Office of Environment & Heritage

The NSW State Vegetation Type Map: Methodology for a regional-scale map of NSW plant community types

A description of the mapping method
Version 3

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1 Summary

This document describes the methodology for a regional scale map of plant community types for New South Wales (NSW), Australia. The methods were developed and applied by the Office of Environment and Heritage (OEH) to create a unified State Vegetation Type Map (SVTM).

Regional scale vegetation mapping supports government, industry and the community with information for conservation and investment. Applications include fire management, conservation planning, connectivity studies, water management, and condition assessment. The NSW Native Vegetation Information Strategy 2014–2018 (OEH 2014) provides the strategic context for the SVTM and related programs.

The SVTM uses the best available aerial (ADS–40/80) and satellite imagery (SPOT 5, SRTM, Landsat) and a collection of environmental variables. Several thousand new vegetation survey records have been collected and added to NSW Vegetation Information System (VIS).

Each plot-based vegetation survey record in the VIS is assigned to a plant community type (PCT). These assignments are used to map PCTs by combining the visual interpretation of vegetation patterns and predictive models. Expert rules and manual edits are applied to incorporate what is already known about the extent of each PCT. Recently published vegetation maps are included where available.

The SVTM provides baseline knowledge about the plant communities of NSW that will be updated and improved over time. It can be accessed via the SVTM webpage.

2 State Vegetation Type Map workflow

The State Vegetation Type Map (SVTM) workflow is divided into six modules (Figure 1). There are two parallel pathways that are applied in turn for each broad region of NSW:

1. *Classification*, dealing with biological data and aiming to classify plot-based survey data into plant community types (PCTs). This includes two sub-streams comprising the acquisition of field and type data, and classification and allocation
2. *Spatial analysis*, dealing with remotely sensed or interpolated data with continuous coverage across the state. This includes two sub-streams of acquiring the spatial data and spatial analysis.

These parallel pathways are integrated in Module 5 *Spatial product development*, which includes interpreting vegetation photo patterns, modelling plant community distributions, eliciting expert input and engaging users in testing and evaluation of the vegetation map products. Following user testing and feedback the finalised vegetation map products are published under Module 6.

This workflow is consistent with the national methodology recommended for producing vegetation maps, described in Thackway et al. (2008).

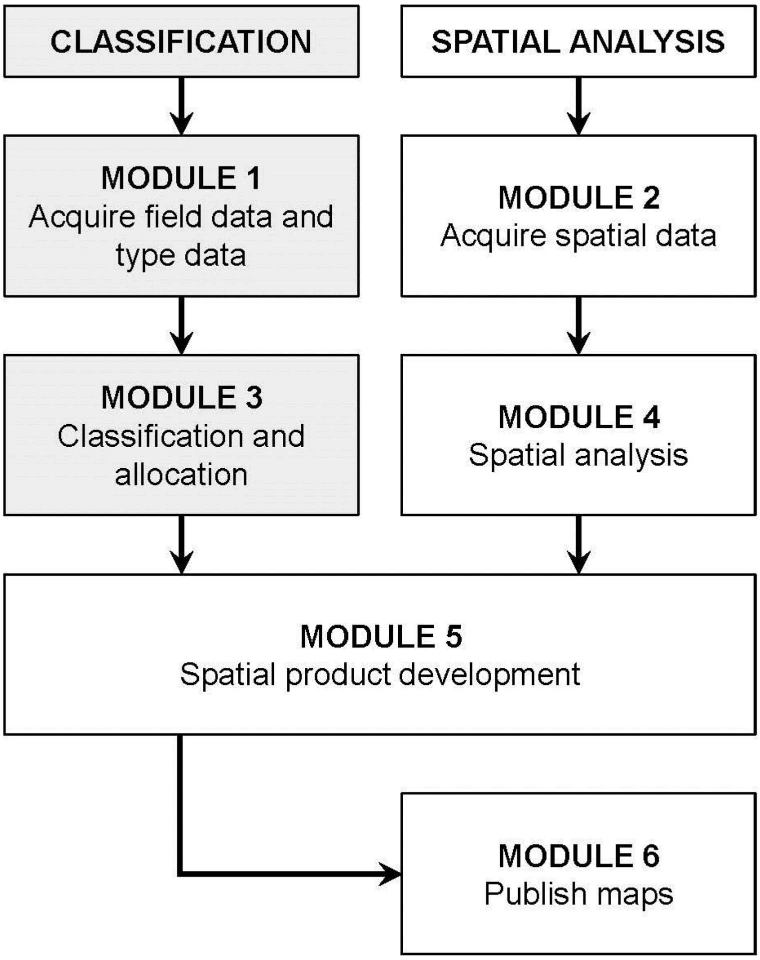

Figure 1: State Vegetation Type mapping methodology featuring parallel workflows of classification and spatial analysis

3 Method details

The six modules shown in Figure 1 are described in more detail below.

3.1 Module 1: Acquire field data and type data

Module 1 comprises three sub-modules:

1. Acquire existing surveys and suitable PCTs
2. Acquire new survey data
3. Stratify the landscape for field survey.

3.1.1 Acquire existing surveys and suitable plant community types

This first module is dedicated to an audit of relevant classifications of native vegetation community types, including any existing vegetation surveys that have been assigned a vegetation type. The audit includes information from private and public sources as well as data from local, state and federal government agencies.

Survey and type information includes:

- full floristic survey data in a spatial database, including all living vascular flora in area-defined surveys
- rapid survey data, in written or mapped form, describing the composition and/or patterns in vegetation community distribution
- PCTs from the NSW Vegetation Information System (VIS)
- classified native vegetation communities based on analysis and interpretation of field data
- non-empirical classifications and descriptions.

Many native vegetation survey records are held in the VIS Flora Survey database. The surveys represent empirical information about the structure and composition of native vegetation at individual, geolocated survey sites.

The VIS Classification database holds the master list of native vegetation types for NSW. The descriptions include each PCT's geophysical, structural and floristic characteristics. The PCT list is currently not comprehensive nor definitive, as it has been established from a variety of sources supported by different levels of observed, qualitative and quantitative analysis. Broadly, PCTs include some 1600 types in NSW. There are recognised gaps and duplications within the PCT list that are being progressively resolved.

Additional sources of vegetation survey data and classification are assessed for their site data values and/or for contribution to vegetation community classification. Site information is sought for candidate vegetation communities that have no existing site information.

Some important survey and plant type information is held by individuals or is found in published and 'grey' literature. Acquisition of these data can be time-consuming so efforts strategically target those of most importance for mapping purposes.

3.1.2 Acquire new survey data

The State Vegetation Type Map relies primarily on the availability of pre-existing full floristic vegetation survey information held in the VIS Flora Survey database. Additional surveys are commissioned to help fill gaps across NSW but collectively make only a relatively small contribution to the state's site vegetation survey resources. Ideally, the SVTM would use random-stratified field survey techniques to survey the whole population of classes across the entire landscape using full floristic surveys. In practice, new random-stratified surveys are confined to 'gap' areas that have few or no existing records.

The nature and extent of any new survey is a function of existing (legacy) survey density and quality as well as available funds and survey resources. Areas prioritised include those with little or no previous survey information, complex landscapes, and candidate communities lacking documented survey sites.

Three types of survey data can be collected:

- *full floristic surveys (20m by 20m)* include a comprehensive list of vascular plants. This information is a prerequisite for quantitative classification of vegetation communities
- *rapid surveys* include the top three species in each stratum. Rapid surveys can be used for gap filling and in some cases, for vegetation modelling
- *observations* of canopy species or communities on roadsides. These are used to aid visual interpretation of imagery, but cannot be used in modelling.

The type of survey and the number of surveys undertaken is dictated by purpose, desired sampling intensity, time, cost and access constraints. Several extra sites are provided to account for potential redundancies such as area accessibility.

3.1.3 Stratify the landscape for field survey

To maximise the likelihood of the samples representing the full population, the landscape is stratified into unique environmental units. Environmental units are derived by intersecting environmental layers to identify a range of environmental domains. Those domains that are under-sampled by existing data are identified. New survey locations are selected randomly but confined to accessible locations using infrastructure layers such as administrative and access boundaries.

For example, stratification may include:

- a soil layer, on the assumption that clay and sandy soils have an impact on species distribution
- foliage projective cover (FPC) based on Landsat data, to help sample both woody and non-woody communities.

Other factors considered include:

- tenure, with a focus on getting access to traditionally under-sampled communities on private property
- distance-from-roads, in accordance with survey contracting requirements
- distance from existing surveys, to avoid clustering of surveys where existing information is already available.

3.2 Module 2: Acquire spatial data

Module 2 comprises three sub-modules:

1. Acquire existing environmental layers
2. Acquire and process imagery
3. Acquire existing native vegetation mapping.

3.2.1 Acquire existing environmental layers

A suite of environmental predictor layers, including climate, geology, soil, geophysical data, remote sensing and terrain indices has been compiled. The layers have all been snapped to the same 30 metre grid cell size. A list of environmental predictors is available on the SVTM webpage. Examples of predictor layers are provided in Appendix A.

Environmental predictors are used in Module 5 for modelling the relationships between PCTs and environment, and enabling prediction across the landscape.

The age of individual layers, their quality and resolution varies. Shortfalls in coverage or quality require gap filling by extrapolation, sourcing new data or commissioning revised assessments.

3.2.2 Acquire and process imagery

The NSW Office of Environment and Heritage (OEH) has acquired an extensive catalogue of imagery. This imagery archive is used for the visual interpretation and automated delineation of vegetation patterns. It is also used to calculate a range of image derived modelling predictor layers such as texture and greenness indices.

The key resources for regional vegetation mapping include ADS–40/80 digital aerial photography (50cm resolution), time-series SPOT 5 satellite imagery (2.5m, 2005–2013), time-series Landsat imagery (25m, 1989–2008) and Lidar.

ADS–40/80 imagery is used across eastern NSW for image interpretation and automated delineation of vegetation patterns. In western NSW, the SPOT 5 High Resolution Geometric (HRG) is the preferred sensor for the automated delineation of vegetation patterns. SPOT 5 has an advantage in western NSW due to its multispectral values (visible to shortwave infrared) and multi-temporal seamless coverage.

OEH has developed an enhanced resolution version of SPOT 5 imagery (‘super-resolution’) for both delineation and interpretation purposes. Super-resolution is a time-series product based on the NSW SPOT 5 catalogue. Creating a time-series minimises scene-to-scene differences, removes cloud artefacts, improves perceivable detail and provides patterns based on plant functional responses over time (Day et al. in prep).

The NSW Land and Property Information group has produced ADS–40/80 digital aerial photography for eastern and central NSW. A program has been implemented to complete coverage for all of NSW by 2018. The SVTM has been designed to be dynamically updated as new information becomes available, including new remote sensing imagery.

3.2.3 Acquire existing native vegetation mapping

Existing native vegetation mapping provides one of the tools used to gain knowledge about vegetation types. The primary source is the VIS map catalogue but research is required to obtain other mapping that will contribute to the current ecological understanding of the region (e.g. local government agencies that hold mapping not available via the VIS).

The availability of contemporary and high quality mapping generally decreases across NSW from east to west. Suitable high quality mapping coverage is patchy, even along the eastern seaboard.

Existing mapping may be used in several ways:

- extraction of survey sites (including pseudo-sites[1])
- use of existing line work
- use of existing (or translated) plant community attribution
- a reference set for plant communities.

3.3 Module 3: Classification and allocation

Module 3 comprises two sub-modules:

1. Vegetation community compilation
2. Plant community type allocation.

3.3.1 Vegetation community compilation

The VIS Classification database provides an *a priori* vegetation community classification for NSW. These types are taken as the foundation set on which to develop a candidate vegetation community list for mapping purposes. The work done in Module 1 (collating surveys and extant PCTs) is brought together here to develop a candidate native PCT classification for the mapping area.

PCTs are not equally supported by quantitative evidence. Where PCTs have been formulated with a high confidence value based on statistical analysis they can be directly employed. Where there is low or very low confidence in a PCT, full floristic data (both new and existing) may be required to develop a new classification that confirms or replaces the PCT. This process is managed by an OEH panel. Survey records that cannot be used for classification are retained for visual reference.

3.3.2 Plant community type allocation

For mapping of community types, all plot-based records must be allocated to a PCT. The preferred approach is to use systematic quantitative classification (Native Vegetation Interim Type Standard); however, the quality and density of vegetation data varies across NSW.

Therefore, separate approaches have been developed and applied in central and western NSW, in contrast to eastern NSW. While there are differences in the two approaches, they are internally consistent and repeatable, enabling a consistent vegetation map product to be produced across NSW.

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[1] Pseudo-sites are polygon centroids extracted from existing mapping that can be used to extrapolate information from a data rich to a data poor locality.

Central and western NSW

In central and western NSW, an *a priori* PCT classification was used (Benson 2006; Benson 2008; Benson et al. 2006; Benson et al. 2010). Individual plot-based records were assigned to candidate vegetation classes using a combination of cluster analysis and expert knowledge. More specifically, the SVTM uses a semi-automated classification of surveys to assign them to an existing PCT using the SAAP software program (Oliver et al. 2013). The survey records are classified using agglomerative hierarchical clustering in PRIMER (Clarke & Gorley 2015), which classifies each survey record into groups and displays a dendrogram of their relationship.

SAAP was used to calculate a quantitative goodness-of-fit score between plots and types. This approach recommends PCT allocations for each survey and expert knowledge is required to evaluate the outputs. Reference material includes floristic and structural information; relative species cover and abundance, location, photo-pattern and landscape location as well as any reference to the original classification in the PCT.

Where a new classification was required, quantitative classification routines such as agglomerative hierarchical clustering (PATN) (Belpin 1991) were used.

Eastern NSW

OEH has proposed to objectively define a revised set of PCTs for eastern NSW (OEH 2017). The revision aims to apply multivariate analytical techniques to a vegetation dataset comprising approximately 48,000 standard survey plots and will fit within the existing NSW vegetation classification hierarchy. A framework described by De Cáceres and Wiser (2012) will be used to position our classification efforts within an international context and to address longstanding issues around the consistency and performance of vegetation classification in the region.

The current PCT schema in eastern NSW represents a compilation of types from multiple independently constructed and overlapping regional and local classifications, which have been combined to describe over 800 types within eastern NSW. Source projects have applied a range of plot-based and type-based methods across various overlapping spatial contexts. Plot-based classifications have used related classification protocols, but differed in data selection rules, clustering methods, classification scales and classification evaluation processes.

Revision of eastern PCTs is required because users experience difficulties in locating and consistently discriminating current types during biodiversity assessment applications. Redressing the current limitations to improve the utility of PCTs requires application of consistent processes of data treatment, classification method and type characterisation. Classification will not be constrained to reproduce existing PCTs; however, there are strong practical reasons to minimise disruption to existing PCTs, and existing PCTs which are based on source types derived from numerical classification of plot data will be evaluated to identify a subset which meet objective criteria for stable homogeneous clusters. When assessing alternative clustering solutions, the degree of concordance with these ‘good’ existing PCTs will be considered.

3.4 Module 4: Spatial analysis

Module 4 comprises two sub-modules:

1. Image object segmentation
2. Assessment and equivalence of legacy mapping.

3.4.1 Image object segmentation

Segmentation of imagery is a method for recognising features, including native vegetation patterns, in imagery. The SVTM uses the multiresolution segmentation algorithm of the software package eCognition (Baatz & Schäpe 2000; Benz et al. 2004) to define image objects with low internal variation (low heterogeneity).

Image objects represent patches of vegetation that can later be classified based on attributes such as crown cover, spectral response, or soil type. The algorithm works by iteratively merging nearby objects that contribute the least to heterogeneity. The algorithm is novel in that it includes the shape of the object in its measurement of heterogeneity. It allows the user to skew the segmentation in favour of regions with smooth edges and a compact form. The software also allows for the classification of image objects at multiple scales.

ADS–40/80 very high resolution imagery is currently the preferred data for image analysis where it is available, otherwise time-series enhanced SPOT 5 is available as the next best option. The segmentation parameters are chosen based on visual inspection. Vegetation patterns from existing stereoscopic aerial photo interpretation and those recognized in high spatial resolution imagery (ADS–40/80) are used as a reference.

Assessing the quality of feature boundaries in segmentation is simple for sharply defined features where the transition zone between classes is smooth. It is more difficult where the transition does not have a linear function of change, such as ecotones. These diffuse boundaries are delineated based on user visual interpretation and user defined thresholds of sub-pixel abundance.

Object boundaries can be distorted to include adjoining dissimilar features, due to their similar spectral responses, or missed due to scale issues, such as diffuse woodland boundaries. These dissimilarities are minimised through manual editing and interpretation.

3.4.2 Assessment and equivalence of legacy mapping

Legacy native vegetation mapping is an important historical and technical resource upon which to build a contemporary regional-scale map. Each legacy map is systematically evaluated to assess its potential to contribute to the contemporary coverage. The criteria include:

- thematic accuracy
- spatial precision
- currency.

It is also important to provide an explicit relationship between the mapping classification (PCTs) and that of legacy mapping. An equivalence table performs this function; however, ‘equivalent’ should not be interpreted as ‘identical’.

This expert-driven process examines relationships between characteristic (high fidelity) species, dominant species, floristic composition, geographic range, substrates, spatial distribution, and landforms.

3.5 Module 5: Spatial product development

This module integrates the two parallel streams of Classification and Spatial analysis described in Figure 1.

Module 5 comprises six sub-modules:

1. Interpret vegetation photo patterns
2. Community distribution modelling
3. Expert Input
4. Accuracy assessment
5. User acceptance testing and evaluation.

3.5.1 Interpret vegetation photo patterns

The candidate PCTs for each region are examined and assigned one or multiple vegetation photo pattern[2] (VPP) classes based on their growth form and habit. VPPs are mapped by selecting image objects and assigning them class, based on the visual interpretation of very high resolution aerial and satellite imagery (at 1:8000 in eastern NSW and at around 1:25,000 for western NSW). Every polygon in the region is assigned a VPP in what is largely a manual process. Multiple interpreters are used to create a draft VPP map and a single interpreter makes corrections to produce a consistent product.

In some cases, specific PCTs can be assigned their own class where there is an obvious VPP or landscape position. Some vegetation patterns retain large numbers of potential PCTs such as ‘forests’ in eastern NSW. Where possible, further subdivisions are made based on factors such as topography, shrubby/grassy components, and ecological envelopes.

VPP classes reduce the number of PCTs that are likely to occur at a location and allow for the creation of unique vegetation models tailored for each VPP. This allows each model to use the subset of environmental layers best suited for the purpose. For example, the environmental predictors used in the ‘wetland’ model are specialised for wetlands and will differ from those used in the ‘rainforest’ model.

Some examples of vegetation photo patterns include: grasslands, riparian forests, chenopods, open woodlands, dry sclerophyll forests, rainforests, wet sclerophyll forests, belah, weeping myall, non-woody wetland, floodplain forests, mallee, and lignum shrublands. The number of VPP classes varies and is informed by the region, landscape type, the imagery pattern, available environmental layers, and the number and complexity of PCTs.

Since all polygons are assigned a VPP class, what constitutes native and non-native vegetation needs to be defined.

Native vegetation

Remote sensing interpreters visually assess each image object to decide if it is composed of native vegetation. A polygon with greater than 10% native vegetation by area is tagged as native and attributed a VPP. The interpretation is based on digital aerial photography, time-series remote sensing data, landscape position, survey records, environmental layers, existing mapping and personal knowledge.

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[2] This is not synonymous with Keith’s (2004) Formation or Class

Native vegetation polygons can include other coincident features such as rock outcrops, small farm dams, watercourses and wetlands, and isolated buildings. Recent fire scarring is classified as native and interpreted relative to the adjoining land cover or by referencing earlier imagery.

Native grasslands are the most difficult to characterise due to the lack of distinctive spatial signatures or VPP in the available imagery and the paucity of survey records.

Non-native

Polygons are categorised as non-native where they contain less than 10% native vegetation by area or have clear modification. Examples include roads, intensively or recently modified grazing areas, exposed soil, closely settled urban and industrial land, cropping, silviculture, infrastructure, home paddocks and buildings.

3.5.2 Community distribution modelling

The goal of modelling is to establish a relationship between VPP, environmental variables and survey records (PCTs). The relationships developed at survey locations are applied across the landscape to predict where those vegetation types are most likely to occur.

To constrain PCTs from being modelled outside of their known range spatial envelopes are applied. Envelopes are based on a review of the literature, expert opinion, VPP, and by IBRA subregion (Commonwealth of Australia 2012). Constraining PCTs by a maximum geographic range reduces the number of types competing within the model at any location and avoids a source of error.

The spatial extent of regional-scale mapping and the complex relationships between environmental variables and PCTs support the case for a model-based approach. A variety of modelling approaches have been applied in the SVTM program but the most common is boosted regression trees (BRTs). BRTs combine the strengths of two algorithms: regression trees (models that relate a response to their predictors by recursive binary splits) and boosting (an adaptive method for combining many simple models to give improved predictive performance) (Elith et al. 2008).

BRTs can handle different types of predictor variables and accommodate missing data. They have no need for prior data transformation or elimination of outliers, can fit complex nonlinear relationships, and automatically handle interaction effects between predictors. Although BRT models are complex, they can be summarised in ways that give powerful ecological insight, and their predictive performance is superior to most traditional modelling methods (Elith et al. 2008).

Separate models are built, one for each VPP class. In some cases, dry sclerophyll forests are further divided using IBRA bioregions. Each VPP class is given a set of PCTs that could occur and only survey records belonging to those PCTs are used to train the model. As the relationship between PCTs to landscape class can, in some cases, be one-to-many, sites can be used in more than one model.

The collated environmental layers form a large set, many of which are highly correlated. A combination of expert knowledge and statistical inference is used to create a subset for each VPP class (e.g. rainforest or wetland). Groups of similar environmental variables (such as climate) are tested using backwards elimination to identify and retain the layers that explain the most variance in the model. Highly correlated variables are removed by assessing the deviance between models. An average of 10–20 environmental layers are used in the regional-scale models. An example of the layers available is in Appendix A and a full list is available on the SVTM webpage.

BRT models are implemented with PCTs as classes using the GBM package (Ridgeway 2006) for the R application (R Core Team 2013), and using 10-fold cross-validation for model selection and evaluation. All classes (i.e. all candidate PCTs) can be modelled in one overarching model, by setting up the BRT as a multinomial regression model.

Some candidate vegetation community types are not modelled as they lack sufficient survey information or cannot be differentiated by remote sensing or environmental spatial layers. Additional visual interpretation is applied to PCTs in this category, resulting in some being included in the mapping. A list of unmapped PCTs is provided for each region mapped.

3.5.3 Expert input

A maximum spatial extent or 'envelope' is developed for each PCT. This allows local expert knowledge to inform the possible extent and range of each PCT. The envelopes are based on the survey data, a review of the literature, environmental predictors, and the IBRA subregions (Interim Bioregionalisation of Australia v7; Commonwealth of Australia 2012).

Constraining PCTs by a maximum geographic range reduces the number of types competing within the model at any location and minimises gross errors. Some envelopes can be quite specific, where a PCT is known to only be found in a specific location, or quite broad, such as a PCT that occurs at high altitude but across multiple bioregions.

Initial map outputs are visually checked using a range of primary and secondary spatial products, and expert and local knowledge. Where errors are known, or detected, the map is manually adjusted.

PCTs with fewer than five records are not included in the modelling. These PCTs are mapped manually based on available sites, existing mapping and expert knowledge. It is likely that their mapped distribution has been underestimated in some cases. A table is included to distinguish those PCTs that were mapped by hand, not mapped at all, and those sites that could not be assigned a PCT.

3.5.4 Accuracy assessment

Accuracy assessments are used by OEH to communicate map confidence and help guide how maps can be used. The SVTM reports user accuracy of vegetation models for PCTs, Class and Formation. User accuracy of each vegetation model gives a measure of how well the classes can be differentiated based on environmental variables.

It should be noted that user accuracy of vegetation models should not be interpreted as a reflection of the map accuracy, or how accurate a map is likely to be in the field at a location. To date, accuracy assessment has only been applied to the vegetation models and has not included the visual interpretation of photo patterns, nor subsequent editing, corrections, or inclusion of existing vegetation mapping. Peer reviewed scientific articles are in preparation to report the accuracy of VPPs (e.g. Day et al. in prep.).

The accuracy of the models depends on the reliability and spatial distribution of the vegetation surveys and the quality of the environmental layers, but also on whether there are clear links between the PCT and its environment. PCTs that have a definable environmental niche and sufficient survey records will tend to be modelled with high accuracy. PCTs that share their niche with many PCTs and/or have few survey records indicating their presence will be mapped with lower confidence.

User accuracy of the modelling is determined using cross validation of the entire modelling data set. This involves producing statistics based on multiple successive iterations of re-sampling (usually 10%) the modelling data set. Cross validation provides an estimate of how well the model would perform on a new, unmapped location.

User accuracy statistics are published for:

- individual PCTs
- top 3 PCTs
- Keith (2004) Formation and Class.

Future work will aim to provide map user accuracy for the SVTM. To report on map user accuracy requires an assessment of vegetation photo patterns and how they relate to the model results. It is expected that this will involve using multiple lines of evidence including Lidar and other reference data, independent image interpreters, and additional survey.

3.5.5 User acceptance testing and evaluation

Map products are distributed to users that have expressed or are known to have specific interest. Comments and further information are invited from those clients as part of a user testing program. New information (such as new sites) is incorporated into the mapping before production release where possible.

The SVTM has a broad range of users across government and the wider community including federal, state and local agencies as well as ecological consultants.

3.6 Module 6: Publish maps

Module 6 comprises two sub-modules:

1. Published maps
2. Updating the State Vegetation Type Map.

3.6.1 Published maps

Using Modules 1–5 above, several regional-scale vegetation map products have been completed and published (e.g. Office of Environment and Heritage 2015). OEH is developing a spatial platform for improved delivery of mapped information including web map services across a variety of platforms. As we transition to this service, completed regional-scale vegetation maps (ESRI Geodatabase) and reports are available for download via the SVTM webpage.

An example of the vegetation mapping is included in Appendix B. It features an area from the Mathoura map sheet in the Riverina and Murray (1:15,000).

3.6.2 Updating the State Vegetation Type Map

The nature of the methodology used to produce the regional-scale vegetation map products relies on locating and accessing, as well as collecting the best available data that are fit for purpose and validating the final mapped products.

We recognise that there will be variation between what has been mapped and what is found on the ground. We also acknowledge that the methodology itself is being improved as we learn from users who are applying the map products. We welcome opportunities to engage with users who have used the vegetation map products and have identified situations where errors or inconsistencies might be investigated and resolved.

Where available, existing published vegetation maps are used to inform the allocation of PCTs. The results of any new local and property-scale vegetation maps will be progressively integrated into the SVTM to allow these data to be viewed in a regional context.

At present information provided to OEH that has potential for updating or improving the SVTM is considered manually on a case by case basis. OEH's new web map services will provide an opportunity for users to geotag comments directly onto the map from their computer or device. OEH plans to provide a systematic approach for evaluating comments and incorporating edits to the SVTM.

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Appendix A: Example predictor layers

Table 1: A sample of the environmental predictor layers available to the model

Group	Predictor variable	Predictor description	Units	Original resolution
Energy	ce_radann	Annual mean radiation (bio20)	Wm^2	1 sec
Climate	ct_temp_maxann	Average daily max. temperature – annual	°C	3 sec (~90m)
Water	cw_precipann	Annual precipitation (bio12)	mm	1 sec
Drainage	dl_strmdstge2	Euclidean distance to 2nd order streams and above	m	30m
Geophysics	gp_k_fillspl	Filtered potassium (K), gaps filled in using geographically weighted regression model and spline function	pct	100m
Landscape	lf_dems1s	1 sec SRTM smoothed DEM (DEM-S)	mm	1 sec (~30m)
Landscape	lf_tpi2000	Topographic position index using neighbourhood of 2000m radius	index	1 sec (~30m)
Remote imagery	rs_euc_waterobs	Euclidean distance to water observations	m	30m
Remote imagery	rs_fpc	Foliage projective cover or the percentage of ground cover occupied by the vertical projection of foliage. Predicted using a time-series of SPOT images from 2008–2011	%	30m
Soil	sm_illite20	Relative abundance of illite clay minerals in surficial topsoil (0–20cm)	proportion	3 sec (~ 90m)
Soil	sm_kaol20	Relative abundance of kaolinite clay minerals in surficial topsoil (0–20cm)	proportion	3 sec (~90m)
Soil	sp_snd100_200	Sand content (%) (100–200cm)	%	3 sec (~90m)

Appendix B: Example maps

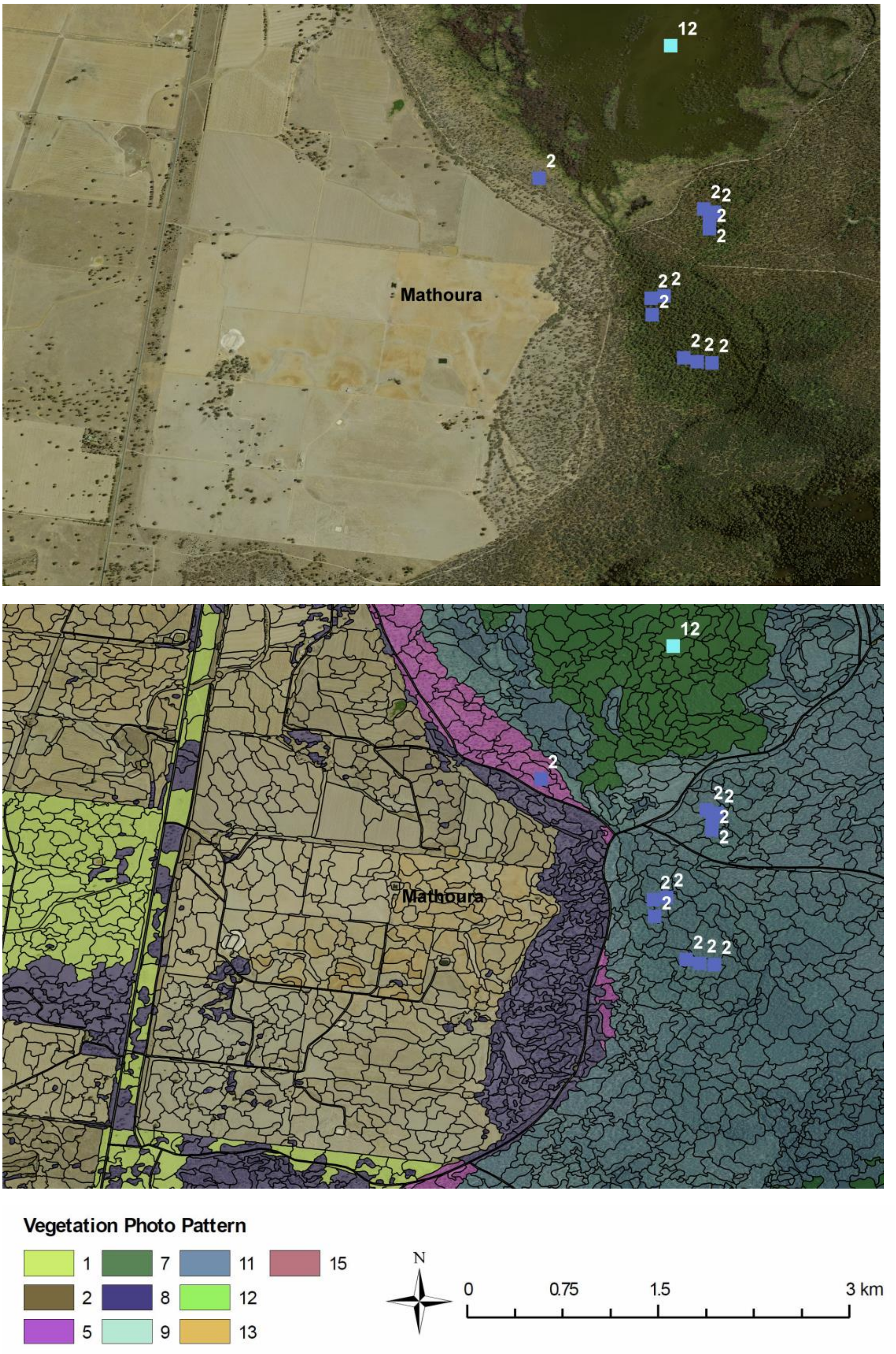

Figure 2: A sample of the ADS–40 imagery (50cm) (top) and the vegetation photo pattern (bottom) observed at 1:15,000

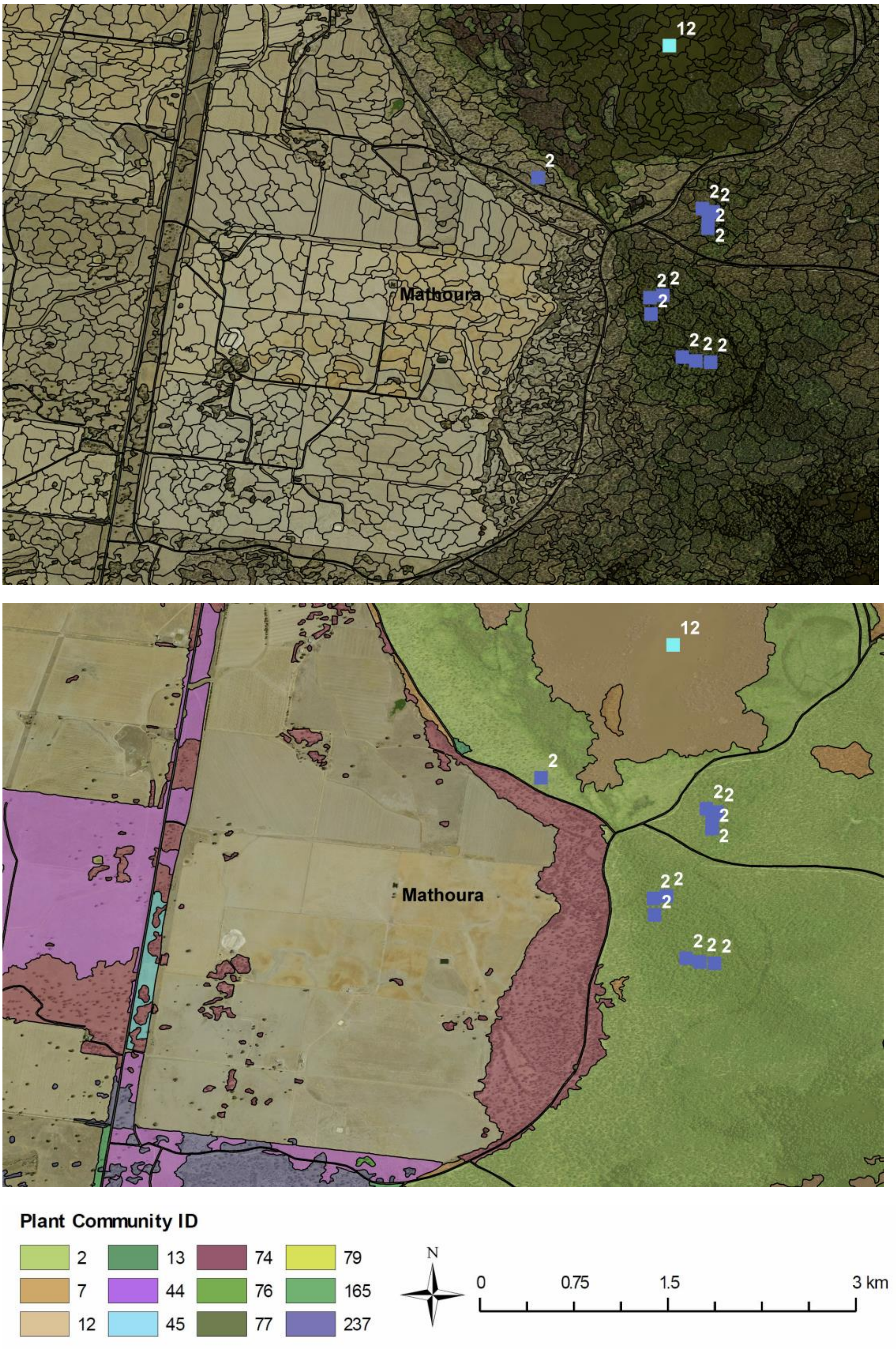

Figure 3: A sample of the raw image objects (top) and a model of plant community types (bottom) at 1:15,000