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Using high resolution digital aerial imagery interpreted in a 3-D digital GIS environment to map predefined plant communities in central-southern New South Wales

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Abstract: Aerial photo interpretation of high resolution airborne imagery (ADS40) was used in a three-dimensional (3-D) digital Geographic Information System (GIS) environment to map native plant communities defined in the NSW Vegetation Classification and Assessment (NSW VCA) in central-southern New South Wales. NSW VCA plant community types form part of the NSW *BioMetric* vegetation type dataset underpinning NSW natural resource management (NRM) planning frameworks. This region was previously devoid of detailed vegetation mapping. In addition to developing a novel method for mapping plant communities, the use of ADS40 imagery allowed for capture of multiple attributes in each map polygon including attributes pertaining to dominant species and vegetation condition. Such data informs multi-attribute models used in conservation planning, providing utility beyond that of a singular plant community map.

A total of 546,150 hectares of native vegetation in 100 native plant communities was mapped across the study area (Coolamon, Cootamundra, Junee, Lockhart, Narrandera, Tarcutta, Urana, Wagga Wagga and Yanco 1:100,000 mapsheets and Ariah Park, Wallaroobie Range and Yoogali 1:50,000 mapsheets). Exotic pine plantations and native species plantings were also mapped. Remnants of greater than one hectare were captured through on-screen GIS digitising at scales of approximately 1:4,000. The plant community type mapping was independently assessed using random blind validation points as having a user accuracy of 87%. This level of accuracy demonstrates the applicability of the methodology for mapping open forests, woodlands and open woodlands of south-eastern Australia and probably other vegetation elsewhere. Such accurate mapping provides end users with confidence when using vegetation maps in environmental assessment and land use planning.

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Introduction

Native vegetation maps provide details on the spatial extent of each vegetation type and are widely used to predict ecological values within the landscape. They can also be used in landscape restoration for listing and recovery of threatened ecological communities, identification and recovery of habitat for threatened species and endangered populations, and modelling the distribution of biological assets. In combination with other mapped landscape variables, they can be used to predict the pre-1750 distribution of biological entities. The NSW VCA plant community types are embedded within NSW State environmental regulatory systems, providing a platform for assessment in planning and regulatory frameworks under a range of State legislation. Similar frameworks also exist in other parts of Australia (e.g. Parkes *et al*. 2003, DERM 2011).

The central-southern NSW study area includes parts of the NSW South Western Slopes (SWS), Central West Slopes (CWS) and South Western Plains (SWP) botanical subdivisions (Anderson 1961) and parts of the South Western Slopes, Riverina and Cobar Peneplain bioregions (Thackway & Cresswell 1995). It is a very fragmented natural landscape. About 92.5% (2.4 million hectares) of the study area is managed as freehold agricultural land with an additional 4.6% (121,000 hectares) managed as Crown (primarily grazing) leasehold. Only 1.1% (28,500 hectares) is managed in formal conservation reserves, with 1.2% (31,540 hectares) in state forest, and 0.6% (16,626 hectares) in travelling stock reserves.

The region is characterised by broad areas of lowland ecosystems containing remnants of threatened plant communities, and the high proportion of agricultural land has led to habitat loss resulting from clearing and vegetation structural decline (DEH 2000). As such, it is a highly important region in which to develop information for prioritisation and targeting of investment for environmental restoration programs. Before the mapping presented here, the study area lacked fine thematic level (congruent with classification Level D in Sivertsen 2009) vegetation map data except for a few conservation reserves and one local government area.

Jurisdictional vegetation classifications have been mapped in other States including Victoria (Victorian DNR 2002, DSE 2011) and Queensland (Sattler & Williams 1999, Queensland Herbarium 2003, DERM 2011). Elsewhere, vegetation maps have aligned types with jurisdictional vegetation classifications including the mapping of Voygeours National Park in Minnesota in the United States (Faber-Langendoen *et al*. 2007), which related mapped units to the pre-existing United States National Vegetation Classification (Grossman *et al.* 1998, Jennings *et al.* 2006). Recent mapping in inland NSW with aligned mapped units to the NSW VCA plant communities include NGH Environmental (2008) mapping north of Broken Hill; Porteners (2011) map of Cobbora State Conservation Area near Dubbo; Westbrooke *et al.* (2011) map of part of Paroo-Darling National Park in far western NSW; Roff *et al.* (2010) SPOT5 imagery map of the Murray CMA area; and Bowen & Simpson (2009) sequential maps of the plant communities in the Gwydir wetlands near Moree.

For the fragmented landscapes in central-southern NSW, this study aimed to produce a highly accurate regional vegetation map expressing a fine thematic classification of plant community types and vegetation conditions using high resolution ADS40 digital imagery. In doing so, the study developed and refined a methodology utilising technological advances in digital airborne imagery and on-screen 3-D interpretation methods for mapping defined vegetation types.

Study Area

The central-southern NSW study area covers an area of 2.6 million hectares encompassing the Coolamon, Cootamundra, Junee, Lockhart, Narrandera, Tarcutta, Urana, Wagga Wagga and Yanco 1:100,000 mapsheets and Ariah Park, Wallaroobie Range and Yoogali 1:50,000 mapsheets (Figure 1). It includes the Coolamon, Junee and Leeton local government areas in their entirety, as well as large portions of the Cootamundra, Griffith, Gundagai, Harden, Lockhart, Murrumbidgee, Narrandera, Temora, Urana and Wagga Wagga local government areas. Small parts of the Bland, Carathool,

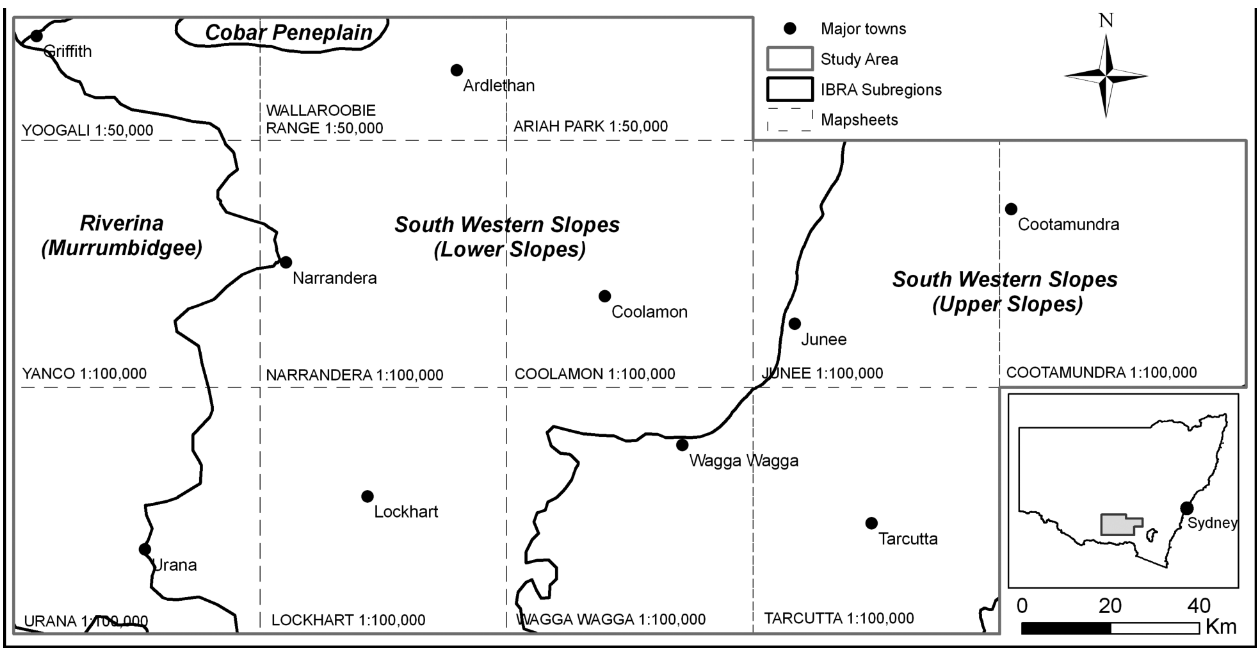

Fig. 1. The study area showing bioregions, subregions, topographic mapsheets and major towns.

Greater Hume, Jerilderie and Tumut local government areas are also mapped. The study area extends across portions of three NSW Catchment Management Authority (CMA) areas, including central parts of the Murrumbidgee CMA, the Urana – Lockhart part of the Murray CMA, and small areas along the southern boundary of the Lachlan CMA.

Climate

The climate is temperate, characterised by hot dry summers and cool winters. Precipitation increases in areas of greater topographic relief in the east and is relatively even across seasons, with slightly less occurring in hotter months when evaporation rates are higher. Mean daily maximum and minimum temperatures are slightly higher in western parts of the study area, however temperature variance is relatively consistent. Climatic data for key weather stations within the study area is presented in Table 1 (BoM 2011).

Physiography

The study area contains a variety of landforms and soils reflecting the broad variation between the NSW South Western Slopes, Riverina and Cobar Peneplain bioregions (Figure 1). The Riverina bioregion, in the west of the study area, includes most of the Urana and Yanco 1:100,000 mapsheets. It is characterised by broad alluvial floodplains and alluvial plain landform patterns composed of black to red clay and silt soils deposited by repeated flooding of the Murrumbidgee, Murray and Lachlan river systems (NPWS 2003, Tuckwell 1976, Wynn 1977). Landform elements include river channels, backplains, swamps, lakes and restricted areas of sandy lunettes formed in the Quaternary period.

The Cobar Peneplain occupies a small area in the north-west of the study area and includes northern sections of the Yoogali and Walleroobie Range 1:50,000 mapsheets. This area is characterised by low hills, plains and stony ranges formed on the northwesterly extension of the Lachlan Fold Belt (NPWS 2003) primarily composed of Barrat Conglomerates of the Cocopara Group of the Devonian period (Wynn 1977).

The NSW South Western Slopes bioregion comprises the majority of the study area, encompassing most of the land east of Narrandera and Urana and extending west towards Griffith on the Yoogali 1:50,000 mapsheet. It contains two sub-bioregions: the Lower Slopes in the west and the Upper Slopes in the east. Features of these subregions are described in NPWS (2003) and Benson (2008). The Lower Slopes subregion is characterised by alluvial valleys with undulating and hilly ranges and isolated peaks. The Upper Slopes subregion, which occurs east of Junee and Wagga Wagga, receives greater precipitation and contains greater topographic relief. It is characterised by Ordovician to Devonian folded and faulted sedimentary substrates and areas of intrusive granites and metasediments (Adamson & Loudon 1966, NPWS 2003, Tuckwell 1976, Warren *et al*. 1996, Wynn 1977).

Previous botanical studies

Previous vegetation mapping and surveys for south western NSW are outlined in Benson (2008) for the NSW South Western Slopes bioregion and in Benson *et al*. (2006) for the Riverina and Cobar Peneplain bioregions. However, only a few of these previous studies were in the study area and most were botanical surveys rather than vegetation mapping. Moore (1953) described “plant associations” for most of the study area and produced a coarse scale, broad thematic level vegetation map. Brickhill (1985) assessed the conservation status of plant communities in the southern Riverina. Bos & Lockwood (1996) plot sampled some of the state forests in the study area and Benson *et al*. (1997) sampled and classified the native grasslands of the Riverina bioregion, including around Urana and Narrandera. Priday & Mulvaney (2005) sampled and described the vegetation of the Wagga Wagga Shire and Priday (2006) plot sampled the southern part of the NSW South Western Slopes bioregion. EcoGIS (2004) sampled and mapped a number of conservation reserves at fine scales from the southern tablelands to the Upper South Western Slopes and Gellie (2005) provided an initial overall classification of the vegetation for the southern part of the Upper Slopes subregion. Other conservation reserve mapping includes Porteners (2001, 2007) and Whiting (2006).

Table 1. Climate data for key weather stations within the study area (BoM 2011).

Location	Mapsheet	Altitude (m)	Mean daily max temp (°C) (Jan)	Mean daily min temp (°C) (Jul)	Lowest mean monthly rainfall (mm)	Highest mean monthly rainfall (mm)	Mean annual rainfall (mm)
Cootamundra Airport	Cootamundra	335	31.9	1.2	31.6 (May)	59.6 (Jul)	589.6
Griffith Airport	Yoogali	134	32.8	3.5	27.7 (Apr)	48.5 (Oct)	402.5
Junee Treatment Works	Junee	280	32.4	2.3	37.8 (Feb)	51.3 (Oct)	523.0
Murrumburrah Old PO	Cootamundra	370	32.1	0.8	42.9 (Feb)	56.2 (Jun)	606.4
Narrandera Airport	Narrandera	145	33.0	3.0	31.8 (Mar)	43.8 (Oct)	441.3
Urana PO	Urana	125	32.9	3.2	32.0 (Jan)	45.0 (Jun)	442.5
Wagga Wagga Agricultural Institute	Wagga Wagga	219	31.5	3.0	36.4 (Mar)	52.7 (Oct)	523.6
Yanco Agricultural Institute	Yanco	164	34.0	4.9	28.9 (Jan, Nov)	39.6 (Oct)	391.5

The NSW Vegetation Classification and Assessment database

A comprehensive review and assessment of NSW vegetation datasets including plot analyses and map unit descriptions coupled with extensive field traverses and rapid sampling forms the basis of the NSW Vegetation Classification and Assessment database (Benson 2006). The NSW VCA aims to provide a consistent plant community classification across NSW and full distributional perspectives on extent, threats and protected area status for each classified plant community. As of 2011, the NSW VCA covered approximately 78% of NSW across 11½ bioregions west of the Great Dividing Range (Benson *et al.* 2010). The NSW VCA database also contains a range of protected area and threat assessments useful for conservation assessment and planning purposes. These include a set of threat criteria for grading each plant community into a threat code (Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern) and an audit of plant communities in all protected areas (public conservation reserves and secure property agreements) providing an assessment of the protected area status of each plant community (see descriptions of all NSW VCA fields in Benson 2006). For NSW VCA classification of plant communities in the NSW Western Plains, including the Riverina bioregion, see Benson *et al.* (2006), and South Western Slopes bioregion, see Benson (2008).

As the NSW VCA progresses, it is being submitted for incorporation into the NSW Government Vegetation Information System (VIS) vegetation classification (OEH unpub.a) database that links to the *BioMetric* plant community type dataset (OEH unpub.b) for use in natural resource management regulatory tools such as the Property Vegetation Plan Developer (Gibbons *et al.* 2005). These tools are used to assess land use change applications, incentive payments and development offset proposals under the *Native Vegetation Act 2003* and the Biobanking Assessment Methodology (DECC 2008). The NSW VCA informs listings and descriptions of threatened ecological communities under the NSW *Threatened Species Conservation Act 1995* and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.* A consistent plant community type classification provides a common reference for Commonwealth, State and regional bodies to undertake strategic conservation planning. An expert Change Panel has been established within the NSW Government to update plant communities listed in the VIS vegetation classification (OEH unpub. a) and the regulatory *BioMetric* Tool (Gibbons *et al*. 2005). Procedures are in place for the Change Panel to deliberate on proposed additions, deletions, splits and descriptive changes to plant communities listed in these databases.

Background

The study focussed on mapping NSW VCA plant communities that occur in the study area using high resolution ADS40 digital imagery. Cultural plantings including exotic pine plantations (mainly *Pinus radiata*) and native species re-vegetation plantings were also mapped.

ADS40 Imagery

While the study applied many of the principles of traditional Aerial Photograph Interpretation (API), it harnessed high resolution airborne digital imagery known as ADS40 (Airborne Digital Sensor) being flown by the NSW Department of Land and Property Information. Since 2007 this imagery has been replacing existing wet-film aerial photography through digital image capture by a Leica ADS40 camera (Leica Geosystems 2004, Black & Peasley 2008), and is now available for most of the eastern half of NSW. The NSW Government's ADS40 imagery is captured at 50cm resolution (standard) with six transparent layers including 16-bit Red Green Blue (RGB) values, Near Infra Red (NIR) and two panchromatic bands, and may be captured at other scales by request. Even when utilising only RGB bands of the imagery, as in this study, such image detail allows for far greater depth of information than traditional wet film aerial photography. Important for vegetation mapping purposes, the high resolution level and increased sharpness of the imagery when viewed in 3-D increases the ability of Digital Aerial Photograph Interpretation (DAPI) operators to identify individual species signatures, phytogeography and ecotone boundaries between plant community types. Table 2 outlines the specifications of the ADS40 imagery in comparison with other imagery regularly used in making vegetation maps in Australia. Figure 2 contains a visual representation of the differences between imagery in a 2-D environment.

Twelve 1:100,000 mapsheet blocks of ADS40 images each comprising 11 to 12 north-south running strips of approximately 55 x 5km were used in the mapping process, with their lineage (Table 3) indicating the currency of the vegetation map product for each mapsheet.

Stereo Analyst and 3-D Planar technology

Vegetation polygon attributes were interpreted and recorded through the use of the Stereo Analyst for ArcGIS (SAFA) extension (ERDAS 2010) within ArcGIS (ESRI 2011). DAPI was undertaken in a 3-D environment using methods similar to traditional API (DUAP 2000). The 3-D stereo environment was created by SAFA and viewed with 20 inch 3-D Planar screen technology (Planar 2011), allowing linework to be digitised directly onto the screen and attributed by the DAPI operator, thus enabling the data capture process to be commenced and completed entirely within the 3-D digital environment (Figure 3). This eliminates the traditional API process of scanning acetate overlays containing stereoscope interpreted linework traced over aerial photographs followed by manual data entry for attribution by non-API personnel, a process which was subject to errors for a number of reasons.

The vegetation map

Existing vegetation information

Pre-existing vegetation mapping products across portions of the study area (e.g. DEC 2006, DEC 2007, EcoGIS

Table 2. ADS40 imagery specifications and comparisons with other imagery.

	ADS40	**Wet-film Aerial Photography**	**SPOT5**
Coverage	Most of the central and coastal divisions, all areas except western division to be flown by Spring 2012. Portions of the Western Division may be flown upon request.	State	State
Resolution (GSD – ground sampling distance)	50 GSD (50 x 50cm pixel standard); range 10 GSD to 80 GSD	N/A. Scale variable, generally 1:50,000 or 1:25,000	500 GSD (5 x 5m pixel) to 1000 GSD (10 x 10m pixel). Can pan-sharpen to 250 GSD
RGB	16-bit	8-bit	16-bit
NIR	Yes (2nd generation)	No	Yes
Panchromatic bands	Two	Nil	One (500 GSD); Nil (1000 GSD)

2004, Gellie 2005, Maguire *et al*. 2000, Priday & Mulvaney 2005, Roberts & Roberts 2001, White *et al*. 2002) were not considered useful for guiding the capture and attribution of new vegetation polygon linework because they were:

- Captured at a coarser scale as they were developed through interpretation of relatively small scale wet-film photography;
- Subject to loss of spatial accuracy through the transfer of linework into the digital environment from acetate overlays used as part of traditional API processes; and
- Mapped to different (generally broader) plant community classifications, reducing the relevance of polygon delineation.

724 existing floristic plots across 19 previous flora surveys (Bedward *et al.* 2011) were reviewed, with suitable plot data providing useful checks to identify the vegetation type on the ground. Providing that plot data had been accurately georeferenced, DAPI operators used this information along with their own reconnaissance data when attributing vegetation polygons.

Field reconnaissance and checking

Before DAPI commenced, DAPI operators and botanists undertook reconnaissance of the study area to gain familiarity with the NSW VCA plant communities, their constituent plant species and relationship to landform position and soil type. Importantly, field checking provided an opportunity to correlate visual signatures on ADS40 imagery for each plant species and community. The majority of field observations were recorded by inspecting land in public tenure (national parks, state forests, roadside reserves, travelling stock reserves and council reserves), although some private tenure land was also checked. Where access to private land was not feasible, observations of dominant tree species and relationships with abiotic features were recorded using binoculars. The reconnassiance and checking process was repeated throughout the mapping study whereby DAPI operators and at times, botanists, field-checked vegetated landscapes to maximise correlations between field observations and signatures on the ADS40 imagery. All information was recorded directly in the field onto printed ADS40 imagery, or through georeferenced data capture.

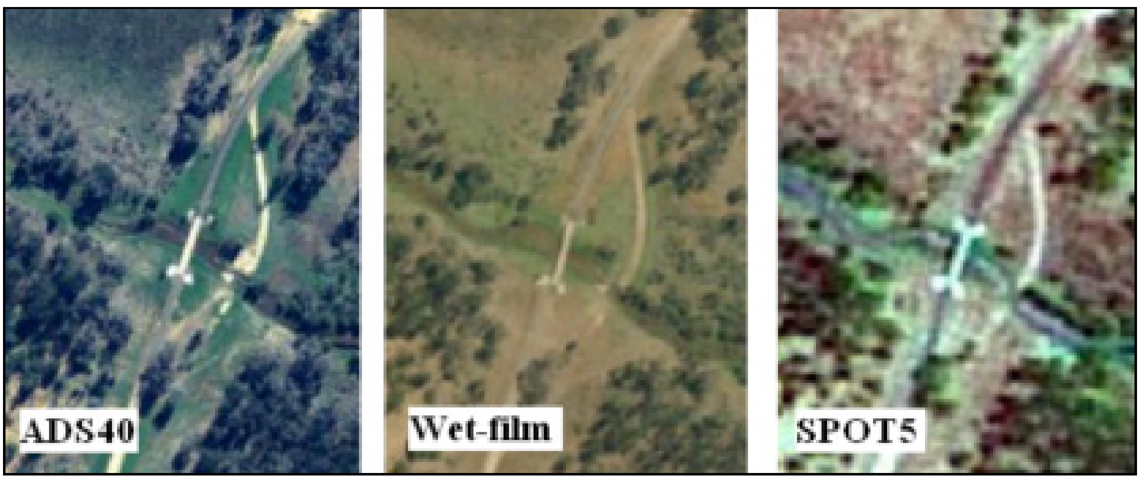

Fig. 2. Visual differences between ADS40, wet-film aerial photography and SPOT5 imagery (Black & Peasley 2008).

Fig. 3. DAPI operators at 3-D Planar workstations using Stereo Analyst for ArcGIS map software.

Digital Aerial Photograph Interpretation

The methods and principles of traditional API are well documented (e.g. DUAP 2000) and this method has been used for most vegetation mapping programs throughout the world, including in NSW. This study varied from the usual methods of API by using high resolution ADS40 imagery with image interpretation occurring directly on-screen in a 3-D GIS environment. The image interpretation used a 3-D SAFA platform (ERDAS 2010) to capture information into a 3-D polygon shapefile. The differences between traditional API and DAPI are listed in Table 4.

Interpretation of NSW VCA plant community types using ADS40 imagery was based on the identification of the ADS40 photo signatures of plant canopy species, and at times understorey structure, present in an area. Once this mix of species was determined through DAPI, the interpreter assigned the most appropriate VCA type in conjunction with factors such as landscape position and geographic distribution. Correlating field observations with various vegetation signatures observed on 3-D ADS40 imagery was critical to the mapping exercise. Differences in interpretation of signatures between DAPI operators were minimised by cross checking and undertaking joint field inspections. Use of botanically astute DAPI operators in conjunction with field observation was particularly important in mapping mixed eucalypt forests and woodlands, where even with high

Table 3. Lineage of ADS40 image sets used in this study.

Image	Lineage
Ardlethan (Wallaroobie Range 1:50,000)	12/2007
Barmedman (Ariah Park 1:50,000)	10/2007
Coolamon	9/2007
Cootamundra	1/2008
Griffith (Yoogali 1:50,000)	2/2008
Junee	9/2007
Lockhart	9/2008
Narrandera	10/2007
Tarcutta	3/2010
Urana	4/2008
Wagga Wagga	4/2008
Yanco	2/2008

Table 4. Differences between traditional API and DAPI.

	Traditional API	DAPI with ADS40 imagery
Data Capture	On acetates draped over Aerial Photographs, with a secondary process to scan linework and enter attribution data	Directly on screen in a 3-D shapefile
Scale	As per wet-film photography	Essentially 'scale-less', as the interpreter can use digital zoom functions. Image begins to lose quality at *circa* 1:1,000.
Viewing Platform	Stereoscope	3-D Planar Screen (Figure 3) or other 3-D platform, allowing for multiple-viewers and increased ability to conference complex decisions.
Image quality [1]	Moderate	High

[1] refer to Table 2 and Figure 2 for image comparison

resolution imagery one plant community type may exhibit several patterns in both natural and modified environments (e.g. different growth stages, densities and topographic situations). Further fieldwork was sometimes undertaken after intial DAPI to refine map polygon attributes and plant community boundaries.

As the information was captured directly into ArcGIS using the SAFA extension, DAPI operators were able to use the SAFA zoom functions, thus improving the scale of capture. DAPI operators also utilised the SAFA colour tuning functions to distinguish and more clearly separate differing species to greater degrees, including the various colour stretch modes in combination with degrees of brightness and contrast. As a guide, DAPI operators were encouraged to draw polygons at an optimal zoom scale of 1:4,000, however at times it was necessary to zoom in beyond this level to determine the suite of canopy species in complex areas. The operational environment of the Stereo Analyst for ArcGIS interface is shown in Figure 4.

All naturally vegetated areas of greater than one hectare were mapped including non-woody vegetation such as native grasslands and swamps. Some smaller areas were also mapped including linear remnants along roadsides with a width of two or more tree crowns. Single rows of trees were not mapped, but single rows on each side of a road or creek were mapped as one polygon with the road or creek included. Areas with greater than 5% crown cover were mapped as woody vegetation. In order to enhance the utility of the final vegetation map product beyond that of a standard plant community type map, a suite of additional attributes were collected for each polygon (Table 5). Polygons were driven by NSW VCA type, but split on dominant species, density class and/or crown condition. Thus, polygons of a single NSW VCA plant community type may contain several polygons split on these attribute variations. All other attributes within a polygon were only to provide additional information. Collecting additional attributes allows map users to develop multi-attribute models to answer a range of ecological questions beyond that of a standard vegetation map.

The attributes of NSW Vegetation Class, NSW Threatened Ecological Community, NSW VCA Threat Category, % Cleared, % Remaining, Over 70% Cleared and Source % Cleared Estimate were added to the shapefile post-DAPI data capture. Consistency of attribution was achieved between DAPI operators through regular cross-checks among themselves and botanists. Decision rules were developed for determining the differences between similar NSW VCA plant community types.

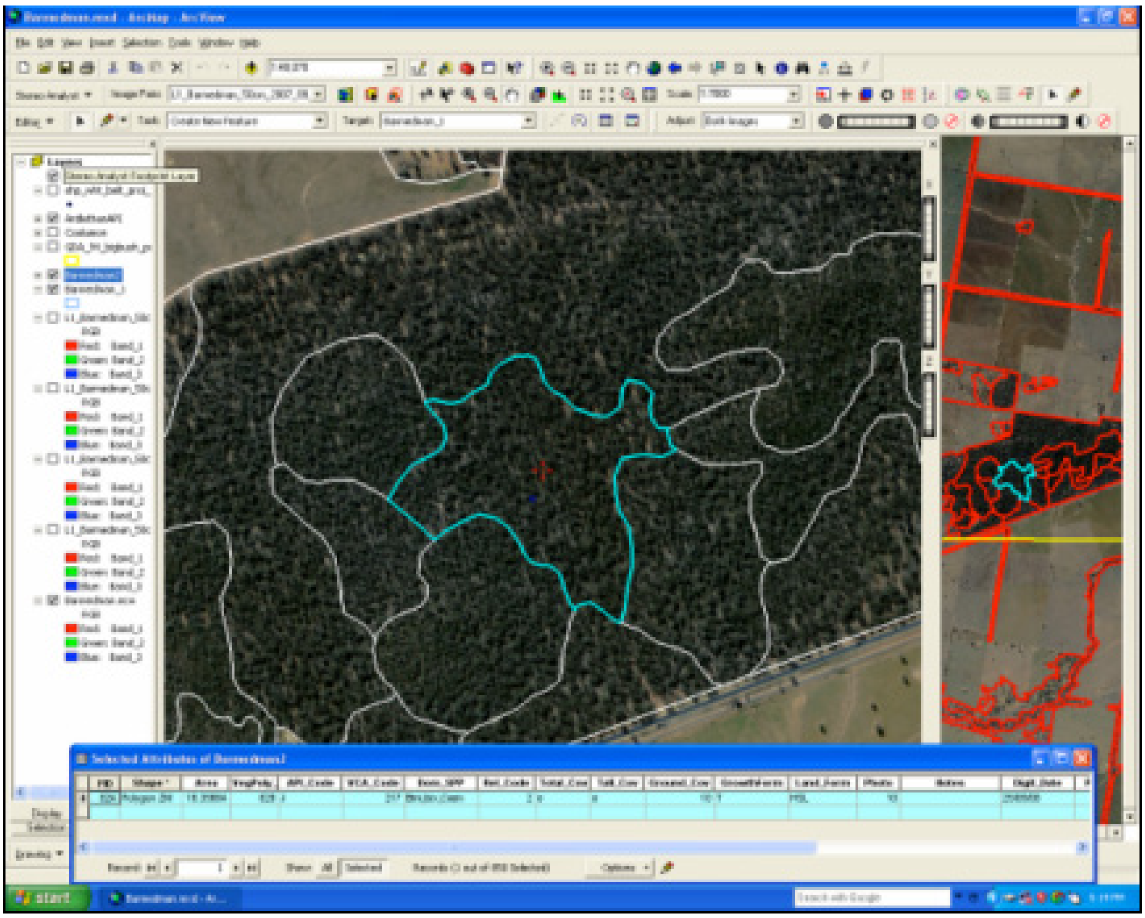

Fig. 4. Stereo Analyst – ArcGIS screen interface. Stereo window (at centre) and ArcMap window (right). The same polygon is selected in each window and its record in the attribute table.

Table 5. Polygon attributes captured as part of the study.

Land Cover	Agricultural Land; Agricultural Land 20–50% rock; Bare earth; Natural wetlands; Non-woody native vegetation with previous cultivation pattern observed on imagery < 20% rock; Non-woody native vegetation with previous cultivation pattern observed on imagery 20–50% rock; Woody native vegetation with previous cultivation pattern observed on imagery; Non-woody native vegetation without previous cultivation pattern observed on imagery; Non-woody native vegetation without previous cultivation pattern observed on imagery <20% rock; Non-woody native vegetation without previous cultivation pattern observed on imagery 20–50% rock; Non-woody native vegetation without previous cultivation pattern observed on imagery 50–70% rock; Non-woody native vegetation without previous cultivation pattern observed on imagery > 70% rock; Non-natural; Not identified; Open water; Woody vegetation; Woody vegetation 20–50% rock; Woody vegetation 50–70% rock; Woody vegetation > 70% rock; Woody native vegetation with previous cultivation pattern observed on imagery; Woody native vegetation with previous cultivation pattern observed on imagery < 20% rock; Woody native vegetation with previous cultivation pattern observed on imagery 20–50% rock
Aggregate	Aggregate code for vegetation within the polygon: Acacias; Casuarinas; Commercial plantations; Cypress pine; Environmental plantations; Eucalypts; Native/derived grassland; Shrub mosaic; Swamp mosaic; Excluded (not native vegetation)
NSW VCA ID	Identification code for NSW VCA type: e.g. ID186
NSW VCA Plant Community Type Name	Plant community type name for NSW VCA type: e.g. Dwyers Red Gum - Black Cypress Pine - Currawang shrubby low woodland on rocky hills mainly in the NSW South-western Slopes bioregion
Hectares	Hectare area within the polygon
Dominant Species 1	Dominant species in polygon (generally tallest stratum): e.g *Eucalyptus dwyeri*
Dominant Species 2	2nd dominant species in polygon (generally tallest stratum): e.g. *Callitris endlicheri*
Dominant Species 3	3rd dominant species in polygon (generally tallest stratum): e.g. *Allocasuarina verticillata*
Reliability	For NSW VCA plant community type and dominant species: Verified (polygon verified on ground, or strong obvious features); High Confidence (high certainty of features /species interpretation, confident extrapolation from localised sampling); Moderate Confidence (moderate certainty of features, some similarity with features sampled elsewhere, some uncertainty in species interpretation); Educated Guess (low certainty of features, remote area, inconsistent with features sampled elsewhere, low confidence in species interpretation)
Total Woody Cover	Density of all native woody vegetation (woody groundcover excepted): None; 0-1%; 1-5%; 5-10%; 10-20%; 50-80%; >80%; <1% in clumps; 1-5% in clumps; 5-10% in clumps; 10-20% in clumps; Not relevant
Tall Cover	Density of native woody vegetation in tallest stratum: None; 0-1%; 1-5%; 5-10%; 10-20%; 50-80%; >80%; <1% in clumps; 1-5% in clumps; 5-10% in clumps; 10-20% in clumps; Not relevant
Regrowth	Density of woody regrowth (as a % of Tall Cover): None; 0-1%; 1-5%; 5-10%; 10-20%; 50-80%; >80%; <1% in clumps; 1-5% in clumps; 5-10% in clumps; 10-20% in clumps; Not relevant
Crown Condition	Condition rating for canopy species: Good health (healthy crowns); Moderate Health (some crown dieback at limb extremities); Poor health (advanced crown dieback, pronounced bayonets); Dead/poor health (near dead, or dead stags).
Ground Cover	Descriptor code for groundcover within the polygon: Barren; Chenopods with native grasses; Cropping/improved pastures; Heath; Native grasses; Native/naturalised grasses; Naturalised grasses; Rock (>70%); Sand ridge; Sedge/rush/fern/wet species; Shrub mosaic; Not identifiable; Not assessed; Not present
Growth Form	Chenopod shrub; Fern; Forb; Heath shrub; Hummock grass; Mallee; Mallee shrub; Moss; Rush; Sedge; Shrub; Sod grass; Tree; Tussock grass; Vine; Not relevant
Landform	Dominant landform within the polygon. Refer to Walker & Hopkins (1990)
Notes	Additional information recorded by DAPI operator
Map Sheet	1:100,000 mapsheet name
Photo	Number of ADS40 photo strip
Photo Date	Date of capture of ADS40 image
Digitiser	Name of Remote Image Interpreter
Digitising Date	Date of digitising of polygon
NSW Vegetation Class	NSW Vegetation Class as per Keith (2004)
Threatened Ecological Community	Name and Status of Threatened Ecological Community under the NSW *Threatened Species Conservation Act 1995* or the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*
NSW VCA Threat Category	Threat category as per Benson (2006): Critically endangered; Endangered; Vulnerable; Near Threatened; Least Concern
% Cleared	Percent of NSW VCA plant community type cleared
% Remaining	Percent of NSW VCA plant community type remaining
Over 70% Cleared	NSW VCA plant community types with greater than 70% cleared (less than 30% remaining)
Source % Cleared Estimate	Source of clearing estimate data (OEH unpub. b; Benson *et al.* 2010)

Geographic Information System (GIS) post-processing

Post-mapping GIS editing and processing was undertaken using ArcGIS. All 3-D shapefiles were first converted to 2-D and edgematchings were completed using a 2-D orthophoto as a base to ensure a seamless multi-attribute product across mapsheet boundaries and enable the various shapefiles to be merged into one. Topology errors resulting from the 3-D to 2-D conversion were corrected and any coding errors investigated and amended.

Feedback to the NSW VCA

Where polygons could not be clearly attributed to a particular NSW VCA plant community type, DAPI operators and botanists liaised directly with the NSW VCA administrator to determine whether a NSW VCA plant community type could accommodate slight variation or whether a potential new plant community type had been identified. For potential new plant communities, field information was gathered and compared with compositionally similar existing NSW VCA plant communities. The mapping process also provided feedback to the NSW VCA administrator on changes in the geographic extent of NSW VCA plant communities such as amending occurrences in Local Government Areas or sub-bioregions. On occasion, the NSW VCA administrator undertook field survey with DAPI operators to provide perspective on how particular areas may fit into the NSW VCA plant commuity type classification.

Independent Accuracy Assessment

Independent third-party accuracy assessment of completed mapsheets was incorporated. Independent botanists collected field data and undertook double-blind analysis of NSW VCA plant community type attribution (EcoLogical 2009, 2010, 2011a, 2011b, GHD unpub., SKM 2009).

The native vegetation footprint of the mapsheets was provided to independent assessors, and stratified using Mitchell landscapes (Mitchell 2003), an abiotic landscape classification considered appropriate as a surrogate for differences in vegetation without making specific inference to NSW VCA plant community types. Within stratified areas, random field validation points were allocated and restricted to within 100 m of all public tenure and selected private tenured parcels. Decision rules were developed to randomly allocate field validation plots within stratified units across the mapsheets. Plot (50 x 50 m) information collected at georeferenced field validation points comprised the three dominant plant species in each stratum, landform element (Walker & Hopkins 1990), NSW VCA plant community type (and if applicable 2nd and 3rd options where field decisions were not clear), and additional notes including canopy species within the same apparent plant community type within the direct viewshed from the validation point. While validation was undertaken after the final mapping product was completed, NSW VCA plant community types are robustly defined to ensure that seasonality is a negligible issue in sampling and determining plant community types.

Independent third-party botanists were not provided with the final NSW VCA plant community type map product until all field validation point data had been gathered in order to remove any potential bias in field observations. Accuracy assessment was then undertaken through GIS by intersecting the final NSW VCA plant community type map product with the georeferenced field data to determine 'degrees of correctness' as per Table 6 (modified from Gopal & Woodcock 1994) in accordance with the NSW Interim Vegetation Type Mapping Standard (Sivertsen 2009).

Results

Mapped Plant Community Types

A total of 100 NSW VCA plant community types were mapped across the study area (listed in Table 7 with an example of the mapping in Figure 5). A total of 546,151 hectares of native vegetation (20.5% of the study area) was mapped, with 13.5% (358,594 hectares) comprising treed woody vegetation types, 4,336 hectares of shrubland (including chenopod shrublands and 'Shrub Mosaic), 5,343 hectares of native/derived grassland types and 663 hectares of wetland types. A further 177,215 hectares of non-woody native vegetation were mapped into broader mosaics of communities without specific NSW VCA plant community type attribution. This included 148,130 hectares of 'Native Grassland Mosaic' with 3,260 hectares containing an observed cultivation pattern, and 29,085 hectares of 'Swamp Mosaic'. A total of 31,511 hectares (8.8% of extant native woody vegetation) persists as paddock remnant vegetation with a cropped or exotic understorey.

The mapping process identified one new community (NSW VCA 426) defined with agreement, checking and sampling by the NSW VCA administrator. Dominant species attribution of each polygon should assist updating of plant community type attribution for relevant polygons over time if there are revisions of the NSW VCA plant communities, although the latter would be mainly driven by full floristic plot analyses and expert review.

Native grassland, swamp and shrub mosaics were mapped where a number of NSW VCA plant community types occurred at a finer scale than DAPI operators were able to delineate within project timelines. In these instances, mapping of woody vegetation was prioritised. There were also some instances where spatial distributions of these NSW VCA plant community types were below the minimum polygon size, were ephemeral in nature or could only be distinguished with detailed site-based field survey in the absence of temporal synchronisation between ADS40 image capture and field survey. Native grassland mosaics were not differentiated into natural (non-woody in pre-European times) and derived grasslands (e.g. where trees have been removed since European settlement). However, it is considered that most of the grasslands of the eastern Riverina bioregion are primarily natural (McDougall 2008), whereas grasslands of the NSW South Western Slopes and Cobar Peneplain bioregions are

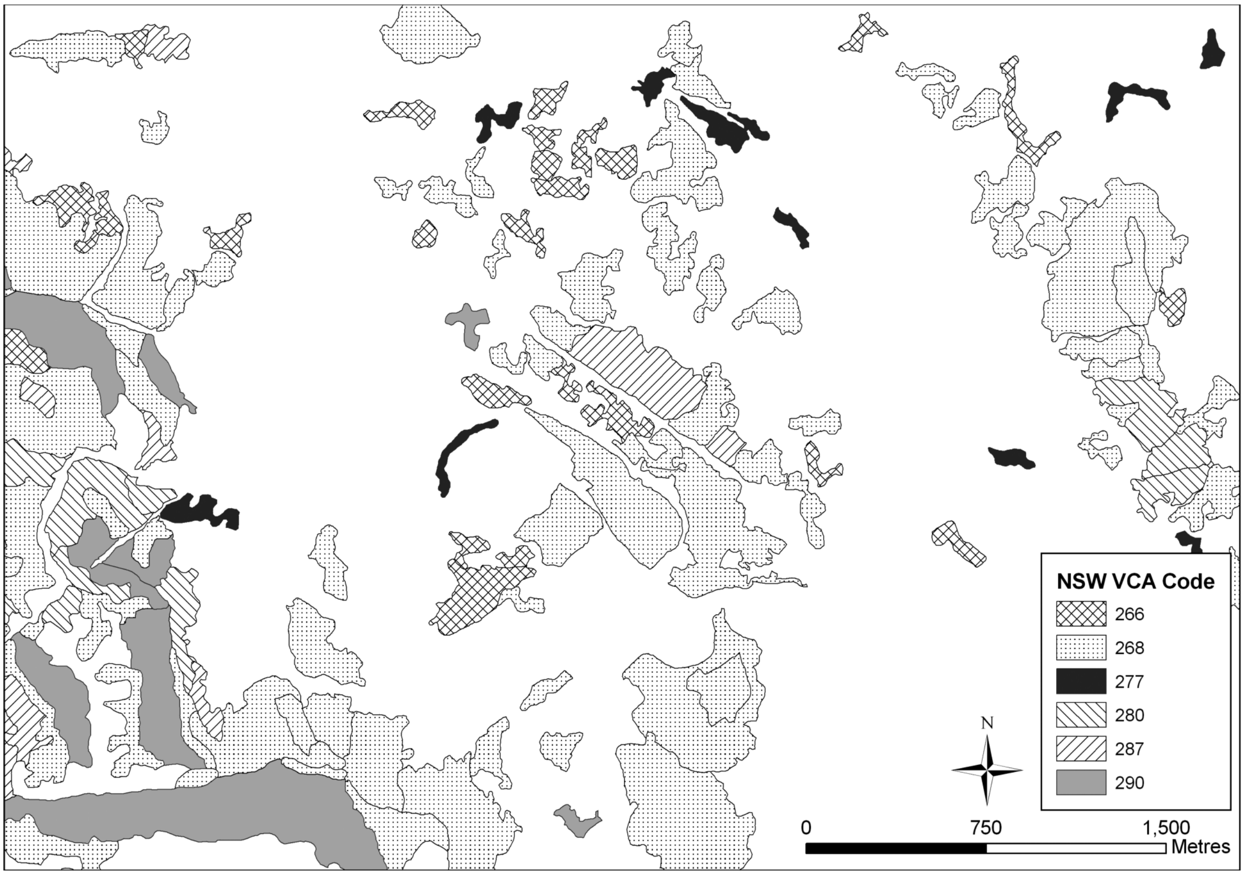

Fig. 5. Section of the Tarcutta 1:100,000 mapsheet showing the polygon detail able to be accurately mapped using ADS40 imagery. NOTE: Where polyon of the same NSW VCA type adjoin they are split on dominant speices mix, crown density or crown condition.

primarily derived from tree clearing. There may be small remnants of natural grassland in the lower slopes subregion of the NSW South Western Slopes bioregion.

The area of treed remnants with cropped ground cover (approximately 9% of the study area) along with a very large area of scattered paddock trees below 5% crown cover that are not mapped as native vegetation, supports the findings about remnant woody vegetation in Gibbons & Boak (2002) in their study of the nearby Holbrook region. Isolated trees are particularly common in the lowland plant communities within the Floodplain Transition Woodlands, Riverine Plain Woodlands and Western Slopes Grassy Woodlands NSW Vegetation Classes. Some of these plant communities are part of threatened ecological community listings under the NSW *Threatened Species Conservation Act 1995* and/or the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999.* Some NSW VCA plant community types were mapped over a small extent as they were either naturally restricted in distribution, highly cleared within the region or the study area represented the edge of their geographic distribution.

Planted woody vegetation (primarily commercial *Pinus radiata* plantations and small-scale shelterbelt plantings) represented 18,623 hectares of the study area.

Descriptions of the 100 NSW VCA plant communities mapped in this study are found in Appendix A with the twelve vegetation maps saved as PDF files in Appendix B. The original ArcGIS shapefile is available under licence by emailing data.broker@environment. nsw.gov.au or http://mapdata.environment.nsw.gov.au/DDWA/.

Independent Accuracy Assessment

A total of 1,041 blind field validation plots were collected and analysed across the study area (Figure 6), yielding an overall user accuracy of 87 %. Attribution accuracy for NSW VCA plant community types is presented in Table 8, with accuracy categorised by the broad NSW Vegetation Classes of Keith (2004). For woody vegetation types, the number of validation plot samples is relatively proportional to the extent of each NSW Vegetation Class across the study area, with a mean sampling intensity of one plot per 385 hectares. Due to access issues, vegetation types within non-woody NSW Vegetation Classes were validated at a lower intensity of one plot per 1,790 hectares. NSW VCA plant communities within five NSW Vegetation Classes (North-west Plain Shrublands – 184 ha; North-west Floodplain Woodlands – 154 ha; Semi-arid Sand Plain Woodlands – 89 ha; Southern Tableland Dry Sclerophyll Forests – 955 ha; and Southern Tableland Wet Sclerophyll Forests – 32 ha), were not sampled in the accuracy assessment process as they were of minimal extent in the study area.

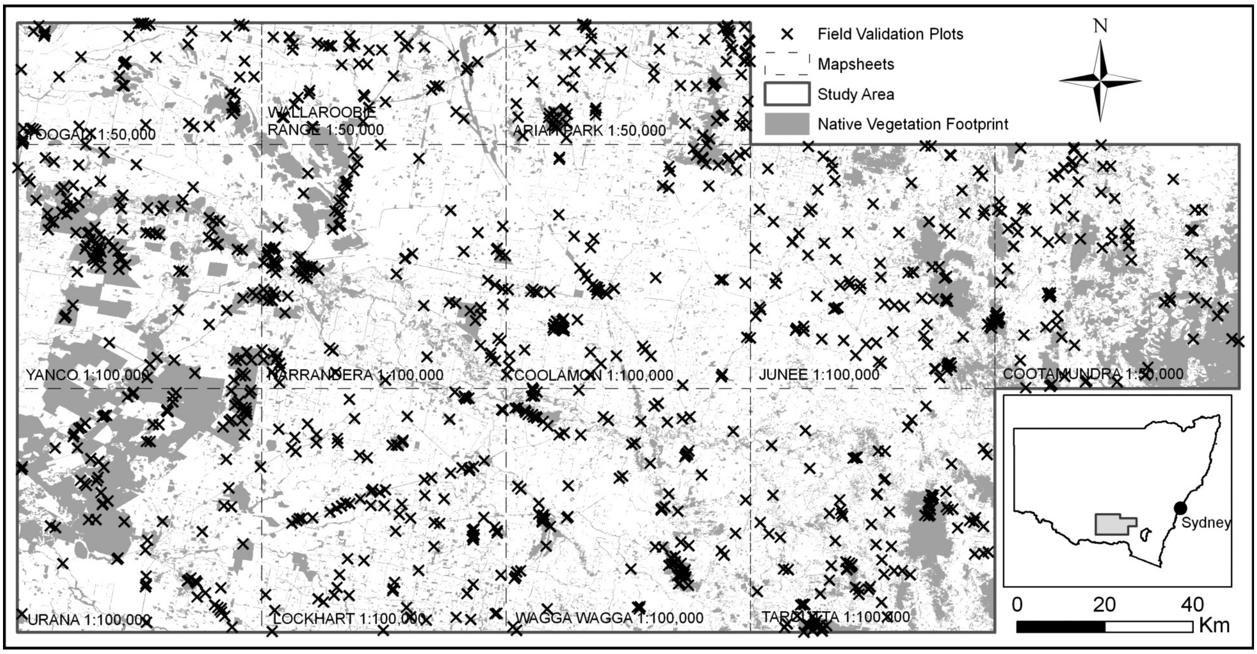

Fig. 6. Location of independent blind accuracy assessment plots.

Discussion

Use of digital stereo imagery

The mapping of 100 NSW VCA plant communties within the South Western Slopes and Riverina bioregions in central-southern NSW, one of the most highly fragmented landscapes in Australia, provides spatial data for environmental planning and assessment. The quality of the mapping is similar to fine thematic mapping of plant communities in parts of Europe and Great Britain (Bradtner *et al*. 2011). In Switzerland the Swiss Federal Institute of Forest, Snow and Landscapes has interpreted ADS40 imagery using Stereo Analyst for ArcGIS software and 3D Planar screen hardware to undertake forest inventory and other ecological assessments (Hastedt *et al.* 2009a & 2009b), while the National Inventory of Landscapes in Sweden (NILS) programs aerial photo interpretation approach (Allard *et al.* 2003) uses Planar screens with similar software (DAT/EM's Summit Evolution) for stereo observation and delineation, with ArcGIS used for polygon generation and registering interpreted data into their database (Heiskanen *et al.* 2008). This study in central-south NSW represents the first time the software has been used to develop a regional vegetation map in Australia. Stereo Analyst software had been used by Forests NSW for forest inventory assessments, however, this was undertaken using Cathode-Ray Tube (CRT) screens and flicker glasses to interpret scanned wet-film aerial photography contact prints in a digital 3-D environment (Webster 2008, Webster & Turner 2007).

High resolution ADS40 multi-spectral imagery produced maps with high pixel accuracy and greater image depth than traditional API mapping using wet-film aerial photography (DUAP 2000). The resolution of the ADS40 imagery, along with a systematic DAPI process including extensive field checking, is more likely to produce accurate mapping at the fine hierarchical level of a plant community ('plant association' in Beadle & Costin 1952, 'plant community' in Benson 2006, 'Classification Level D' in Sivertsen 2009), than interpretation of digital satellite imagery such as SPOT5 or LANDSAT TM, which is captured at a coarser scale and

Table 6. Accuracy assessment degrees of correctness (Sivertsen 2009).

Accuracy Level	Degree of Correctness	Description
1	Absolutely Right	No doubt about the match. **Perfect**
2	Reasonable or Acceptable Answer	May not be the best possible but is acceptable; this does not pose a problem to the user if it is seen on the map. **Right**
3	Understandable but Wrong	Not good; there is something about the site that makes the answer understandable but there is clearly a better answer. This answer would pose a problem for users of the map. **Not Right**
4	Absolutely Wrong	Absolutely unacceptable. **Very wrong**

Table 7. NSW VCA plant communities mapped in the study area listed under NSW Vegetation Formations and Classes (Keith 2004).

ID	NSW VCA Plant Community Type	Hectares
Wet Sclerophyll Forests		
Southern Tableland Wet Sclerophyll Forests		
295	Robertson's Peppermint - Broad-leaved Peppermint - Norton's Box - stringybark shrub-fern open forest of the NSW South Western Slopes and South Eastern Highlands Bioregions	13
300	Ribbon Gum - Narrow-leaved (Robertson's) Peppermint montane fern - grass tall open forest on deep clay loam soils in the upper NSW South Western Slopes Bioregion and western Kosciuszko escarpment	19
Grassy Woodlands		
Southern Tableland Grassy Woodlands		
283	Apple Box - Blakely's Red Gum moist valley and footslopes grass-forb open forest of the NSW South Western Slopes Bioregion	263
312	Yellow Box grassy tall woodland on valley flats in the upper slopes of the South Western Slopes and South Eastern Highlands Bioregions	2
Western Slopes Grassy Woodlands		
266	White Box grassy woodland in the upper slopes sub-region of the NSW South Western Slopes Bioregion	26,437
267	White Box - White Cypress Pine - Western Grey Box shrub/grass/forb woodland in the NSW South Western Slopes Bioregion	4,893
268	White Box - Blakely's Red Gum - Long-leaved Box - Norton's Box - Red Stringybark grass-shrub woodland on shallow soils on hills in the NSW South Western Slopes Bioregion	10,863
276	Yellow Box grassy tall woodland on alluvium or parna loams and clays on flats in NSW South Western Slopes Bioregion	2,411
277	Blakely's Red Gum - Yellow Box grassy tall woodland of the NSW South Western Slopes Bioregion	24,946
278	Riparian Blakely's Red Gum - box - shrub - sedge - grass tall open forest of the central NSW South Western Slopes Bioregion	298
280	Red Stringybark - Blakely's Red Gum -/+ Long-leaved Box shrub/grass hill woodland of the NSW South Western Slopes Bioregion	9,949
282	Blakely's Red Gum - White Box - Yellow Box - Black Cypress Pine box grass/shrub woodland on clay loam soils on undulating hills of central NSW South Western Slopes Bioregion	4,969
284	Red Stringybark - Blakely's Red Gum - tea tree herbaceous swampy valley open forest of the southern NSW South Western Slopes Bioregion	10
301	Drooping Sheoke - *Ricinocarpos bowmannii* - grasstree tall open shrubland of the Coolac - Tumut Serpentinite Belt	143
316	Norton's Box - Red Box - Red Stringybark -/+ Nodding Flax Lily forb-grass open forest mainly on the Tumut region	32
347	White Box - Blakely's Red Gum shrub/grass woodland on metamorphic hillslopes in the mid-southern part of the upper slopes sub-region of the NSW South Western Slopes Bioregion	4,679
426	Red Box - White Box +/- Red Stringybark hill woodland in the NSW South Western Slopes Bioregion	178
Floodplain Transition Woodlands		
56	Poplar Box - Belah woodland on clay-loam soils on alluvial plains of north-central NSW	19
70	White Cypress Pine woodland on sandy loams in central NSW wheatbelt	7,857
74	Yellow Box - River Red Gum tall grassy riverine woodland of NSW South Western Slopes and Riverina Bioregions	11,839
76	Western Grey Box tall grassy woodland on alluvial loam and clay soils in the NSW South Western Slopes and Riverina Bioregions	8,392
80	Western Grey Box - White Cypress Pine tall woodland on loam soil on alluvial plains of NSW South Western Slopes and Riverina Bioregions	44,991
82	Western Grey Box - Poplar Box - White Cypress Pine tall woodland on red loams mainly of the eastern Cobar Peneplain Bioregion	10,796
237	Riverine Western Grey Box grassy woodland of the semi-arid (warm) climate zone	1,410
248	Mixed box eucalypt woodland on low sandy-loam rises on alluvial plains in central western NSW	48
Grasslands		
Riverine Plain Grasslands		
44	Forb-rich Speargrass - Windmill Grass - White Top grassland of the Riverina Bioregion	1,941
45	Plains Grass grassland on alluvial mainly clay soils in the Riverina and NSW South Western Slopes Bioregions	2,224
46	Curly Windmill Grass - speargrass - wallaby grass grassland on alluvial clay and loam on the Hay Plain, Riverina Bioregion	169
165	Derived corkscrew grass grassland/forbland on sandplains and plains in the semi-arid (warm) climate zone	1,009
n/a	Native grassland (can include mosaics of some or all of the above four NSW VCAs)	148,130
Dry Sclerophyll Forests		
Upper Riverina Dry Sclerophyll Forests		
285	Broad-leaved Sally grass - sedge woodland on valley flats and swamps in the NSW South Western Slopes and adjoining South Eastern Highlands Bioregions	149
289	Mugga Ironbark - Inland Scribbly Gum - Red Box shrub/grass open forest on hills in the upper slopes sub-region of the NSW South Western Slopes Bioregion	3,562

ID	NSW VCA Plant Community Type	Hectares
290	Red Stringybark - Red Box - Long-leaved Box - Inland Scribbly Gum tussock grass - shrub low open forest on hills in the southern part of the NSW South Western Slopes Bioregion	12,486
294	Norton's Box - Red Box - White Box tussock grass open forest of the southern section of the NSW South Western Slopes Bioregion	5
297	Broad-leaved Peppermint - Norton's Box - Red Stringybark tall open forest on red clay on hills in the southern part of the NSW South Western Slopes Bioregion	2
298	Apple Box - Norton's Box - Blakely's Red Gum valley flat moist grassy tall open forest in the southern NSW South Western Slopes and adjoining South East Highlands Bioregions	282
306	Red Box - Red Stringybark - Norton's Box hill heath shrub - tussock grass open forest of the Tumut region	303
310	Norton's Box - Red Stringybark grassy tall open forest on sheltered slopes in the Tumbarumba - Murray River region of the NSW South Western Slopes Bioregion	453
342	Mugga Ironbark - mixed box woodland on hills in the Cowra - Boorowa - Young region of the NSW South Western Slopes Bioregion	2,855
Southern Tableland Dry Sclerophyll Forests		
299	Riparian Ribbon Gum - Robertsons Peppermint - Apple Box riverine very tall open forest of the NSW South Western Slopes and South East Highlands Bioregions	630
352	Red Stringybark - Blakely's Red Gum hillslope open forest on meta-sediments in the Yass - Boorowa - Crookwell region of the NSW South Western Slopes and South Eastern Highlands Bioregions	325
Western Slopes Dry Sclerophyll Forests		
54	Buloke - White Cypress Pine woodland in the NSW South Western Slopes Bioregion	11
110	Western Grey Box - Cypress Pine shrubby woodland on stony footslopes in the NSW South Western Slopes and Riverina Bioregions	1,908
217	Mugga Ironbark - Western Grey Box - cypress pine tall woodland on footslopes of low hills in the NSW South Western Slopes Bioregion	16,011
243	Mugga Ironbark - White Cypress Pine woodland on low rises mainly in the Cobar Peneplain Bioregion	10
287	Long-leaved Box - Red Box - Red Stringybark mixed open forest on hills and hillslopes in the NSW South Western Slopes Bioregion	4,175
291	Inland Scribbly Gum - Black Cypress Pine - Mugga Ironbark - Daphne Heath low woodland of the Wagga Wagga region in the southern NSW South Western Slopes Bioregion	2,015
309	Black Cypress Pine - Red Stringybark - red gum - box low open forest on siliceous rocky outcrops in the NSW South Western Slopes Bioregion	5,578
321	Red Stringybark - Long-leaved Box - Black Cypress Pine shrub/grass woodland on siliceous sedimentary ranges in the upper NSW South Western Slopes and South Eastern Highlands Bioregions	44
341	Blakely's Red Gum - Red Box - Black Cypress Pine grass/shrub woodland on hills in the upper slopes sub-region of the NSW South Western Slopes and western South Eastern Highlands Bioregions	65
343	Mugga Ironbark - Red Box - Red Stringybark - Western Grey Box grass/shrub woodland on metamophic substrates in the Tarcutta - Gundagai region, NSW South Western Slopes Bioregion	4,187
346	White Box - Blakely's Red Gum - White Cypress Pine shrubby woodland on metamorphic hills in the Wagga Wagga - Cootamundra region of the NSW South Western Slopes Bioregion	4,076
348	Red Stringybark - Long-leaved Box - *Rytidosperma pallidum* grassy open forest in the upper Lachlan catchment, NSWSWS and South Eastern Highlands Bioregions	559
354	Red Stringybark - Long-leaved Box - Black Cypress Pine shrub/grass woodland on siliceous sedimentary ranges in the upper NSW South Western Slopes and South Eastern Highlands Bioregions	44
Freshwater Wetlands		
Inland Floodplain Swamps		
12	Shallow marsh wetland of regularly flooded depressions on floodplains mainly in the semi-arid (warm) climatic zone (mainly Riverina and Murray Darling Depression Bioregions)	36
47	Swamp grassland wetland of the Riverine Plain	4,605
53	Shallow freshwater wetland sedgeland in depressions on floodplains on inland alluivial plains and floodplains	8
181	Common Reed - Bushy Groundsel aquatic tall reedland grassland wetland of inland river systems	56
182	Cumbungi rushland wetland of shallow semi-permanent water bodies and inland watercourses	312
238	Permanent and semi-permanent freshwater lakes wetland of the inland slopes and plains	16
335	Tussock grass - sedgeland fen - rushland - reedland wetland in impeded creeks in valleys in the upper slopes sub-region of the NSW South Western Slopes Bioregion	125
336	Rush - Sedge - Common Reed mainly lentic channel wetland of the Upper Murray and mid-Murrumbidgee River floodplains in the NSW South Western Slopes Bioregion	111
n/a	Swamp mosaic (some, or all, of NSW VCAs 17, 24, 47, 53, 181, 182 & 999)	29,085
Inland Floodplain Shrublands		
17	Lignum shrubland wetland of the semi-arid (warm) plains (mainly Riverina and Murray Darling Depression Bioregions)	1,082
24	Canegrass swamp tall grassland wetland of drainage depressions, lakes and pans of the inland plains	3,138
160	Nitre Goosefoot shrubland wetland on clays of the inland floodplains	286

ID	NSW VCA Plant Community Type	Hectares
Forested Wetlands		
Eastern Riverine Forests		
85	River Oak forest and woodland wetland of the NSW South Western Slopes and South Eastern Highlands Bioregions	252
Inland Riverine Forests		
2	River Red Gum-sedge dominated very tall open forest in frequently flooded forest wetland along major rivers and floodplains in south-western NSW	2,204
5	River Red Gum herbaceous-grassy very tall open forest on inner floodplains in the lower slopes subregion of the NSW South Western Slopes and Riverina Bioregions	27,405
7	River Red Gum - Warrego Grass - herbaceous riparian tall open forest wetland mainly in the Riverina Bioregion	3,996
9	River Red Gum - wallaby grass tall woodland wetland on the outer River Red Gum zone mainly in the Riverina Bioregion	7,846
10	River Red Gum - Black Box woodland wetland of the semi-arid (warm) climatic zone (mainly Riverina and Murray Darling Depression Bioregions)	1,304
11	River Red Gum - Lignum very tall open forest or woodland wetland on floodplains of semi-arid (warm) climate zone (mainly Riverina and Murray Darling Depression Bioregions)	55
79	River Red Gum shrub/grass riparian tall woodland or open forest wetland mainly in the upper slopes sub-region of the NSW South Western Slopes and western South East Highlands Bioregions	5,011
249	River Red Gum swampy woodland wetland on cowals (lakes) and associated flood channels in central NSW	3,259
Semi-arid Woodlands		
Inland Floodplain Woodlands		
13	Black Box - Lignum woodland wetland of the inner floodplains in the semi-arid (warm) climate zone (mainly Riverina and Murray Darling Depression Bioregions)	355
15	Black Box open woodland wetland with chenopod understorey mainly on the outer floodplains in south-western NSW (mainly Riverina and Murray Darling Depression Bioregions)	5
16	Black Box grassy open woodland wetland of rarely flooded depressions in south western NSW (mainly Riverina and Murray Darling Depression Bioregions)	6,470
North-west Floodplain Woodlands		
55	Belah woodland on alluvial plains and low rises in the central NSW wheatbelt to Pilliga and Liverpool Plains regions	154
Riverine Plain Woodlands		
26	Weeping Myall open woodland of the Riverina and NSW South Western Slopes Bioregions	2,815
Riverine Sandhill Woodlands		
20	Buloke - Moonah - Black Box open woodland on sandy rises of semi arid (warm) climate zone (mainly Riverina and Murray Darling Depression Bioregions)	704
28	White Cypress Pine open woodland of sand plains, prior streams and dunes mainly of the semi-arid (warm) climate zone	3,256
48	White Cypress Pine - Drooping Sheoak grassy open woodland of the Riverine Plain	14
75	Yellow Box - White Cypress Pine grassy woodland on deep sandy-loam alluvial soils of the eastern Riverina and western NSW South Western Slopes Bioregions	13,076
Inland Rocky Hill Woodlands		
176	Green Mallee - White Cypress Pine very tall mallee woodland on gravel rises mainly in the Cobar Peneplain Bioregion	739
178	Broombush - Green Mallee - Blue Mallee very tall shrubland on stony rises in the NSW South Western Slopes Bioregion	17
185	Dwyer's Red Gum - White Cypress Pine - Currawang shrubby woodland mainly in the NSW South Western Slopes Bioregion	17,201
186	Dwyer's Red Gum - Black Cypress Pine - Currawang shrubby low woodland on rocky hills mainly in the NSW South Western Slopes Bioregion	11,829
239	Red Stringybark – Dwyer's Red Gum - Black Cypress Pine woodland on siliceous ranges in the Lockhart to Griffith regions, South Western Slopes and Cobar Peneplain Bioregions	154
257	Dwyer's Red Gum - Currawang grassy low woodland of the central western plains of NSW	195
292	She oak - Fringe Myrtle heathland on rocky ranges in the NSW South Western Slopes Bioregion	984
317	Currawang very tall shrubland on siliceous rocky ridges and cliffs mainly in the NSW South Western Slopes Bioregion	5,810
318	Mugga Ironbark - Tumbledown Red Gum - Red Box - Black Cypress Pine open forest on shallow stony soils on hills in the NSW South Western Slopes Bioregion	1,470
319	Tumbledown Red Gum - White Cypress Pine hill woodland in the southern part of the NSW South Western Slopes Bioregion	2,176
634	White Cypress Pine woodland on hills in the eastern Riverina to western NSW South Western Slopes Bioregions	702
Sand Plain Mallee Woodlands		
173	Sandplain mallee of central NSW	405
174	Mallee - Gum Coolabah woodland on red earth flats of the eastern Cobar Peneplain Bioregion	246
Semi-arid Sand Plain Woodlands		
57	Belah/Black Oak - Western Rosewood - Wilga woodland of central NSW including the Cobar Peneplain Bioregion	89

ID	NSW VCA Plant Community Type	Hectares
Arid Shrublands		
Riverine Chenopod Shrublands		
164	Cotton Bush open shrubland of the semi-arid (warm) zone	1,958
216	Black Roly Poly low open shrubland of the Riverina and Murray-Darling Depression Bioregions	894
n/a	Shrub mosaic (some, or all, of NSW VCAs 17, 160, 164, 216)	801
North-west Plain Shrublands		
77	Yarran shrubland of the NSW central to northern slopes and plains	69
229	Derived mixed shrubland on loamy-clay soils in the Cobar Peneplain Bioregion	115
Total Native Vegetation		**546,151**
Additional		
n/a	Native grass with previous cultivation pattern observed on imagery	3,260
n/a	Native Trees - no NSW VCA plant community [1]	16
n/a	Commercial plantations (primarily *Pinus radiata*)	8,629
n/a	Environmental plantings (primarily *Eucalyptus* spp.)	9,984
n/a	Non-vegetated land and non-native vegetation (including improved pasture, cropping and areas below mapping thresholds which contain native species)	2,091,669

[1] A total of 16 hectares of woody native vegetation was unable to be assigned a NSW VCA plant community type due to high levels of disturbance and the presence of regrowth *Acacia* spp.

with less/nil panchromatic bands. The high spatial accuracy in ADS40 linework delineation and thematic accuracy in identifying plant community types meets a range of user needs such as regional, local and site level environmental assessment including aspects of regulatory compliance.

The detailed vegetation mapping combined with the comprehensive description, threat and protected area assessment of each plant community in the NSW VCA database provides a useful combination of spatial and non-spatial information for land use planning. An advantage of this mapping method over traditional wet film API mapping is that polygon digitising and attribution occurs directly in the digital GIS environment so there is no need for secondary data capture processes that can lead to transfer errors. We found that field reconnaissance to identify NSW VCA plant community types facilitated rapid assessment of multiple attributes of the vegetation and reduced errors in coding of plant communities in the map polygons. Since DAPI operators and botanists were able to view ADS40 images in a 3-D environment simultaneously, this lead to group discussion and increased map attribution consistency.

Grassland mapping

In western parts of the study area the detail within the ADS40 imagery and the use of zoom functions in the GIS environment allowed DAPI operators to confidently distinguish between low chenopod shrublands and grassland communities. When occurring in a natural / ungrazed state, tall grasslands, such as NSW VCA 45 [Plains Grass grassland on alluvial mainly clay soils in the Riverina and NSW South-western Slopes Bioregions] could be separated from low grasslands, such as NSW VCA 44 [Forb-rich Speargrass – Windmill Grass – White Top grassland of the Riverina Bioregion]. However, delineation between low grasslands such as NSW VCA 44 and NSW VCA 46 [Curly Windmill Grass – speargrass – wallaby grass grassland on alluvial clay and loam on the Hay Plain, Riverina Bioregion] was less certain due to high structural similarities. Low grasslands were delineated with high confidence at times, and such delineation would have been improved if additional resources were allocated to field reconnaissance and mapping time. While the technology shows much capability in this area, accurate delineation of structurally similar non-woody vegetation types, requires a level of reconnaissance beyond the scope of this study, or a reliance on vast amounts of existing vegetation plot data presenting strong correlations with accurate edaphic datasets. This was not available for the parts of the study area where these vegetation types occur. As a result, the majority of natural grasslands were mapped as 'Native Grassland Mosaic'. The ADS40 imagery used for this study was captured after eight to ten years of severe drought, and much of the reconnaissance was undertaken during drought conditions. Therefore, it is likely that the limitation of mapping mosaics would be alleviated if ADS40 image capture and field reconnaissance were synchronised during times of vigorous vegetative growth, or additional resources were allocated to field reconnaissance and mapping time.

Differentiating between natural and derived grasslands within the 'native grassland mosaic' mapped type was not considered in the original study design. As such, the 'native grassland mosaic' contains a combination of natural and derived grasslands. It is considered that grasslands within the Riverina bioregion are likely to be natural in origin (primarily NSW VCA 44, 45 & 46), with derived grasslands primarily being NSW VCA 165. The majority of native grasslands in the South Western Slopes bioregion are derived primarily from plant communities occurring in grassy woodland formations. Some areas mapped as 'native grassland mosaic' in the Riverina bioregion may be derived from NSW VCA 26 [*Weeping Myall open woodland of the Riverina and NSW South Western Slopes bioregion*].

Woodland and open forest mapping

With the exception of non-woody vegetation types with similar structure (e.g. native grasslands), the NSW VCA plant community types were able to be accurately delineated in this study. However, at times there was some difficulty in the polygon attribution of NSW VCA plant community types on hill mosaics in the Upper Slopes subregion of the South Western Slopes bioregion. This was due to the overlap of canopy species between compositionally similar NSW VCA plant community types with broad ecotonal boundaries (e.g. (NSW VCA 289 and 291 on the Tarcutta 1:100,000 mapsheet).

An issue with some vegetation type maps has been the ability to consistently delineate between open woodland and non-woody vegetation at ecotonal boundaries. In this study the delineation between non-woody and open woodland environments was set at 5% crown cover (or a crown separation ratio of 3:1 (Penridge & Walker 1988). However, when mapping in a digital environment there is potential to provide quantitative assessment of crown separation ratio in a GIS platform. For instance, in recent years technological advances have seen the development of 'tree canopy layers' to spatially represent the presence of woody vegetation (e.g. Roff et al. 2010, Roff & Davies 2011). Such products provide a level of guidance as to the presence of woody vegetation including scattered and isolated paddock trees. Digitally displaying the relative distance between tree crown edges provides an opportunity to utilise the digital environment to provide a consistent on-screen guide when delineating between woodland and non-woody vegetation. One option of quantifying this delineation is to develop zonal statistics models from tree canopy layers to quantify crown separation ratio.

Independent Accuracy Assessment

The independent validation of the accuracy of the vegetation map product provides a level of confidence for the end-user of the vegetation map. While there are a number of methods for developing comprehensive, efficient and statistically valid sampling stratifications to guide vegetation surveys (refer to Neldner et al. 1995), these are generally aimed at guiding sampling strategies to collect new survey data, or to confidently classify assemblages of plants. Although the concept of validating the accuracy of vegetation maps is discussed in some literature (e.g. Gopal & Woodcock 1994, Townsend 2000), appropriate sampling adequacy guidelines to determine accuracy of polygon-based vegetation maps are yet to be developed relative to landscape heterogeneity, and as such the true adequacy of the validation can only be inferred by the number of blind field validation plots analysed in this study.

Independent assessors undertook a blind stratification process based on the native vegetation footprint of each NSW Landscape (Mitchell 2003). This resulted in some plant community types with small distributions in the study area having limited samples. In order to present the independent accuracy assessment data in a meaningful way, it was necessary to present the plant community type accuracy levels at a NSW Class level (as per Table 8). There are significant resources required in collecting independent field validation data and it has rarely been done to the levels undertaken here, however improvements could be made for future mapping projects by developing a sampling stratification based on a blind delineation of the study area using a finer scale stratification such as plant community types.

While accuracy was validated by direct point comparison it could be improved by considering levels of error in delineating vegetation polygon boundaries, separate validation botanists having similar interpretive understanding of NSW VCA plant communities and increased checking on private land. Additionally, it is reasonable to accept that, even at a capture scale of circa 1:4,000, a vegetation polygon boundary may have an error of approximately 5–10 metres. In considering an error level of 10 metres in the accuracy assessment analysis, it is possible that the user accuracy level may increase through enabling field validation plots that occur

Table 8. User accuracy of NSW VCA plant community types, categorised by NSW Vegetation Class (Keith 2004) with number of replicate samples in brackets.

NSW Vegetation Class	User Accuracy of Plant Community Types within NSW Vegetation Class	
Eastern Riverine Forests	100 %	(2)
Floodplain Transition Woodlands	87 %	(354)
Inland Floodplain Shrublands	100 %	(3)
Inland Floodplain Swamps	55 %	(11)
Inland Floodplain Woodlands	96 %	(23)
Inland Riverine Forests	95 %	(97)
Inland Rocky Hill Woodlands	77 %	(48)
North-west Plain Shrublands	100 %	(1)
Riverine Chenopod Shrublands	100 %	(2)
Riverine Plain Grasslands	96 %	(90)
Riverine Plain Woodlands	92 %	(13)
Riverine Sandhill Woodlands	75 %	(57)
Sand Plain Mallee Woodlands	100 %	(3)
Southern Tableland Grassy Woodlands	100 %	(3)
Upper Riverina Dry Sclerophyll Forests	72 %	(32)
Western Slopes Dry Sclerophyll Forests	87 %	(74)
Western Slopes Grassy Woodlands	87.3%	(228)
Overall User Accuracy	**87 %**	**(1041)**

Sources: EcoLogical (2009, 2010, 2011a, 2011b), GHD (unpub.), SKM (2009) in this ten metre error zone to be assigned to the adjacent polygon.

Polygon attribution to NSW VCA plant community type, undertaken by DAPI operators, was based on whole of polygon observations of dominant species observed on the imagery and their position in the landscape. Such ecological community polygon-scale observations do not always correlate with that of fine-scale quadrat observations. For this study, independent field validation plots were based on 50 x 50 metre plot observations (plus viewshed within the same apparent NSW VCA type), which at 0.25 hectares is below the one hectare specification for minimum polygon size in this study. In some instances a polygon may be considered incorrect based on such fine-scale observations within a broader polygon. The same is true when deciding between similar vegetation types within broad ecotones, or between NSW VCA plant community types which are compositionally similar. The method described by Gopal & Woodcock (1994) helps to address this by allowing for 'levels of correctness'.

Map application flexibility

Development of a vegetation map capturing multiple attributes such as those collected as part of this study enhances uses of the vegetation map product. For example, Modelling the distribution of polygons containing *Allocasuarina verticillata* as a dominant species can give a strong indication of potential feed areas for the glossy black-cockatoo (*Calyptorhynchus lathami*), a cockatoo which favours foraging habitat with an abundance of Casuarina (Cameron 2007, Higgins et al. 1999).

Modelling the distribution of polygons attributed to a NSW VCA plant community type containing Eucalyptus camaldulensis, coupled with polygons attributed to good crown health can give a strong indication of Eucalyptus camaldulensis forests with relatively healthy hydrological function.

Modelling the distribution of the critically endangered community White Box grassy woodland in the upper slopes sub-region of the NSW South Western Slopes Bioregion (NSW VCA 266) containing woody regrowth can indicate remnants with regrowth of key woody species. Multiple attribute vegetation mapping has the potential to greatly reduce site assessment costs for some conservation and planning programs such as:

- *Landscape-scale conservation including reserve acquisition, regional conservation planning, targeted conservation investment, threatened species, and other habitat modelling and landscape restoration;*
- *Property vegetation planning;*
- *Private native forestry assessments;*
- *Native vegetation compliance assessments;*
- *Biobanking assessments;*
- *Biodiversity certification for local councils;*
- *Monitoring, evaluation and reporting; and*
- *Fire behaviour modelling.*

The detailed mapping developed in this study should form a basis for monitoring change over coming decades and we encourage management authorities to use the data for conservation planning, vegetation and environmental restoration projects with the aim to protect biodiversity and improve the extent and condition of native vegetation in the region.

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Downloadable Appendices

Folder 1: NSW VCA database plant community type descriptions

Folder 2: PDF format vegetation maps for each of nine 1:100,000 and three 1:50,000 map tiles in the study area.

Note: GIS format data of this mapping can be obtained under licence by emailing data.broker@environment. nsw.gov.au or downloading VIS product '3884' from http://mapdata. environment.nsw.gov.au/DDWA/.

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