discriminated more reliably on the alternative source map. In addition, minor adjustments were made to rankings to improve edge matching between overlapping source maps. At the completion of this process, each candidate source map had a unique rank reflecting its suitability for incorporation into the composite map. The full set of source maps (including segregated features) were then merged using an ArcMap script such that higher-ranked maps covered lower-ranked maps. Due to the combined size and complexity of the component source maps, it was necessary to implement this operation in a number of stages. At the completion of the merge, the topology of the combined data layer was checked and corrected where necessary. Small polygons (≤625 m^2) created as a result of the merge operation were deleted from the combined data layer. The integration process is illustrated in Fig. 1 (from Keith 2004).

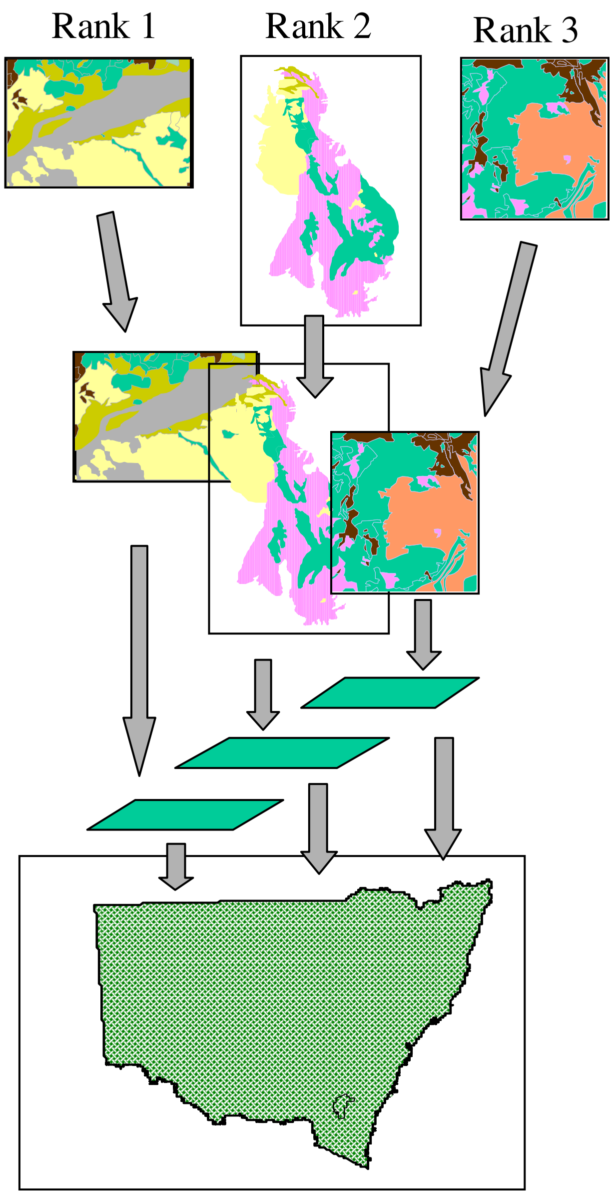

Figure 1. Schematic showing assembly of compilation maps from three candidate source maps according to their suitability rank. In this example, the source map on the right has the highest suitability rank (3), and its features therefore contribute to the compilation map with priority over the other two source maps.

Masking extant vegetation

A mask of extant native vegetation was assembled from the subset of candidate source maps that had earlier been tagged for this purpose. The source maps were first reclassified into binary data layers with polygons of extant native vegetation assigned a value of '1' and polygons of non-native or no vegetation assigned a value of '0'. Each binary source map was then ranked using the procedure described by Keith & Simpson (2006) such that maps of recent currency, high spatial resolution and accuracy were assigned high suitability ranks. The full set of binary maps was then merged and assembled using a merge operation similar to that described above so that higher-ranked maps covered lower-ranked maps. The merged binary layer was then merged with the composite map of vegetation formations produced in the previous step. The topology of the resulting map of extant vegetation formations was then checked and corrected where necessary. Small polygons (≤0.1 ha), including many that were created as a result of the merge operation, were deleted from the combined data layer. The resulting product was then inspected extensively to identify anomalies in the distribution of each vegetation formation. These were traced to respective source data sets, rectified and the composite map was re-assembled as described above.

Communicating limitations in the underlying source data

Due to the varying specifications and methods used to prepare the candidate source maps, the reliability of the composite map will vary from place to place. To allow users to interrogate and display characteristics of the underlying map data, a relational table was compiled including the classification skill, thematic resolution, spatial resolution, date of major imagery (where available) and overall uncertainty class for each candidate source map. Candidate source maps were identified using a name and, where available, their numeric identifier in the NSW Vegetation Information System (VIS). The relational table was then joined to the attribute table of the final map (NSW vegetation map, version 3.0).

Map of vegetation formations

Version 3.0 of the vegetation formations for NSW is shown in Fig. 2 (spatial data appended to this report). The map provides a 'seamless' coverage for all of NSW, however specifications of the underlying data vary substantially across the mapped area. These specifications are summarised in Appendix 1 for each of the 112 spatial data sets used in the compilation and joined to the map attribute table, enable users to interrogate and display properties of the underlying source maps.

Fig. 3 shows spatial variation in the reliability of the map data, and hence where future efforts to improve map accuracy could be profitably employed. Each of the map attributes follows a generally similar geographic pattern, which may be displayed in a GIS. Approximately two-thirds of the state, mainly west of the Great Dividing Range, is covered by data sources with high or very high levels of uncertainty (maps in Uncertainty Classes 1 and 2, Fig, 3). Source maps with moderate uncertainties (Class 3) cover parts of the north coast, tablelands and western slopes, while mapping with low levels of uncertainty (Class 4) are confined mainly to the coast and escarpment south from Sydney, the north coast sand plains, a small portion of the New England and some conservation reserves (Fig. 3a). Source mapping with very low levels of uncertainty (Class 5) is restricted to the Sydney metropolitan area and a few small conservation reserves.

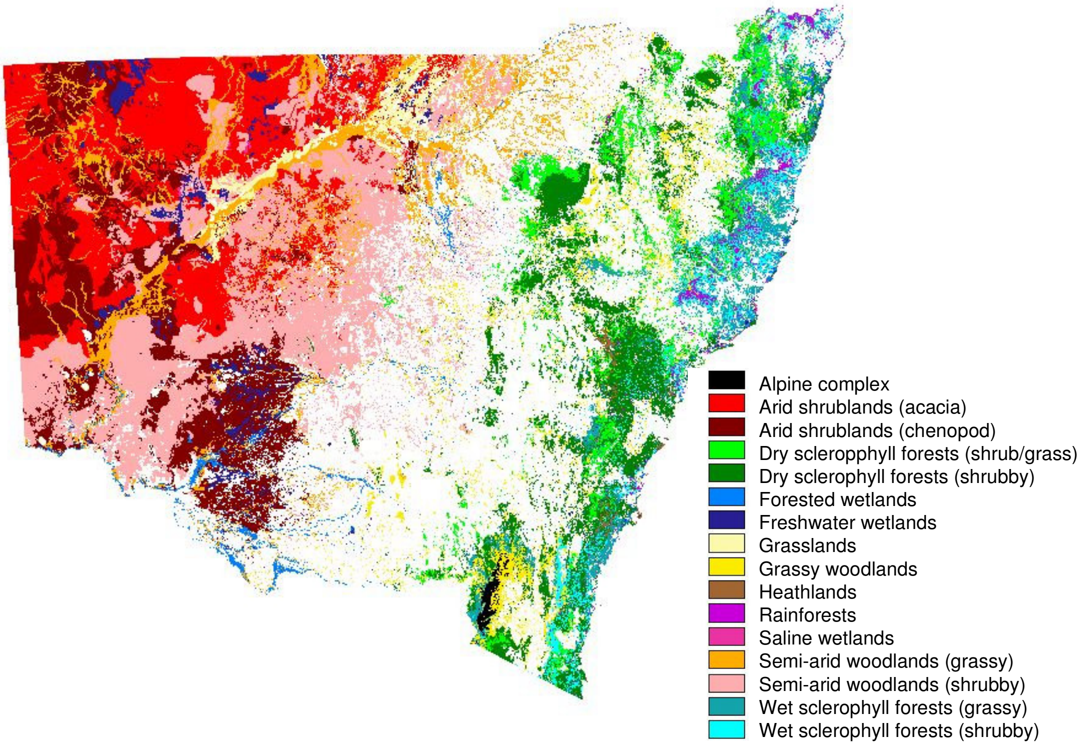

Fig. 2. Extant distribution of vegetation formations in New South Wales (version 3.0).

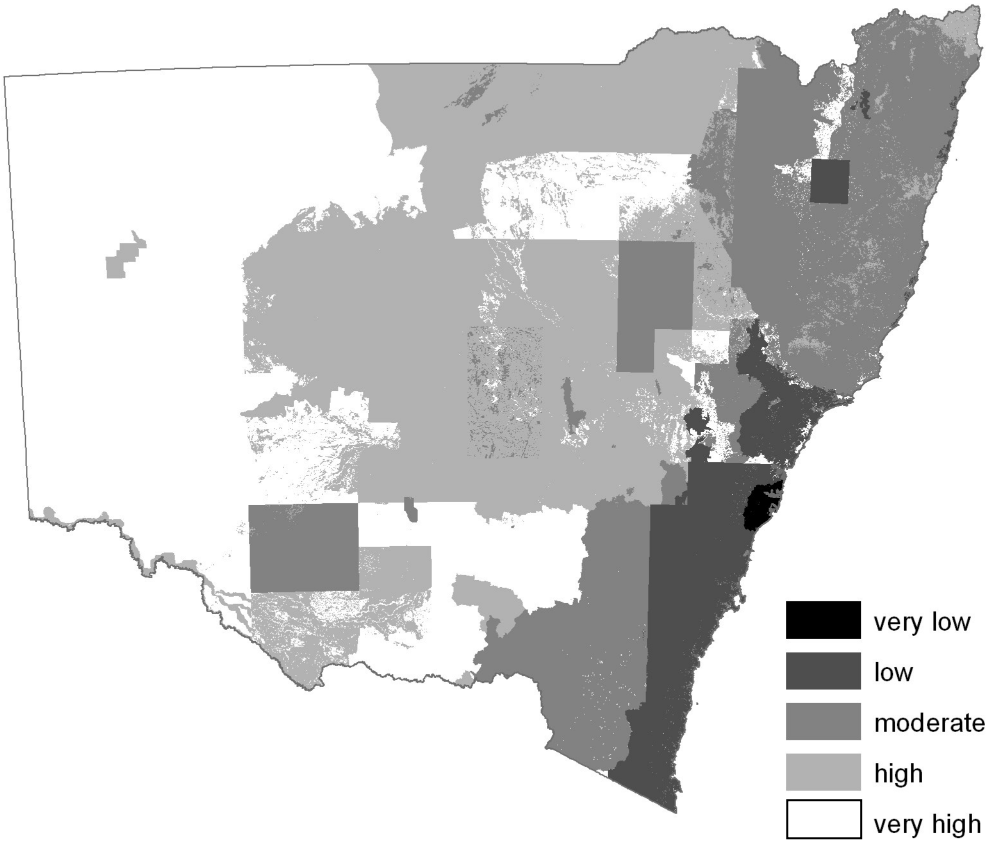

Fig. 3a. Spatial patterns in uncertainty of the underlying source maps used in the compilation of the NSW map of vegetation formations (version 3.0).

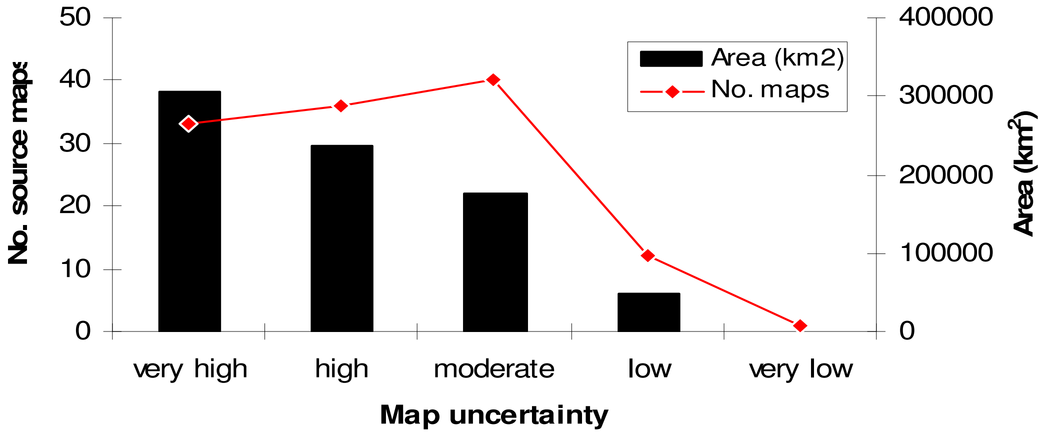

Fig. 3b. Number and area of source maps in each uncertainty class (see Table2).

Approximately 10 % of NSW is covered by source maps with high or very high levels of classification skill, and a further 20% covered by maps of intermediate classification skill (Fig. 4).

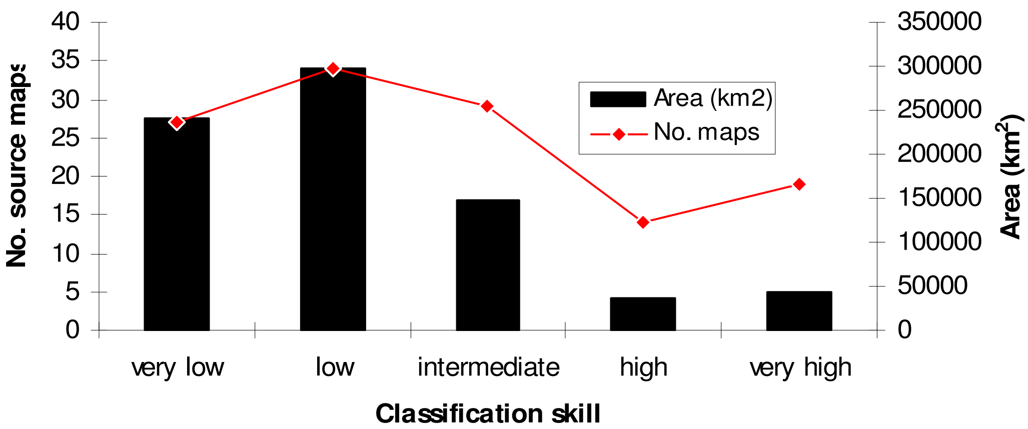

Fig. 4. Number and area of source maps in each level of classification skill (see Methods for explanation of levels).

Approximately 45 % of NSW is covered by source maps with fine or intermediate thematic resolution, and a further 1% covered by maps in which the classification is likely to be overfitted to thematic information (Fig. 5).

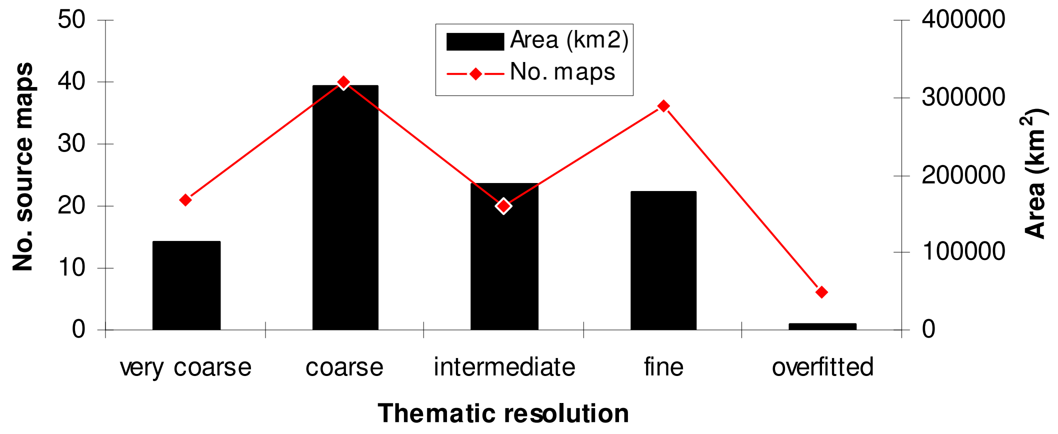

Fig. 5. Number and area of source maps in each level of thematic resolution (relative number of map units).

Just over 10% of NSW is covered by source maps with fine spatial resolution (imagery scale 1:25 000 or finer, minimum patch size of 1 ha or smaller), of which 1% is very fine (≥1:5 000, ≤0.5 ha). A further 30% is covered by source maps with intermediate spatial resolution (1:25 000 - 1:50 000, ≤5 ha) (Fig. 6).

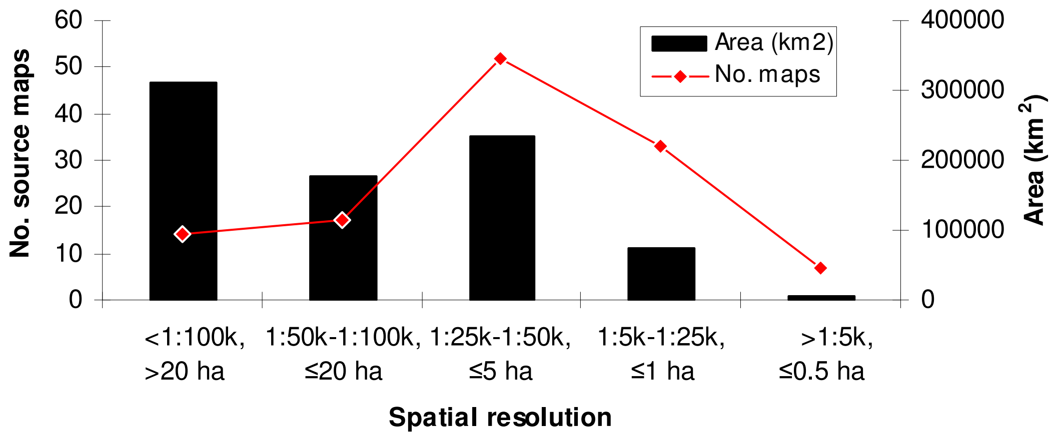

Fig. 6. Number and area of source maps in each level of spatial resolution (scale of base imagery, minimum mapped patch size).

Approximately 35 % of NSW is covered by source maps that were based on or updated with imagery that was captured since the beginning of year 2000, and a further 35% covered by maps based on imagery captured during 1990-2000 (Fig. 7).

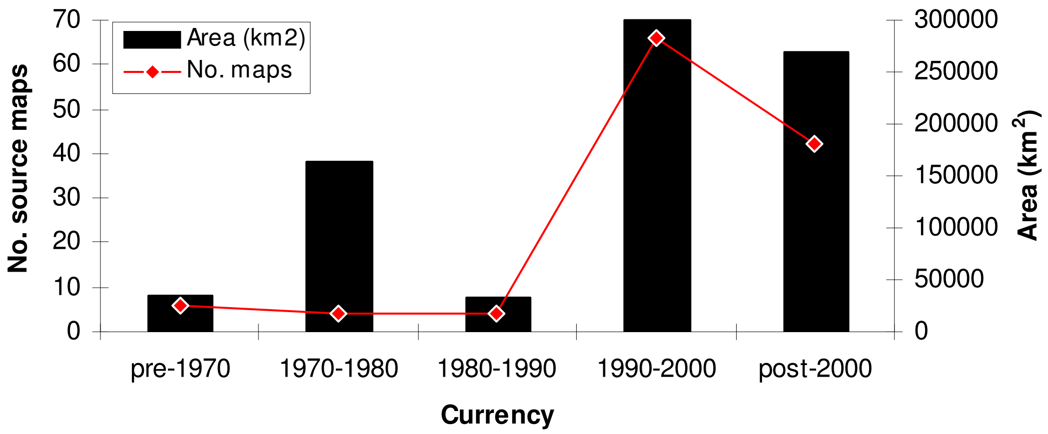

Fig. 7. Number and area of source maps in each level of currency (date of base or update imagery).

Descriptions of Vegetation Formations, their distributions & fuel characteristics

The 16 vegetation formations and subformations occurring in New South Wales are described below based on Keith (2004). An identification key to the formations is provided in Appendix 2. Fig. 2 shows their distributions based on the map data assembled in version 3.0 of the NSW vegetation map as described above. The bushfire fuel characteristics of the formations are currently being researched by Dr Penny Watson (University of Wollongong Fuels Modelling Project). Qualitative characteristics of fuels are described below.

Rainforests

Forests of broad-leaved mesomorphic trees, with vines, ferns and palms. They include a broad range of tree species but generally lack eucalypts except where these are emergent from a canopy of other trees. All forms of rainforest are characterised by a closed and continuous tree canopy composed of relatively soft, horizontally-held leaves. They range from subtropical forests with palms, tall complex tree canopies up to 40 m tall, epiphytic ferns and mosses, to dry vine thickets, which may be no more than 4 m tall and contain some sclerophyllous plants. Rainforests also include temperate and littoral communities. They occur mainly on the coast and escarpment in areas that are reliably moist, mostly free of fire and have soils of moderate to high fertility. Some forms of rainforest (dry rainforest, vine thickets) extend to the western slopes and outlying ranges, but their distribution is restricted.

Rainforest fuels include leaf litter, woody debris and perennial standing biomass. Litter generally has high rates of turnover. Their flammability is generally low due to moisture content, which remains high except under prolonged periods of hot dry weather. Fuels of dry rainforests and vine thickets are prone to dry more frequently than those of subtropical or cool temperate rainforests. Some rainforest fuels also have relatively high concentrations of mineral salts, which may reduce flammability. Depending on conditions, rainforests may act as barriers to fire spread, although incursion has been documented.

Wet sclerophyll forests (shrubby)

Tall forests dominated by straight-trunked eucalypts (especially blue gums and ashes), with a prominent understorey or subcanopy of soft-leaved shrubs and/or tree ferns. The ground layer is dominated by ferns, forbs and occasional grasses. The open tree canopy is commonly 30 – 50 m tall, occasionally exceeding 70 m. The combination of hard-leaved 'sclerophyllous' tree canopy and soft-leaved 'mesophyllous' subcanopy or shrub stratum understorey plants sets the shrubby wet sclerophyll forests apart from other structural forms of vegetation. In New South Wales the shrubby wet sclerophyll forests are limited to the coastal ranges and eastern side of the escarpment wherever moderately fertile soils occur in areas of high rainfall, although outliers do occur on western extensions of the Great Dividing Range.

The fuels occurring within this formation include leaf litter, woody debris and perennial standing biomass. Accumulation rates of litter and woody debris can be extremely high. High fuel moisture content usually limits fire spread, but fuels become available for combustion under prolonged warm dry weather. Crown fires may occur under extreme conditions. Fuel elements such as loose bark or small leafy branches may detach when ignited and promote fire spread through spotting, especially in forests dominated by ash eucalypts.

Wet sclerophyll forests (grassy)

Grassy wet sclerophyll forests resemble the shrubby subformation, but have a less developed stratum of mesophyllous small trees and shrubs, which allows greater abundance of grasses in the groundlayer. Dominant eucalypts often exceed 40 m tall, but on average the tree canopy is not as tall as may be attained in shrubby wet sclerophyll forests and a more diverse range of species may be present (including blue gums, grey gums, ashes, mahoganies, bloodwoods and ironbarks). The grassy wet sclerophyll forests occur throughout the coast and escarpment and may extend to slightly drier sites, including the edge of the tableland, than shrubby wet sclerophyll forests.

Although they share many similarities, two salient differences distinguish the bushfire fuel characteristics of grassy and shrubby wet sclerophyll forests. Firstly, mid-storey fuel elements of standing biomass are less abundant in grassy forests than shrubby forests, and secondly, ground layer fuel elements, particularly grasses, are more abundant in grassy than shrubby forests. Reduced shading from mid-storey shrubs allows greater drying of the ground and litter layer in grassy wet sclerophyll forests. Consequently, their fuels are ignitable under a broader range of antecedent weather conditions than those of shrubby wet sclerophyll forests. However, their less developed mid-storey may also reduce the vertical connectivity of fuels which may sometimes inhibit progression of surface fires into crown fires. The greater variety of eucalypt bark types present in grassy wet sclerophyll forests may also influence the availability of embers for spotting.

Grassy Woodlands

Grassy woodlands are dominated by well-spaced eucalypts (mostly boxes and red gums) with a conspicuous and diverse ground cover of grasses and herbs and a typically sparse layer of shrubs. Trees may exceed 30 m tall. Perennial tussock grasses form the structural matrix of the ground layer, while perennial herbs occupy the inter-tussock spaces, supplemented by various ephemeral grasses and herbs, which emerge after sufficient rain. The grassy woodlands originally formed an extensive band on fine-textured soils of moderate to high fertility, principally on flat to undulating terrain, running from southern Queensland to central Victoria through the tablelands and western slopes of New South Wales in areas where the annual rainfall is 500–900 mm. Outliers also occur in the major rain shadow valleys along the New South Wales coast (e.g. Clarence, Hunter, Cumberland, Bega), where the rainfall varies from 700 to 1000 mm. This distribution is now highly fragmented by crop fields and grazing pastures.

The key fuel elements of grassy woodlands include perennial grasses, which cure over early summer (winter grasses) or late summer (summer grasses). Ephemeral components may add to this dynamic pattern. As many of these components are palatable, grazing may influence their abundance. The ground fuel also includes leaf litter and woody debris shed from trees and shrubs, which is less sensitive to grazing. The open tree and shrub layers permit rapid drying of ground fuels, but limit vertical connectivity of standing biomass. Consequently, surface fires are more typical than crown fires. The bark types of dominant eucalypts also limit the capacity for spotting when crown fires occur.

Grasslands

The uniting features of grasslands include dominance by large perennial tussock grasses, a lack of woody plants, the presence of broad-leaved herbs in the inter-tussock spaces, and their ecological association with fertile, heavy clay soils on flat topography in regions with low to moderate rainfall. In drier climates, they may have a significant ephemeral component amongst perennial grass tussocks. Principal areas of occurrence include clay headlands and offshore islands, the Monaro tableland, Liverpool plains, Darling riverine plains, and the Riverina. Like grassy woodlands, their distribution has been heavily fragmented.

Grassland bushfire fuels resemble those of grassy woodlands, but lack trees, shrubs and their litter that they produce. The ground layer dries rapidly after rain, cures seasonally, may accumulate rapidly after fire although some variation may be expected between temperate, subtropical and semi-arid climates. When dry, grasslands may support rapid rates of fire spread. Litter may accumulate in the form of ‘thatch’. Major fuel components are palatable and therefore sensitive to grazing.

Dry sclerophyll forests (shrub/grass)

The shrub/grass subformation of dry sclerophyll forests is dominated by eucalypts sometimes exceeding 30 m tall, and has a shrubby understorey with conspicuous component of grasses in the ground layer. The shrubs may include a mixture of sclerophyllous and non-sclerophyllous species from the Asteraceae, Dilleniaceae, Euphorbiaceae, Fabaceae and Myrtaceae families. The shrub/grass dry sclerophyll forests form a transition between the grassy woodlands and the shrubby subformation of dry sclerophyll forest: the stature and composition of their tree stratum, the relative proportion of shrubs and grasses in the understorey, and the soils on which they occur, are all intermediate between these two other forms. The forests are widespread on the coast, escarpment and tablelands, extending to the western slopes. They span a wide range of altitude and rainfall and occupy soils of moderately low fertility.

These forests possess a diverse array of fuel components, including leaf litter, woody debris, a perennial grassy ground layer and standing woody biomass. The open structure of the vegetation permit rapid drying so that fuel moisture levels do not limit flammability for prolonged periods. The tussock grass component cures seasonally and is sensitive to grazing. Shrubs and low tree branches provide vertical continuity of fuel to the tree canopies and a diverse range of barck types including stringybarks and ashes promote the potential for spotting.

Dry sclerophyll forests (shrubby)

The shrubby dry sclerophyll forests differ from the shrub/grass subformation in having a lower tree canopy (usually <20-25 m) and greater abundance and diversity of sclerophyll shrubs in their understorey, particularly in the Proteaceae, Myrtaceae, Fabaceae and Ericaceae families. They also generally lack a substantial tussock grass component in their ground layer, although tussock grasses maintain a presence in lower rainfall climates. Instead the ground layer includes a sparser cover of sclerophyll sedges and rushes and scattered herbs. The two subformations share similar distributions from the coast to the western slopes, but the shrubby dry sclerophyll forests occur on more depauperate sandy loams and sands.

The major fuel components of shrubby dry sclerophyll forests include leaf litter, woody debris and standing woody plant biomass. Fuels are little-affected by grazing due to the unpalatable nature of these components. Rates of fuel drying depend on shrub density and topographic shelter, but relatively open structure generally prevents fuel from maintaining high moisture levels for long periods. The high cellulose:mineral composition and small particles size of fuels also promotes flammability. Shrubs and low tree branches provide vertical continuity of fuel to the tree canopies and a diverse range of bark types including stringybarks and ashes promote the potential for spotting.

Heathlands

Heathlands are sclerophyll shrublands, mostly treeless but may include mallee eucalypts or scattered emergent eucalypt or banksia trees. The shrub canopy may be closed or open and typically has small leaves. The ground layer includes sclerophyll sedges and rushes and occasional herbs. Heathlands are scattered along the coast and escarpment on rocky or sandy soils.

The principal fuel component in heathlands are the canopies of living shrubs which are highly flammable due to high cellulose:mineral composition and small particle sizes. The well-aerated shrub canopies dry rapidly after rainfall and their flammability is generally not limited by high moisture content. The pattern of fuel accumulation is governed by whether the dominant shrubs are obligate seeders or resprouters, the latter reaching roughly stable biomass earlier than seeders, which may continue to increase in biomass for two or more decades. Litter fuels are generally compacted and poorly aerated, and therefore have limited capacity to propagate fire on their own.

Alpine Complex.

Alpine vegetation encompasses an essentially treeless mosaic of heathlands, herbfields, grasslands and bogs in which small-leaved shrubs, herbs and tussock grasses are seasonally dormant and snow-tolerant. In New South Wales, this formation is found only on the Koscuiszko alpine plateau and extends south-west into Victoria along a series of high mountain plateaus.

Fuels of the Alpine Complex are comprised of standing biomass and leaf litter, primarily thatch produced by grass tussocks. Biomass levels are relatively small and slow to accumulate. Despite their exposure and open structure, they retain high moisture content for most of the year due to prevailing cold moist weather conditions. Consequently, they are capable of propagating fire only during restricted periods of extreme fire weather.

Freshwater Wetlands

Freshwater wetlands include a diverse range of essentially treeless communities dominated by shrubs, sedges or herbs that are capable of tolerating prolonged periods of inundation or waterlogging. Inundation may be essentially permanent (in perennial wetlands) or punctuated by periods of dryness that may extend for months to decades (in ephemeral wetlands). As a consequence of this diversity of water regimes, as well as variation in catchment characteristics, freshwater wetlands encompass a range of structural forms including dense graminoid heathlands, open shrublands, sedgelands, and aquatic herbfields. Submerged, floating, emergent and amphibious plant growth forms are represented. Freshwater wetlands are locally restricted, but scattered throughout New South Wales. Their greatest extent is west of the Great Divide where most wetlands are ephemeral.

Bushfire fuel characteristics vary greatly between the six vegetation classes within the freshwater wetland formation. Coastal Heath Swamps and Montane Bogs and Fens are the most flammable classes due to their dense standing biomass of shrubs and sedges, which re-establishes rapidly after fire and dries after antecedent rain more rapidly on coastal lowlands than in cool temperate climates. These wetlands also contain peat, which may undergo prolonged combustion if sufficiently dry at the time of ignition. In contrast, Coastal Freshwater Lagoons and Montane Lakes are very rarely flammable due to the longevity of standing water and low density of fuel. Although their water regime is more ephemeral, the flammability of Inland Floodplain Swamps and Inland Floodplain Shrublands is also limited. Occasionally their standing biomass is sufficiently continuous and dry to carry a fire.

Forested Wetlands

Forested wetlands are dominated by sclerophyllous trees (eucalypts, paperbarks or she-oaks) 5-40 m tall with an understorey of hydrophytic shrubs, sedges, ferns and herbs. Both the tree canopy and the understorey are often relatively dense, although this varies depending on the water regime. Forested wetlands include a diverse range of communities associated with riparian corridors and floodplains throughout New South Wales.

Like freshwater wetlands, the fuel characteristics of forested wetlands vary considerably between classes within the formation. The Coastal Swamp Forests are the most flammable, as they are dominated by paperbarks and eucalypts that produce copious quantities of flammable litter. Shrubs and large sedges make up a vertically and laterally continuous fuel structure in the understorey, but their high density combined with a dense tree canopy and high water table can maintain high fuel moisture content for varying periods. Inland Riparian Forests have similar characteristics, but the trees may be taller and less dense. The Casuarina-dominated forests of the coastal floodplains are less flammable because their foliage has relatively high mineral salt content and produces a well-compacted, poorly aerated litter layer. In addition, their sparse or absent shrub layer limits connectivity of understorey fuels. Eastern Riverine Forests have similar characteristics though they occur in narrow bands juxtaposed with more flammable vegetation and tree foliage is likely to be lower in mineral salts than on the floodplains.

Saline Wetlands

Saline wetlands are characterised by a range of specialised plant forms equipped to tolerate high concentrations of salt and periodic or permanent inundation. The formation includes Mangrove Forests, Saltmarshes, Seagrass Meadows and Inland Saline Lakes, which vary greatly in species composition and structural form. These wetlands are locally restricted, with the majority occurring in depositional environments along the marine/terrestrial interface, although Inland Saline Lakes are restricted within the arid zone.

Despite the wide variation in structure and composition of saline wetlands, all exhibit extremely low flammability as a consequence of standing water and high moisture content, high mineral salt content and low fuel connectivity. Fires may sometimes penetrate from adjoining vegetation, but rarely propagate over large areas.

Semi-arid Woodlands (grassy)

The grassy semi-arid woodlands are dominated by eucalypts or wattles. Trees may be widely separated and the understorey comprises a sparse layer of shrubs (most typically chenopods) and a highly variable ground layer of perennial and ephemeral grasses and herbs. Brigalow Clay Plain Woodlands are an exception, as these can have quite dense cover of trees with a minimal understorey. Structurally, the eucalypt-dominated grassy semi-arid woodlands resemble the grassy woodlands formation, but are distinguished by the abundance of chenopods relative to other shrub species and a greater ephemeral component in the ground layer. The grassy semi-arid woodlands are found on clay soils within depositional landscapes throughout the semi-arid zone.

This formation has similar fuel characteristics to grassy woodlands, but there are several salient differences. Firstly, trees are generally sparser and hence contribute less leaf litter and woody debris to the ground layer. Secondly, the open chenopod shrub layer is less flammable than one composed of other shrub species that typify grassy woodlands. Thirdly, the stronger ephemeral component of the ground layer makes it more prone to fluctuation with inter-annual and seasonal variation in rainfall. Like grassy woodlands, however, much of the ground vegetation is palatable and therefore potentially sensitive to grazing. Brigalow Clay Plain Woodlands may have extremely sparse or non-existent shrub and ground layers, which greatly curtails the ability of fires to spread.

Semi-arid Woodlands (shrubby)

The shrubby subformation of semi-arid woodlands includes a more varied group of vegetation classes than the grassy subformation. Most are dominated by eucalypts, although some include wattles, pines or she-oaks. Their shrub layer varies in density and includes a range of species, though chenopods are usually not prominent (except in one class). The ground layer includes a relatively sparse layer of perennial grasses with a large ephemeral component that emerges after significant rainfall. The shrubby semi-arid woodlands are extensively distributed on dune landscapes, peneplains and ranges throughout the semi-arid zone.

The fuel characteristics of shrubby semi-arid woodlands vary greatly. Mallee vegetation can be highly flammable. Hummock grasses and shrubs are a key components of understorey fuels but are usually laterally disconnected unless antecedent rain promotes growth of ephemeral grasses and herbs. Mallee eucalypts have combustible canopies capable of spotting and produce copious flammable leaf litter and woody debris. Fuels are slow to accumulate after fire, but moisture content is rarely limiting. At the other extreme, Semi-arid Sandplain Woodlands are dominated by trees and shrubs (belah, chenopods) that produce low-flammability foliage and low amounts of litter and woody debris which are compacted and poorly aerated. Standing biomass in the ground layer is also generally sparse. Other woodlands in this formation are dominated by arborescent eucalypts and may have appreciable flammable shrub and grass components in their understories, although grass cover, and hence ground-fuel connectivity, is sensitive to antecedent rains and grazing.

Arid Shrublands (chenopod)

Chenopod arid shrublands are dominated by saltbushes, bluebushes and copperburrs mostly less than 1.5 m tall. Amongst the dominant shrubs is a mainly ephemeral ground layer of grasses and herbs. They are widespread on lime-rich ‘calcareous’ or saline soils, and which principally occur on residual alluvial plains, aeolian sandplains and gibber landscapes, principally in south-west New South Wales, but extending into subtropical latitudes.

These shrublands are characterised by low flammability. The standing perennial biomass produces low levels of litter and its foliage has relatively high concentrations of mineral salts. Ground layer biomass is generally low, limited by herbivory and has limited lateral connectivity. Cured growth of ephemeral herbage promoted by antecedent rains may occasionally support propagation of fire.

Arid Shrublands (acacia)

This subformation is dominated by various species of *Acacia* and other large shrubs up to about 10m tall. Shrubs are typically spaced widely. Ephemeral herbs and grasses dominate the groundlayer. Hummock grasses may be present at conspicuous densities in some communities. Acacia arid shrublands dominate in the far north-west of the state on silica-rich soils of sandplains and stony peneplains.

Although acacias and other shrubs in the arid shrublands subformation are more flammable than chenopods, fire spread is limited by the connectivity of ground fuels and is therefore highly dependent on the influence of antecedent rains on ephemeral plants. Fuel moisture content is almost never limiting, litter and woody debris are patchily distributed and generally scarce. The presence of hummock grasses enhances the flammability of the some communities within this subformation, although lateral connectivity may still be limited in the absence of abundant ephemeral herbage unless there are strong winds propelling embers between isolated fuel elements. Accumulation of perennial fuels after fire is very slow.

Discussion

The map data synthesised in this report represents the first 'seamless' vegetation map available for modelling fire spread and behaviour across New South Wales. While this is a considerable advance in reducing the interpretive difficulties associated with use of many different maps for different regions, substantial limitations remain in the reliability of the spatial data that may affect the outcomes of fire models. To promote user awareness of these limitations and assist in evaluating the risk of resulting errors in fire model outputs, the spatial data have been attributed with the identity and origin of individual source maps and their salient properties.

The limitations of the vegetation map data fall into two main categories: those associated with the underlying map data themselves; and those associated with the suitability of vegetation formations as a framework for representation of different bushfire fuel types.

Limitations in underlying map data

The current compilation includes more than 100 vegetation map data sets. Additional data sets are available for NSW, but these are yet to be assessed due to limitations on available resources. These include two recent maps of vegetation in the Murray catchment and a considerable number of maps for individual conservation reserves. Incorporation of some of these maps would improve the overall reliability of the compilation map.

Although the fire model is capable of processing input data in a format with 30-metre spatial resolution, only a small portion (<1%) of map data was produced from base imagery at this level of resolution (Fig. 6). This mapping with very high spatial resolution principally covers the catchments of metropolitan Sydney (DECCW 2009). While a number of maps are available electronically in 25 m pixel (or equivalent polygon) format, an unknown proportion of this mapping detail could be spurious because it was derived from imagery of coarser spatial scales. For much of the eastern portion of NSW, current mapping can be regarded as supporting reliable representation of vegetation patches in the order of 5 ha, while reliability of smaller mapped patches is more limited and variable. This may affect fire modelling outcomes in landscapes characterised by patches <5 ha that have contrasting fuel characteristics to the matrix (e.g. fragmented rural landscapes, forested landscapes with rainforest gullies).

Appreciable areas of NSW are covered by mapping with coarse thematic resolution or low classification skill. However, this is not expected to have major impacts at the level of vegetation formations, as most mapping is of sufficient thematic resolution and skill to support reasonably reliable diagnosis of the 16 formations and subformations. Furthermore, most of the mapping with the lowest thematic resolution and classification skill covers areas of western NSW that are not highly fire-prone.

Most of NSW is covered by mapping derived from or updated with imagery that was captured since 1990. Changes in vegetation cover since then may affect the outcomes of fire modelling. These changes may include vegetation clearing, forestry operations, post-clearing regrowth or plantings. Regular updating of respective source maps would help to reduce these effects. Incorporation of vegetation change outputs from the SLATS project would also improve the overall currency of vegetation mapping. These outputs include detectable changes in vegetation cover determined by interpretation of recent satellite imagery on a statewide basis (2004 – present). While detectability of change is limited for sparse vegetation, incorporation of these data should improve the currency of mapping for much of eastern NSW.

Finally, it has not been possible to assess the accuracy of mapping from different sources with currently available resources. Such an assessment would require independent, spatially explicit field observations of vegetation formations (see Keith & Simpson 2006 for an example assessment of binary vegetation maps). These cross-validation data could be compiled from available vegetation plot data held by DECCW, for which the observed vegetation formation would need to be diagnosed and attributed. While the currently available data do not provide a comprehensive coverage of all vegetation formations throughout NSW, the coverage is likely to be sufficient to provide useful accuracy estimates for much of the fire-prone vegetation in the state.

Limitations in bushfire fuel classification

Current practice in NSW uses vegetation formations and subformations as a framework for classifying bushfire fuels that have similar properties of flammability and accumulation. The descriptions above highlight several formations and subformations that encompass great variation in fuel characteristics. In particular, freshwater wetlands, semi-arid woodlands (shrubby) and arid shrublands (acacia) each include some highly flammable and some essentially non-flammable fuel types. Other formations and sub-formations may also encompass significant heterogeneity in fuel types. For example, the University of Wollongong Fuels Modelling Project is elucidating considerable variation in fuel characteristics within both subformations of dry sclerophyll forests (P. Watson, pers. comm., Sept 2010). Heterogeneity in fuel type map units is likely to have a greater impact on fire model outputs when models are applied over large landscapes than applications relating to small areas of vegetation.

The limitations in bushfire fuel classification could be reduced by using an alternative classification framework that more closely represented the characteristics of bushfire fuels. Such a framework could be based on vegetation classes (described in Keith 2004), for which a statewide map could be compiled from available vegetation source maps, similar to that presented in this report for vegetation formations. Vegetation classes having similar bushfire fuels could then be lumped within appropriate map units for fuel types.

A further issue concerns bushfire fuel types associated with non-indigenous vegetation. These include plantations (eucalypts and pines), pastures, croplands and other cleared land. It may be possible to incorporate some information on the spatial distribution of these fuel types by investigating land use maps. These land use maps will have similar issues of resolution, currency and reliability to those identified above.

Recommendations

The reliability of statewide vegetation mapping for modelling fire spread and behaviour in NSW could be improved with the following enhancements:

1. Develop and apply an alternative classification framework and map for bushfire fuels based on NSW vegetation classes (*sensu* Keith 2004) to reduce the heterogeneity in fuel characteristics within map units.
2. Incorporate vegetation change outputs from the SLATS project to improve the overall currency of mapping for fuel types.
3. Incorporate available source maps that are yet to be evaluated into the compilation for areas of NSW where this would substantially improve the reliability of the composite map.
4. Target future regional mapping priorities to improve reliability by upgrading classification skill, thematic resolution, spatial resolution and currency in fire-prone areas of NSW that are currently covered by maps of class 3 reliability or less.
5. Compile appropriate validation data, develop and apply methods for assessing the accuracy of source vegetation maps used in the compilation.
6. Evaluate the performance of fire modelling and its sensitivity to varying uncertainty in vegetation mapping by retrospective analysis of fire spread across landscapes with different levels of map uncertainty.

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Appendix 1. Map attributes for 105 candidate source vegetation maps and 7 supplementary models used in the compilation of the NSW vegetation map (version 3.0). Note some maps have multiple entries where divided into sections.

Map name	VIS-ID	Classification Skill	Thematic resolution	Spatial resolution	Uncertainty Class	Currency
Albury	2907	moderate	very coarse	1:5000<scale≤1:25000, patches ≤1 ha	high	2000-04
Anabranch-Mildura	1873	very low	coarse	scale>1:100000, patches >20 ha	very high	1964-1965
Avisford NR		moderate	intermediate	1:5000<scale≤1:25000, patches ≤1 ha	moderate	2000-04
Balranald	3178	very low	intermediate	scale>1:100000, patches >20 ha	very high	1961-1970, updated 1991
Barton NR	837	very high	very coarse	1:25000<scale≤1:50000, patches ≤5 ha	high	1993
Boginderra NR	848	very high	coarse	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1994
Booligal-Hay-Deniliquin	3179	very low	coarse	scale>1:100000, patches >20 ha	very high	1970-1982, updated 1992
Booligal-Hay-Deniliquin	3179	very low	coarse	scale>1:100000, patches >20 ha	very high	1970-1982, updated 1992
Boorowa	1626	moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1997
Bourke Shire	1661	low	coarse	1:50000<scale≤1:100000, patches ≤20 ha	high	1998
Brewarrina Shire	1659	low	coarse	1:50000<scale≤1:100000, patches ≤20 ha	high	1998, updated 2004
Brigalow Belt South	1028	low	fine	1:25000<scale≤1:50000, patches ≤5 ha	high	2000-2001
Brigalow Belt South	1028	low	fine	1:25000<scale≤1:50000, patches ≤5 ha	high	2000-2001
Byron Shire 1998	6	very low	intermediate	1:5000<scale≤1:25000, patches ≤1 ha	very high	1991
Byron Shire 2008		low	intermediate	1:5000<scale≤1:25000, patches ≤1 ha	high	2000-04
Central Hunter valley	2295	high	intermediate	1:5000<scale≤1:25000, patches ≤1 ha	low	1993-2000
Cessnock	184	very high	fine	1:5000<scale≤1:25000, patches ≤1 ha	low	2004
Coastal Floodplain model		high	coarse	1:5000<scale≤1:25000, patches ≤1 ha	moderate	2000-04
Cobar	3332	low	intermediate	1:25000<scale≤1:50000, patches ≤5 ha	high	2001
Cocopara NP	792	very high	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	c. 1990
Coffs Harbour		low	coarse	scale≤1:5000, patches ≤0.5 ha	high	2004
Coffs Harbour addition		low	very coarse	1:5000<scale≤1:25000, patches ≤1 ha	high	2004
Copperhannia NR	868	very high	intermediate	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1994
Curlewis	803	low	overfitted	1:25000<scale≤1:50000, patches ≤5 ha	high	1998
Dapper NR	872	very high	coarse	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1992
East Walgett	804	low	fine	1:25000<scale≤1:50000, patches ≤5 ha	high	pre-1998
Estuarine macrophytes CCA		moderate	fine	scale≤1:5000, patches ≤0.5 ha	moderate	1997-2004

Map name	VIS-ID	Classification Skill	Thematic resolution	Spatial resolution	Uncertainty Class	Currency
Eugowra NR	880	very high	very coarse	1:25000<scale≤1:50000, patches ≤5 ha	high	c. 1995
Gibraltar Range NP		very high	coarse	scale≤1:5000, patches ≤0.5 ha	moderate	c. 2004
Goobang NP	1051	high	overfitted	1:25000<scale≤1:50000, patches ≤5 ha	moderate	pre-1997
Gundagai	2910	very low	very coarse	1:5000<scale≤1:25000, patches ≤1 ha	very high	1998
Guy Fawkes Addition		moderate	intermediate	scale≤1:5000, patches ≤0.5 ha	moderate	c. 1995
Guy Fawkes River NP		moderate	fine	1:5000<scale≤1:25000, patches ≤1 ha	moderate	1991-1994
Guyra	234	high	intermediate	1:5000<scale≤1:25000, patches ≤1 ha	low	1989
Hunter-Macleay		moderate	very coarse	1:50000<scale≤1:100000, patches ≤20 ha	high	1998
Kosciuzko alpine		high	coarse	1:5000<scale≤1:25000, patches ≤1 ha	moderate	c. 1970
Kosciuzko subalpine		very low	intermediate	1:50000<scale≤1:100000, patches ≤20 ha	very high	c. 1970
Lachlan CMA	3780	low	intermediate	1:50000<scale≤1:100000, patches ≤20 ha	high	1997-2005
Lachlan CMA	3780	low	intermediate	1:50000<scale≤1:100000, patches ≤20 ha	high	1997-2005
Lismore 2008	20	moderate	very coarse	1:5000<scale≤1:25000, patches ≤1 ha	high	2005
Little River	912	moderate	very coarse	scale≤1:5000, patches ≤0.5 ha	high	1995
Liverpool Plains grasslands		moderate	coarse	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1940-1970
Liverpool Plains grasslands		moderate	coarse	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1940-1970
Lord Howe Island	1113	high	fine	1:5000<scale≤1:25000, patches ≤1 ha	low	1966
Lower Hunter Central Coast	2227	high	fine	1:5000<scale≤1:25000, patches ≤1 ha	low	1993-98
Lower Macquarie-Castlereagh	817	low	fine	1:50000<scale≤1:100000, patches ≤20 ha	high	c. 1995
Merriwa	2348	very low	fine	1:25000<scale≤1:50000, patches ≤5 ha	very high	1975-1990
Mid Lachlan		low	fine	scale>1:100000, patches >20 ha	very high	c. 1995
Monaro	762	low	very coarse	scale>1:100000, patches >20 ha	very high	c. 1954
Monaro Grasslands	2513	moderate	fine	1:5000<scale≤1:25000, patches ≤1 ha	moderate	2000-03
Monaro Lakes		very high	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	c. 1995
Moree grassland sites		high	very coarse	1:50000<scale≤1:100000, patches ≤20 ha	high	2002
Moree NW slopes & plains	822	low	overfitted	1:25000<scale≤1:50000, patches ≤5 ha	high	pre-1998
Moree Plains Shire		low	very coarse	scale>1:100000, patches >20 ha	very high	c. 1995
Mt Canobolas SCA	1824	very high	coarse	1:5000<scale≤1:25000, patches ≤1 ha	moderate	pre-1999
Murray River riparian vegetation		low	coarse	1:5000<scale≤1:25000, patches ≤1 ha	high	pre-1986
Murray valley	1089	very low	very coarse	1:5000<scale≤1:25000, patches ≤1 ha	very high	1990-2000
Murray valley	1089	very low	very coarse	1:5000<scale≤1:25000, patches ≤1 ha	very high	1990-2000
Mutawintji NP	823	high	very coarse	1:25000<scale≤1:50000, patches ≤5 ha	high	1995-2002

Map name	VIS-ID	Classification Skill	Thematic resolution	Spatial resolution	Uncertainty Class	Currency
Nambucca	500	high	coarse	1:5000<scale≤1:25000, patches ≤1 ha	moderate	1997
Nandewar bioregion		moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1991-2002
Nandewar bioregion		moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1991-2002
New England NP		very high	coarse	1:5000<scale≤1:25000, patches ≤1 ha	moderate	pre1999
New England tableland		low	very coarse	scale>1:100000, patches >20 ha	very high	c. 1994
Northeast CRA v2		moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1990-1996
Northeast CRA v3		moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1998
North-east Rainforests		low	very coarse	1:25000<scale≤1:50000, patches ≤5 ha	high	1998
Northwest NSW	825	very low	coarse	scale>1:100000, patches >20 ha	very high	1971-1980
NSWmap v2					very high	
NVMP Cobborah 1:250k	2101	moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1998-2003
NVMP Cobborah 1:250k	2101	moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1998-2003
NVMP Cobborah 1:250k	2101	moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1998-2003
NVMP Cobborah 1:250k	2101	moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1998-2003
NVMP Cobborah 1:250k	2101	moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1998-2003
NVMP Deniliquin 1:250k	874	low	coarse	1:25000<scale≤1:50000, patches ≤5 ha	high	2003
NVMP Hay 1:250k	2215	moderate	coarse	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1997
NVMP Inverell 1:250k	2129	moderate	very coarse	1:25000<scale≤1:50000, patches ≤5 ha	high	1996-2001
NVMP Nth Lachlan-Bogan	1595	moderate	intermediate	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1996-1997
Plains Wanderer Habitat	826	low	overfitted	1:25000<scale≤1:50000, patches ≤5 ha	high	1996-1997
Pooncarie	972	very low	intermediate	scale>1:100000, patches >20 ha	very high	1991-1993
Richmond River Catchment		moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	2000
Riverina grassland		low	coarse	1:25000<scale≤1:50000, patches ≤5 ha	high	1995
Riverina reconstructed	974	low	very coarse	scale>1:100000, patches >20 ha	very high	c. 1995
South-east NSW	2230	very high	fine	1:5000<scale≤1:25000, patches ≤1 ha	low	2002
Southeast Riverina	828	very low	very coarse	1:50000<scale≤1:100000, patches ≤20 ha	very high	pre-1953
Southern CRA		moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1997-1998
Southern CRA		moderate	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1997-1998
Southern Mallee	1044	low	coarse	scale>1:100000, patches >20 ha	very high	2004
Southern Mallee	1044	low	coarse	scale>1:100000, patches >20 ha	very high	2004
Southwest slopes	2907, 2910	very low	coarse	1:25000<scale≤1:50000, patches ≤5 ha	very high	1998
Southwest slopes	2907, 2910	very low	coarse	1:25000<scale≤1:50000, patches ≤5 ha	very high	1998

Map name	**VIS-ID**	**Classification Skill**	**Thematic resolution**	**Spatial resolution**	**Uncertainty Class**	**Currency**
Southwest slopes	2907, 2910	very low	coarse	1:25000<scale≤1:50000, patches ≤5 ha	very high	1998
Southwest slopes	2907, 2910	very low	coarse	1:25000<scale≤1:50000, patches ≤5 ha	very high	1998
Southwest slopes	2907, 2910	very low	coarse	1:25000<scale≤1:50000, patches ≤5 ha	very high	1998
Southwest slopes	2907, 2910	very low	coarse	1:25000<scale≤1:50000, patches ≤5 ha	very high	1998
Southwest slopes	2907, 2910	very low	coarse	1:25000<scale≤1:50000, patches ≤5 ha	very high	1998
Southwest slopes	2907, 2910	very low	coarse	1:25000<scale≤1:50000, patches ≤5 ha	very high	1998
Southwest slopes	2907, 2910	very low	coarse	1:25000<scale≤1:50000, patches ≤5 ha	very high	1998
Southwest slopes	2907, 2910	very low	coarse	1:25000<scale≤1:50000, patches ≤5 ha	very high	1998
Sydney Metropolitan CMA		very high	fine	scale≤1:5000, patches ≤0.5 ha	very low	2005
Sydney Sandstone		very low	very coarse	1:50000<scale≤1:100000, patches ≤20 ha	very high	2000-2004
Tamworth-Manilla-Cobbadah		high	intermediate	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1991-2003
Torrington SCA		very high	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	pre-1998
Torrington SCA		very high	fine	1:25000<scale≤1:50000, patches ≤5 ha	moderate	pre-1998
Tweed Shire	673	low	coarse	1:5000<scale≤1:25000, patches ≤1 ha	high	2001
Upper Hunter		very low	intermediate	scale≤1:5000, patches ≤0.5 ha	very high	1998
Upper Shoalhaven Grasslands		high	fine	1:5000<scale≤1:25000, patches ≤1 ha	low	2000-2004
Wagga		low	intermediate	1:5000<scale≤1:25000, patches ≤1 ha	high	1998
Walgett Shire (Western Division)	1663	low	coarse	1:50000<scale≤1:100000, patches ≤20 ha	high	1998, updated 2004
Wallum	201	very high	overfitted	1:5000<scale≤1:25000, patches ≤1 ha	low	1991
Warragamba	2380	very high	fine	1:5000<scale≤1:25000, patches ≤1 ha	low	1994-2000
Washpool NP West		very high	fine	1:5000<scale≤1:25000, patches ≤1 ha	low	pre-1997
Western Blue Mountains	2231	very high	fine	1:5000<scale≤1:25000, patches ≤1 ha	low	1998-2004
Wheatbelt Band A	1629	low	coarse	1:50000<scale≤1:100000, patches ≤20 ha	high	1985, updated 2004

Map name	VIS-ID	Classification Skill	Thematic resolution	Spatial resolution	Uncertainty Class	Currency
Wheatbelt Band A	1629	low	coarse	1:50000<scale≤1:100000, patches ≤20 ha	high	1985, updated 2004
Wheatbelt Band B		very low	coarse	1:50000<scale≤1:100000, patches ≤20 ha	very high	1981, updated 2002-2004
Wheatbelt Band C	1602, 1604, 1606	low	coarse	1:50000<scale≤1:100000, patches ≤20 ha	high	1983, 1984 & 1987, updated 2002
Wheatbelt Band D	1608, 1610	low	coarse	1:50000<scale≤1:100000, patches ≤20 ha	high	1983, 1984 & 1987, updated 2002
Wheatbelt Band E	1613, 1616	low	intermediate	1:50000<scale≤1:100000, patches ≤20 ha	high	1980 & 1989, updated 2000
Wollemi NP	1849	moderate	overfitted	1:5000<scale≤1:25000, patches ≤1 ha	moderate	1983
Wombeira	1772	moderate	intermediate	1:5000<scale≤1:25000, patches ≤1 ha	moderate	1978
Yallaroi-Ashworth-Bingara-Inverell		high	intermediate	1:25000<scale≤1:50000, patches ≤5 ha	moderate	1999-2006
Yengo NP	1852	high	fine	1:5000<scale≤1:25000, patches ≤1 ha	low	

Appendix 2. An identification key to the vegetation formations of New South Wales (from Keith 2004)

The key is a series of questions, each with two alternative answers (e.g. A and A*). To use the key, read both alternative answers, choose the most correct one and go the to next question immediately below the correct answer until you reach a formation name in *italics*. For more information and to confirm your identification, turn to the relevant chapter in Part II. Note that for some formations there is more than one possible path to arrive at the formation. See glossary for definition of terms.

A. Vegetation dominated by trees (single-stemmed woody plants, or multi-stemmed mallee eucalypts that are generally more than 5 m tall when mature).

B. Forests or woodlands dominated by eucalypts.

C. Tall forests (typically >30 m) dominated by tall straight-trunked eucalypts, usually with soft-leaved shrubs, ferns or herbs in the understorey. Largely confined to moderately fertile soils in sheltered locations on the coast and escarpment where average annual rainfall exceeds 900 mm. Excludes riverine forests west of the Great Divide that lack the understorey characteristics described above.

Wet sclerophyll forests (Ch 2)

[The wet sclerophyll forests can be further divided into two subformations: '*shrubby*' which have understories dominated by softed-leaved shrubs but only sparse grass cover; and '*grassy*' which have understories dominated by a more continuous cover of grasses and herbs but only sparse shrub cover.]

C*. Forests or woodlands dominated by short to moderately tall trees (rarely >35 m), usually branching at less than half of their height. The understorey generally lacks ferns and shrubs with broad soft leaves, but may include abundant grasses, hard-leaved shrubs or ephemeral herbs. Widespread east and west of the Great Divide.

D. Forests or woodlands with an abundance of plant groups in the understorey that are able to tolerate periodic inundation or waterlogging, particularly sedges, rushes and reeds. Confined to damp, low-lying parts of the coast, or adjacent to rivers, lakes or swamps in the inland.

Forested Wetlands (Ch 9)

D*. Forests or woodlands generally lacking plants that tolerate inundation or waterlogging. Rarely in damp, low lying sites adjacent to rivers, lakes or swamps.

E. Forests or rarely woodlands with an abundance of hard-leaved (sclerophyllous) shrubs in the understorey. Only rarely dominated by 'box' eucalypts. Ground cover often sparse and typically dominated by sclerophyllous sedges, but may sometimes include reasonably continuous swards of grasses. Confined to the coast, tablelands, and the western slopes where average annual rainfall exceeds 500 mm, largely on infertile sandy or loamy soils.

Dry sclerophyll forests (Ch 5)

[The dry sclerophyll forests can be further divided into two subformations: *'shrubby'* which have understories dominated by hard-leaved shrubs but very sparse grass cover; and '*shrub/grass'* which have understories with a more continuous cover of grasses and herbs but a variable cover of hard-leaved shrubs.]

E*. Woodlands, or rarely forests, that lack an abundance of hard-leaved (sclerophyllous) shrubs in the understorey. 'Box' eucalypts often dominant or present in the tree layer. Grasses prominent in the understorey, except in some semi-arid areas. Widespread across NSW on various soils west of the Great Divide, but typically found on relatively fertile loams on the coast, tablelands and western slopes.

F. Woodlands, or rarely forests, typically 15–35 m tall though shorter at subalpine elevations. Groundcover continuous and dominated by perennial tussock grasses, and interspersed perennial herbs including 'geophytic' orchids and lilies, but few ephemeral herbs and grasses. Shrubs generally sparse and typically not including chenopods or other drought-tolerant species. Widespread on relatively fertile loams and clay loams of the coastal lowlands, the tablelands, and the western slopes where average annual rainfall exceeds 500 mm.

Grassy woodlands (Ch 3)

F*. Woodlands or open woodlands (i.e. with very widely spaced tree canopies) typically 5–20 m tall. Groundcover sparse to continuous, usually with an abundance of ephemeral herbs and grasses apparent after rain, and a variable cover of perennial tussock grasses. Drought tolerant shrubs prominent in the understorey, and often including chenopods (saltbushes, bluebushes, copperburrs). Widespread on a variety of soils on the western plains where average annual rainfall does not exceed 500 mm.

Semi-arid woodlands (Ch 11)

[The semi-arid woodlands can be further divided into two subformations: '*grassy*', found on floodplains occasionally exposed to inundation, often dominated by eucalypts more than 15 m tall and with an understorey predominantly of grasses and/or chenopod shrubs; and '*shrubby*', found on peneplains and hills not exposed to floodwaters, dominated by eucalypts rarely more than 15 m tall and with open understories containing a variety of drought-tolerant shrubs and a variable cover of grasses.]

B*. Forests or woodlands not dominated by eucalypts, although these may be present as scattered individuals.

G. Forests dominated by trees with dense canopies touching those of adjacent trees (i.e. a 'closed' canopy), and with horizontally held leaves. Trees and shrubs typically with soft leaves. Primarily occurring on the coast and escarpment where average annual rainfall exceeds 1000 mm, but with limited occurrences in dry rocky gorges of the escarpment and dry hills of the north-western slopes.

H. Trees tolerant of (and subjected to) tidal inundation, understorey sparse to non-existent. Restricted to tidal estuaries along the coast.

Saline wetlands (Ch 10)
[Mangrove Swamps]

H*. Trees not tolerant of (or subjected to) tidal inundation, understorey usually open to dense, rarely sparse, never non-existent. Found on the coast, escarpment and north-western slopes, but never in tidal estuaries.

I. Trees belonging to various plant families, their leaves broad and usually soft. Vines often occur in the tree canopies or understorey. Understorey typically includes ferns and herbs. Found on the coastal lowlands, islands and escarpment on fertile or moderately fertile soils, extending to restricted locations on the north-western slopes.

Rainforests (Ch 1)

I*. Canopy dominated by wattles with fine feathery leaves. Vines, ferns and grasses uncommon. Understorey with a very sparse cover of shrubs and sedges. Restricted to steep rocky foothills and gorges on the south coast and ranges.

Dry sclerophyll forests (Ch 5)
[Southern Wattle Dry Sclerophyll Forests]

G*. Woodlands and open forests dominated by trees with open canopies that barely touch (typically wattles and casuarinas or paperbarks) and usually with hard pendulous leaves. Widespread on the western plains, with more restricted occurrences on the coast and tablelands.

J. Open forests 15-30 m tall with canopies of adjacent trees often touching and an abundance of plants that tolerate periodic inundation or waterlogging. Dominant trees include casuarinas or paperbarks, but not wattles. Understorey includes a clumped or continuous groundcover of sedges, rushes or grasses and scattered shrubs, but no chenopods. Confined to the coast and tablelands adjacent to streams, lakes or swamps.

Forested wetlands (Ch 9)

J*. Woodlands and open woodlands 5-20 m tall with canopies of adjacent trees rarely touching, and generally lacking plants that tolerate periodic inundation or waterlogging. Dominant trees include wattles or casuarinas, but not paperbarks. Understorey includes an open groundcover of perennial and ephemeral grasses and herbs, and a variable cover of drought-tolerant shrubs, usually including chenopods (saltbushes, bluebushes and copperburrs). Extensive areas of the western plains where average annual rainfall is less than 500 mm.

Semi-arid woodlands (Ch 15)

[The semi-arid woodlands can be further divided into two subformations: '*grassy'*, found on floodplains occasionally exposed to inundation, often dominated by eucalypts more than 15 m tall and with an understorey predominantly of grasses and/or chenopod shrubs; and '*shrubby*', found on peneplains and hills not exposed to floodwaters, dominated by eucalypts rarely more than 15 m tall and with open understories containing a variety of drought-tolerant shrubs and a variable cover of grasses.]

A*. Trees absent, or present only as scattered emergent individuals.

K. Vegetation dominated by plants that tolerate prolonged seasonal burial in snow. Restricted to the alpine zone of the southern tablelands, above 1600–1800 m elevation.

Alpine complex (Ch 7)

K*. Vegetation dominated by plants that cannot tolerate prolonged seasonal burial in snow. Distributed in non-alpine landscapes (below 1800 m elevation).

L. Vegetation with an abundance of plants that tolerate periodic inundation or waterlogging, dominated by emergent sedges, rushes, reeds, grasses or succulent herbs, or in some cases by submerged or floating aquatic herbs. Soils are deep and often black or dark grey with partly decomposed organic matter.

M. Dominated by shrubs, sedges, grasses or non-succulent herbs that tolerate permanent or periodic inundation or waterlogging with freshwater. Restricted to swamps with humic or gleyed soils on the coast, tablelands, western slopes and plains.

Freshwater wetlands (Ch 8)

M*. Dominated by herbs (including succulents), grasses or rarely shrubs that tolerate periodic inundation or waterlogging with saline water. Restricted to tidal estuaries on the coast, and salt lakes on the western plains.

Saline wetlands (Ch 10)

L*. Vegetation with few, if any, plants that tolerate periodic inundation or waterlogging, usually dominated by shrubs or grasses, sometimes including an abundance of sedges, but never submerged or floating aquatic herbs. Soils may be grey, brown, yellow or red; usually dry or damp though may be flooded on rare occasions.

N. Vegetation dominated by perennial tussock grasses with herbs. Shrubs very rarely present. Generally found on clay soils on flat to undulating terrain on the coast, tablelands, western slopes and plains.

Grasslands (Ch 4)

N*. Vegetation dominated by shrubs. Perennial tussock grasses are absent or occasional, though never dominant. Generally found on sandy or loamy soils of the coast, tablelands and western slopes.

O. Vegetation dominated by hard-leaved but not drought-tolerant shrubs, usually also with perennial sedges, herbs and grasses, though generally lacking ephemeral plants. Restricted to infertile soils, often on exposed sites along the coast and tablelands where average annual rainfall exceeds 800 mm.

Heathlands (Ch 6)

O*. Vegetation dominated by drought-tolerant shrubs, including chenopods (saltbushes, bluebushes, copperburrs), with some perennial grasses and herbs, as well as abundant ephemeral grasses and herbs after rain. Widespread on various soils on the western plains where average annual rainfall is less than 500 mm.

Arid shrublands (Ch 12)

[The arid shrublands can be further divided into two subformations: *'chenopod',* which are dominated by chenopod shrubs up to 1.5 m tall and usually have perennial tussock grasses in the groundcover, though never hummock grasses (spinifex); and '*Acacia*', which are dominated by wattles and other hard-leaved shrubs up to 5 m tall, and sometimes have abundant hummock grasses in the groundcover.]