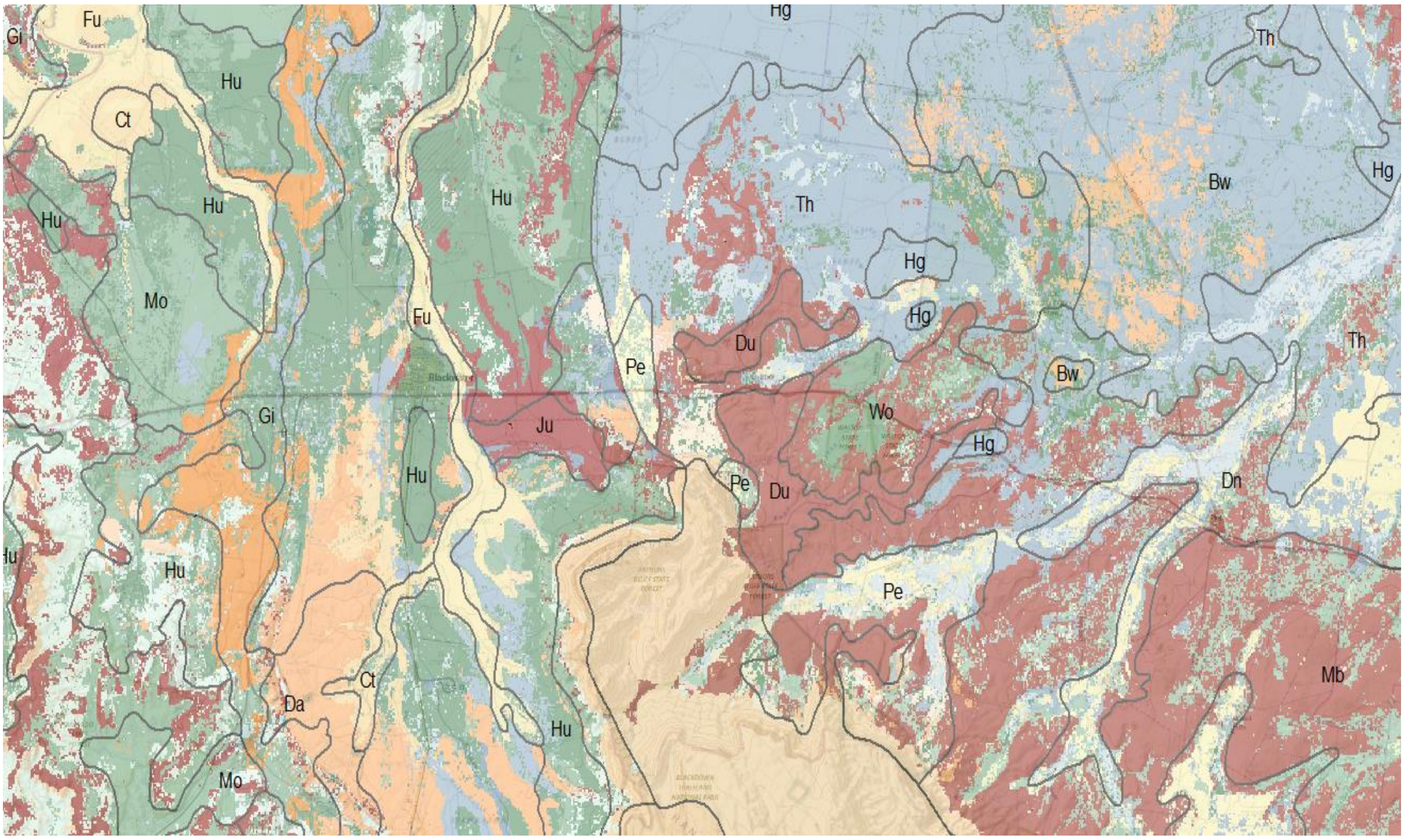
Department of Science, Information Technology, Innovation and the Arts



Disaggregation of land systems mapping

Fitzroy Drainage Basin

Soil and Land Resources (SLR)

Science Division

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Summary

This report describes the methodology used and the results obtained from a project to disaggregate land system mapping into land units for an area in Central Queensland. Land resources of Central Queensland were originally described by CSIRO in three surveys conducted during the 1960's. These surveys produced maps of land systems at a scale of 1:500,000 and described land units for each survey individually but did not map them. The land units across the three surveys were subsequently correlated descriptively by CSIRO in 1977. Since then a number of attempts have been made to map individual land units across the area for example, for the Brigalow Development Scheme and other land suitability studies, but none of these have completed the task successfully to date.

This project used digital soil mapping methodologies and algorithms newly developed by the University of Sydney, to map the correlated land units for the Belyando River and Fitzroy River catchments. The new mapping generated by this project was validated against existing data and detailed surveys, and the results as reported in this paper indicate general agreement between existing knowledge and the predicted land units. Whilst the results show great promise, further work is required to fully validate the mapping and to produce soil attribute maps from the predicted land unit maps before the outputs can be released for general use.

Notes:

This report should be read in conjunction with, Gunn, R.H. and Nix, H.A. (1977) Land units of the Fitzroy region, Queensland, CSIRO, Melbourne, which describes the individual land units.

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1 Introduction

Following a request from the Queensland Government in 1961 the Commonwealth Scientific and Industrial Research Organisation (CSIRO) undertook broad-scale land resource surveys during 1962-64 in three areas covering 198,000 km^2 of eastern central Queensland. These studies covered the catchments of Lakes Buchanan and Galilee, and the Belyando, Suttor, Nogoa (Gunn *et al.* 1967), Isaac, Comet (Story *et al.* 1967) Dawson and Fitzroy, rivers (Speck *et al*. 1968). This area includes the Desert Uplands, Central Highlands, and the Brigalow Belt Biogeographic Regions. These were the first surveys of land resources in the region and for most of this area they are still the best available land resource mapping. The surveys were brief given the extent and diversity of land types they covered, and are equivalent to a reconnaissance scale of 1:500,000 (Gallant *et al.* 2008). They describe landform, geology, soils, vegetation and land capability of the region in the form of land systems and land units.

Land systems are defined as areas with a recurring landform, geology, soil and vegetation pattern (Christian and Stewart 1968). Each land system is made up of a number of land facets with specific landscape attributes (Gallant *et al.* 2008) which are termed land units. In the case of the central Queensland surveys, land units are described in terms of slope class, landform, lithology, soil, land surface, vegetation community structure and composition; and land capability. These land units were <u>not</u> mapped; they are just described in the survey report and the extent of each within each land system was estimated. The purpose of this project is to test a method for disaggregating the land systems into their component land units and to map these land units. By mapping land units it then becomes possible to map individual landscape attributes and overall land capability, characteristics that are only practical to attribute at the land unit level.

For the three adjoining CSIRO land system surveys in central Queensland a total of 120 unique land systems and 863 land units were originally described. Gunn and Nix (1977) correlated the land units across the three report areas reducing this to a consolidated list of 142 unique *simple* land units. They described these land units hierarchically using geomorphology as the principal criterion for division, followed by landform, soil and vegetation. This hierarchy was intended to facilitate the field identification of land units using the published land system maps and aerial photos. The extent of each land unit was also estimated using the estimates of the extent of each land unit published in the original three land system surveys. Creating line-work around the boundaries of these land units was beyond the means of the Gunn and Nix correlation project. This project however aims to achieve that, using DSMART, a newly developed map disaggregation method (Odgers *et al.* 2014).

2 Methodology

DSMART is a software package designed to disaggregate course soil association maps where map units have more than one soil attributed to them. It is written in Python and uses the Geospatial Data Abstraction Library (GDAL) for spatial data processing and the See5 algorithm for generating decision trees to disaggregate map units (Odgers *et al*, 2014). The program uses the map unit proportions originally defined in the soil survey report and the original soil map polygons (mapping units). The program generates random soil sample points within each map polygon and attributes them with a soil type based on the proportions of each soil as originally reported by the survey. DSMART compares each of these soil attributed sample points with a range of user defined environmental covariates related to soil formation and builds a decision tree. For each of the grid cells, the decision trees are used to predict the soil type. The above process is repeated a number of times as defined by the user, in our case 100 iterations. DSMART produces a probability of each soil occurring at each pixel based on the number of times it was predicted in each cell. The final soil map is the most probable soil in each grid cell.

DSMART was initially developed using data from the Dalrymple Land Resource Survey[1] in North Queensland (Odgers, *et al*, 2014). It has since been used in Western Australia to disaggregate soil mapping (Holmes *et al*, 2014) and is currently being tested in South Australia. This project is the first attempt to use DSMART to disaggregate legend based land systems mapping.

The project followed four distinct steps

1. Installation and testing of the DSMART software and associated software using the DSMART v2.10.0 User Guide (Odgers *et al*, 2014).
2. Selection of environmental covariates and determination of most appropriate user defined parameters.
3. Disaggregation of three land systems surveys.
4. Validation of land unit maps.

2.1 Installation and testing of DSMART software

The latest version (v2.10.0) of DSMART was obtained from N. Odgers, University of Sydney/ Terrestrial Ecosystem Research Network – Soil and Land Facility (TERN) and installed on a 64-Bit Dell Workstation running Windows 7 with an Intel Xeon CPU 3.2GHz, 24GB RAM, 3-Core memory. In addition to the installation instructions provided in the DSMART Userguide, it was found that to run the software additional python tools, Scipy and Setuptools need to be installed from http://www.lfd.uci.edu/~gohlke/pythonlibs. It was also found that when installing this software on a 64-bit machine, the batch file to compile the C4.5 plugin for Orange is actually called vcvarsx86_amd64.bat (not vcvars_amd64.bat).

2.2 Environmental covariates and user defined parameters

Environmental covariates were chosen that closely relate to the original land unit concepts as defined by the Fitzroy CSIRO surveys. These concepts are based on geology/lithology; degree of weathering; relief (expressed as modal slope and landform); soil; and vegetation (communities and individual key species). Table 1 lists the covariates chosen for each survey area. Whilst the aim was to keep the set of covariates as consistent as possible across the three original study areas however, due to differences in the availability of covariate information over each area those chosen did vary slightly between survey areas.

Preference was given to covariates that showed greater variability within land system boundaries and that have been mapped to consistent standards over the entire survey area. For example, the geophysical covariates derived from The Radiometric Map of Australia Dataset (Minty *et al.* 2009) were not used because they have not been mapped consistently over the Fitzroy Basin. The Radiometric Map of Australia Dataset is a mosaic of available geophysical survey data which is commonly used in contemporary land resource mapping. In areas where geophysical information does not exist, such as the Nogoa and Belyando catchments, the Dataset was derived using radiometric information interpolated using terrain features (Minty *et al.* 2009). This creates

[1] Rogers LG, Cannon MG, Barry EV, Queensland. Dept. of Natural Resources, CSIRO (1999) 'Land Resources of the Dalrymple Shire.' (Dept. of Natural Resources, Queensland: Brisbane)

inconsistencies in the quality of the mapping and for this reason it was considered unsuitable for use in this study.

Table 1: Environmental covariates used in the modelling

Land unit reference	Covariate	Reference	Survey area*
Geology	Surface Geology of Australia 1:1,000,000 scale 2012 edition - Geologic map unit.	Liu S, Raymond OL, Gallagher R, Zhang W, Highet LM (2012) Surface geology of Australia. 1: 1,000,000	ZCQ, ZDK, ZDD
Lithology	Radiometric potassium percent	Minty B, Franklin R, Milligan P, Richardson M, Wilford J (2009) The radiometric map of Australia. *Exploration Geophysics* **40,** 325-333	ZDK, ZDD
Lithology	Radiometric thorium ppm	Minty B, Franklin R, Milligan P, Richardson M, Wilford J (2009) The radiometric map of Australia. *Exploration Geophysics* **40,** 325-333	ZDD
Lithology	Radiometric uranium ppm	Minty B, Franklin R, Milligan P, Richardson M, Wilford J (2009) The radiometric map of Australia. *Exploration Geophysics* **40,** 325-333	ZDD
Landscape weathering	Weathering intensity index	Wilford J (2012) A weathering intensity index for the Australian continent using airborne gamma-ray spectrometry and digital terrain analysis. *Geoderma* **183–184,** 124-142.	ZDD
Lithology	Modelled radiometric potassium percent	Modelled surface (original at 50m) generated by John Wilford, Geosciences Australia using a Cubist based methodology	ZCQ
Lithology	Modelled radiometric thorium ppm	Modelled surface (original at 50m) generated by John Wilford, Geosciences Australia using a Cubist based methodology	ZCQ, ZDK
Lithology	Modelled radiometric uranium ppm	Modelled surface (original at 50m) generated by John Wilford, Geosciences Australia, using a Cubist based methodology	ZCQ, ZDK
Climate	Prescott Index as modified by Linda Gregory	Gallant, J. : Original reference: Prescott JA (1950) a climatic index for the leaching factor in soil formation. *European Journal of Soil Science* **1,** 9-19	ZCQ, ZDK, ZDD
Elevation	3” SRTM Derived Digital Elevation Model (DEM) version 1.0	Geoscience Australia and CSIRO Land & Water (2010) 1” SRTM-Derived Digital Elevation Model (DSM, DEM, DEM-S and DEM-H) User Guide. Version 1.0. Geoscience Australia. ANZCW0703014182	ZCQ, ZDK, ZDD
Local relief	Elevation Range over 300 m (3" resolution) derived from 1" SRTM DEM-S	John Gallant; Jenet Austin (2012): Relief - Elevation Range over 300 m (3" resolution) derived from 1" SRTM DEM-S. v1. CSIRO. Data Collection. 10.4225/08/50A9C8ADC26A5	ZCQ, ZDK, ZDD
Broad relief	Elevation Range over 1000 m (3" resolution) derived from 1" SRTM DEM-S	John Gallant; Jenet Austin (2012): Relief - Elevation Range over 1000 m (3" resolution) derived from 1" SRTM DEM-S. v1. CSIRO. Data Collection. 10.4225/08/50A9C5DDB5F19	ZCQ, ZDK, ZDD
Slope	Slope (3" resolution) derived from 1" SRTM DEM-S	John Gallant; Jenet Austin (2012): Slope (3" resolution) derived from 1" SRTM DEM-S. v3. CSIRO. Data Collection. 10.4225/08/50A9DF115250E	ZCQ, ZDK, ZDD
Wetness / drainage	Topographic Wetness Index (TWI, 3" resolution) derived from 1" SRTM DEM-H	John Gallant; Jenet Austin (2012): Topographic Wetness Index (3" resolution) derived from 1" SRTM DEM-H. v1. CSIRO. Data Collection. 10.4225/08/50A9DF3968422	ZCQ, ZDK, ZDD
Valley shape	Multi-resolution Valley Bottom Flatness (MrVBF, 3" resolution)	John Gallant; Trevor Dowling; Jenet Austin (2012): Multi-resolution Valley Bottom Flatness (MrVBF, 3" resolution). v2. CSIRO. Data Collection. 10.4225/08/512EF27AC3888	ZCQ, ZDK, ZDD
Slope shape	Profile Curvature (3" resolution) derived from 1" SRTM DEM-S	John Gallant; Jenet Austin (2012): Profile Curvature (3" resolution) derived from 1" SRTM DEM-S. v1. CSIRO. Data Collection. 10.4225/08/50A9DA731AF56	ZCQ, ZDK, ZDD

Landform pattern (Speight 2009)	Slope Relief (3" resolution) derived from 1" SRTM DEM-S	John Gallant; Jenet Austin (2012): Slope Relief (3" resolution) derived from 1" SRTM DEM-S. v1. CSIRO. Data Collection. 10.4225/08/50A9D1D1BA1C1	ZCQ, ZDK, ZDD
Wetness / soil type	Landsat 2000-2010 Persistent Green-Vegetation Fraction	Johansen, K., Gill, T., Trevithick, R., Armston, J., Scarth, P., Flood, N. and Phinn, S. Landsat based Persistent Green-Vegetation Fraction for Australia. 16th Australasian remote sensing and photogrammetry conference. Melbourne, Australia, 2012.	ZCQ, ZDK, ZDD
Vegetation type	Dominant pre-european broad vegetation groups, 1: 1,000,000 scale	Queensland Herbarium (2014) Regional Ecosystem Description Database (REDD). Version 8.1 (April 2014) (Queensland Department of Science, Information Technology, Innovation and the Arts: Brisbane)	ZCQ, ZDK, ZDD

* ZCQ – Nogoa-Belyando Survey; ZDK – Isaac – Comet Survey; ZDD – Dawson – Fitzroy Survey

DSMART requires that all covariates and polygon layers have exactly the same coordinate system and datum (in this case WGS84). All grid cells also need to be the same size (3 seconds of latitude in our case) and exactly coincident. To achieve this we used *gdalwarp* to resample and clip each covariate. The data was clipped to a rectangular box extending 40 to 150km beyond the irregular boundary of the original land system survey. The clipped area was different for each of the surveys and overlapped to some extent between them. DSMART predicts to the entire extent of the clipped area not the original survey extent if they are different. The prediction is less reliable as you extend further beyond the original survey area. This is because no virtual sample points are allocated to these areas.

DSMART allows the user to set a number of project specific parameters. We set these as follows:

- Number of sampling points per polygon = 20 (The smaller the areal proportion, the higher the number of samples per polygon required. In our case proportions of 1% are common).
- Number of iterations / realisations of the land unit distribution = 100 (to ensure a smoother result)
- Uncertainty factor for Dirichlet distribution = 10000 (reflecting that we had high certainty about land unit proportions as they were legend based).
- Number of most probable land units returned = 2 (for each grid cell the most probable and second most probable land unit are returned).

2.3 Disaggregation of three land systems surveys

The land system map units (polygons)[2] were used to define the sample point locations. As noted above, for each polygon DSMART randomly allocated 20 sample points that were attributed with land unit names in the same proportion as defined by Gunn and Nix (1977 – Tables 12-14) for each land system name. Originally, conceptual land unit proportions were noted in each land system description. Gunn and Nix (1977) recalculated the proportions based on the 142 simple land units they derived. Not all of the simple land units occur in each of the three survey areas, Gunn and Nix (1977) have determined proportions for each survey separately (see Gunn and Nix (1977), Appendix 1 – Table 12 – Nogoa-Belyando survey; Table 13 – Isaac – Comet survey and Table 14 – Dawson – Fitzroy survey). These tables form the basis for disaggregating the land units.

[2] The spatially corrected line work (SALI project codes ZCQ2; ZDK2 and ZDD3 respectively) for each of the original land system surveys was used as inputs for DSMART

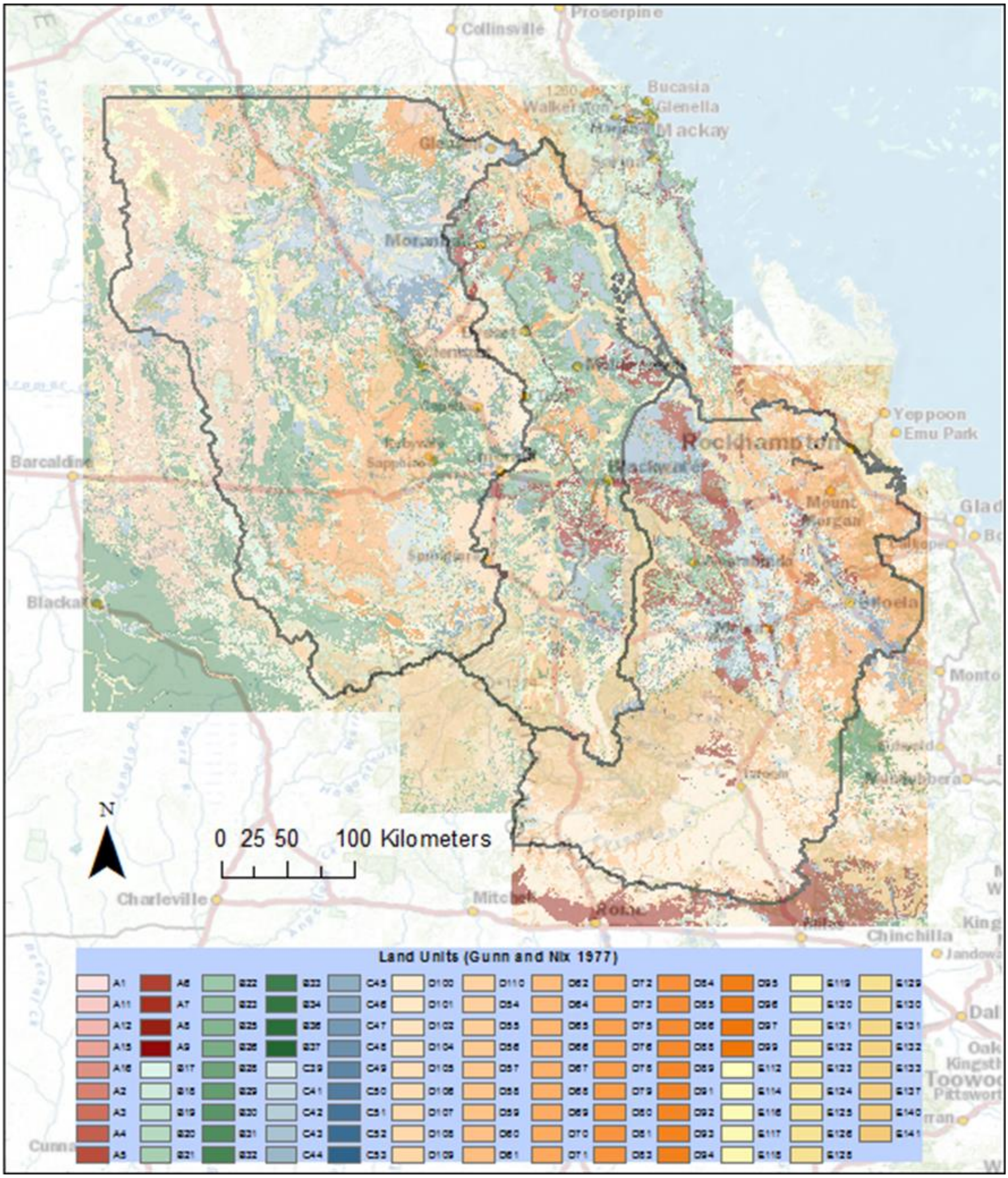
It is possible to run DSMART using points with a known land unit or soil as inputs in a supervised implementation. This is possible in areas where detailed soil-landscape mapping is available however such areas are comparatively limited in the area covered by this study. Consequently we used an unsupervised implementation of DSMART.

3 Results

3.1 Disaggregation to generate land unit maps

Figure 1 broadly shows the land units across the whole region created by disaggregating each land system survey using the correlated simple land units described by Gunn and Nix (1977).

Figure 1: Land units and the original CSIRO survey boundaries in the Fitzroy.



DSMART was run separately for each of the three survey areas resulting in different decision trees being created for the same simple land unit in different survey areas. Hence not all land units are coincident across survey boundaries. The land units have been grouped according to their geomorphic categories (as per Galloway 1967 and shown in Table 3). These categories are reflected in the colour scheme of the map legend. Table 2 shows a summary of the number of described land systems and simple correlated land units as per Gunn and Nix (1977) and the number of predicted simple land units after disaggregation as per the original three survey areas. The number of predicted land units is smaller than the number in the input files because some land units have very small areal proportions and will consequently never be the dominant land unit in a given pixel.

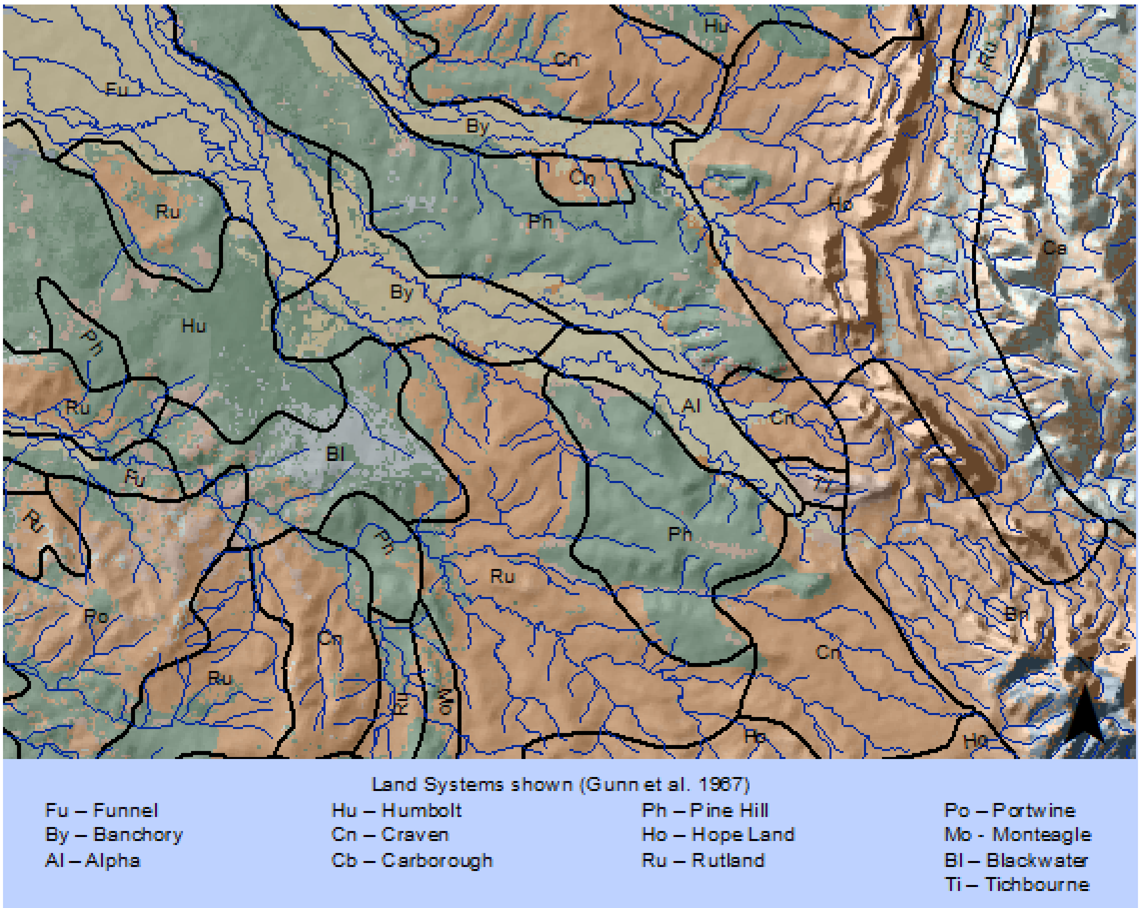
Table 2: Land unit composition summary

Survey	Number of described unique land systems[a]	Number of simple land units[a]	Number of predicted simple land units
Nogoa-Belyando survey (ZCQ)	43	96	70
Isaac-Comet survey (ZDK)	28	82	49
Dawson-Fitzroy survey (ZDD)	63	96	40

[a]Gunn and Nix 1977.

In our unsupervised implementation, DSMART has effectively adjusted some of the land system boundaries to better reflect changes in the landscape. This has occurred because DSMART predicts land unit boundaries from decision trees based on reasonably accurate digital terrain models, geology, lithology and vegetation mapping. The original land systems in the Belyando-Nogoa survey were derived initially from the recognition of 300 unique patterns on 1:50,000 and 1:85,000 scale unrectified black and white aerial photos using a stereoscope. These patterns were examined in the field over a 14 week period in 1964. Later the patterns were merged into 43 land systems on an unknown map base. With the availability of independently derived DEM's and other mapping information and the use of this automated digital soil mapping process, our ability to delineate the boundary of landscape units has improved greatly. An example of this is shown in Figure 2 from an area of the Belyando River catchment showing the original land system boundaries and labels (black lines), 1:100,000 scale topographic map stream network (blue lines) and predicted extent of land units (colours).

Figure 2: Land unit mapping in the Belyando River catchment



3.2 Validation of land unit maps

The land unit maps produced by this project have been validated in a number of ways.

Firstly, the maps were checked to see if the spatial pattern of the predicted land units reflects the pattern which would be expected based on the *simple* land unit descriptions. To undertake this comparison, the *simple* land units were grouped into geomorphic categories as identified by Gunn and Nix (1977) (Table 3). The position land units were mapped in the landscape was then compared with what would be expected based on the geomorphic category. We would expect for instance, that alluvial *simple* land units (Category E) would occur on valley floors. As can be seen from Figure 3 this is generally the case.

Secondly, the land unit maps were compared to more detailed land resource mapping where it exists. To undertake this validation, the land units predicted by DSMART were compared with the 1:100,000 scale soil mapping of Forster and Sugars (2000) at 10,000 random sites throughout the whole Lower Fitzroy study area. Figure 3 shows a close-up of an area near Round Mountain west of Rockhampton, where the more detailed soil mapping of Foster and Sugars (2000) is available. The 1:100,000 scale soil map is shown as black lines over the top of land units predicted by this project (shown in colour). As can be seen, there is good agreement for alluvial land units (yellow) and soils developed from recent alluvium. Land units in depositional landscapes (blue shading) correlates mostly with soils formed from older transported Cainozoic sediments. Land units in fresher erosional landscapes (orange shading) correlates with soils formed from volcanic and sedimentary rocks.

Table 3: Geomorphic categories of the simple land systems

Geomorphic category	Simple land unit No.	Description
A	1 - 16	Stable or moderately stripped land surface on the tertiary weathered zone
B	17 - 38	Erosional land surface on the tertiary weathered zone
C	39 - 53	Depositional land surface in the tertiary weathered zone
D	54 - 111	Erosional land surface below the tertiary weathered zone
E	112 - 142	Alluvial quaternary land surface

[a]Gunn and Nix 1977.

Figure 3: Predicted land unit mapping near Round Mountain, west of Rockhampton on the Fitzroy River.

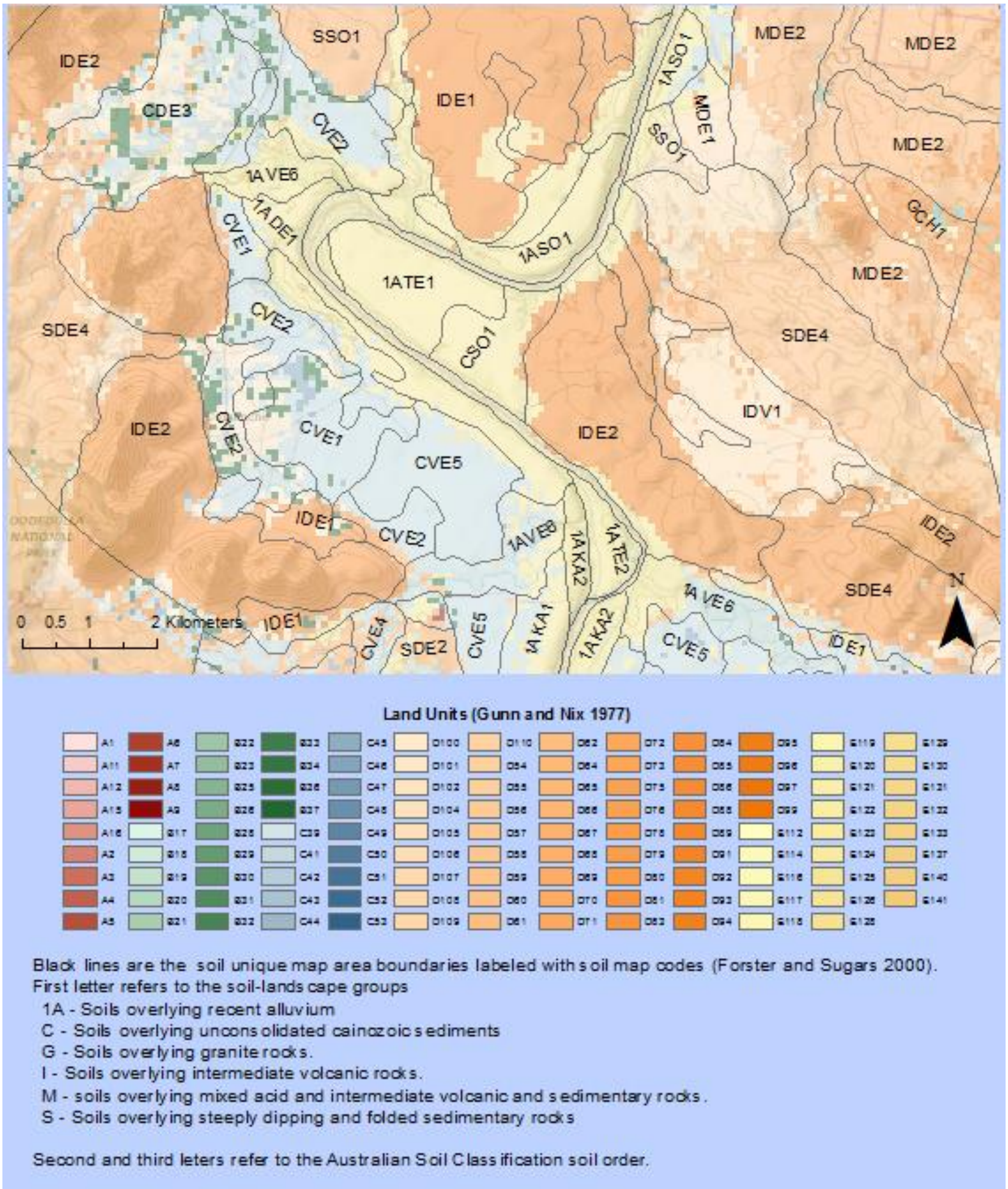


Table 4 summarizes the results of the comparison across all of the predicted land unit geomorphic categories and soil landscape groups as mapped by Forster and Sugars (2000). Although land units contain multiple soil landscape groups making an exact match unlikely, as would be expected there is general agreement at least at the geomorphic group level. Notable exceptions occur for soils formed on basalts, and deeply weathered landscape and rocks below the weathered zone (fresher rocks) falling within soil units on the deeply weathered plains of the Lower Fitzroy. These are explainable as follows:

- Forster and Sugars (2000) grouped both deeply weathered and fresh basalt into a single unit whilst our predicted land units subdivide basaltic sediments into separate, weathered (geomorphic category C), fresh (geomorphic category D) and alluvial (geomorphic category E) units. In alluvial areas, the dominant predicted land unit is E126 (Gunn and Nix 1977) and the major soil within this land unit is *Retro* which has a parent material derived from alluvial, sedimentary and igneous rocks (Sweeney 1968). This might explain why the predictions are spread across the three geomorphic categories.
- While half of the predicted land units correlate with the deeply weathered soil landscape unit of Forster and Sugars (2000), the other half that are mainly from Land Units D64 and D68 and should have shallow sandy soils do not. The land units could have been predicted correctly (with Forster and Sugars mapping being incorrect) or incorrectly.

Table 4: Comparison of predicted land unit geomorphic categories with the Lower Fitzroy River soil landscapes

	Soil landscapes of the Fitzroy River study area (Forster and Sugars 2000)								
Geomorphic category[a]	Alluvial	Basalts	Unconsolidated sediments	Granite rocks	Intermediate volcanic rocks	Acid / Intermediate volcanic rocks	Folded Sediments	Deeply weathered tertiary plains	Ultramafic rocks
A	0%	0%	2%	0%	1%	1%	1%	43%	12%
B	0%	0%	5%	4%	1%	1%	2%	5%	0%
C	19%	23%	58%	2%	3%	7%	6%	7%	1%
D	19%	36%	25%	85%	93%	89%	89%	42%	84%
E	61%	42%	9%	9%	3%	3%	3%	1%	3%

[a]As per Table 3.

Thirdly, predicted land units were validated using soil profile descriptions from the Queensland, Soil and Land Information System database (SALI). While land units are areas of similar lithology, landform, soil and vegetation and do not necessarily match the description of any particular point in the landscape, they have been attributed with commonly occurring soil series and Principal Profile Form (PPF) soil classification of the Factual Key (Northcote 1979). For many land units, more than one PPF has been defined but generally where this occurs these PPF's are associated and have related characteristics at least at higher levels in the soil classification hierarchy. For example PPF's Ug5.12, Ug5.13, Ug5.16 and Ug5.4 are listed for land unit D90. These are all essentially cracking clays and hence it can be assumed a land unit has been correctly predicted if an existing SALI Site with a PPF of Ug5.1x occurs within that grid cell. Table 5 shows the results of this validation.

Table 5: Validation results based on the factual key soil classification

Survey	No. of SALI sites with a PPF	PPF	To class level	To section level	To subdivision level	To division level
Belyando – Nogoa	2869	24%	47%	67%	72%	83%
Isaac – Comet	4245	23%	38%	50%	57%	65%
Dawson - Fitzroy	4823	20%	37%	44%	49%	61%

For between 44% and 67% of the existing sites with a PPF assigned, the land unit description matched the soil classification of the predicted land units to the 'section' level of the Factual Key (i.e. Ug5) (Table 5). Cells in which percentages are acceptable have been shaded green, confirming that matches were acceptable in every instance to Division level and in most to Section level. It can be seen from the Table that the prediction improves as you travel west from the Fitzroy to the Belyando catchments.

4 Conclusions and further work

DSMART land resource disaggregation software was implemented in an unsupervised way to map land units for three adjoining CSIRO land systems studies covering sub-catchments of the Fitzroy River basin in Central Queensland. The outputs confirmed the findings of others (e.g. Odgers, *et al*, 2014, Holmes *et al*, 2014) that disaggregation using DSMART offers the potential to use existing spatial data to greatly improve the utility of land resource mapping and to provide more detailed information for improved decision-making particularly in rangelands and remote areas. The study demonstrates that DSMART can: improve the positional accuracy of boundary line-work (created as rasters) and disaggregate legend-based land systems mapping.

This approach could readily be used to disaggregate other studies in Queensland including: the land systems mapping for the Balonne-Maranoa area (Galloway et al. 1974), which has a similar format and landscape (southern part of the Brigalow Belt); the Western Arid Region Land Use Studies (WARLUS); and, the Burnett and Miriam Vale land systems mapping.

DSMART could also be used with land systems and other existing mapping to further disaggregate to delineate individual soils or soil properties. There is increasing demand for mapping of soils and of individual soil properties. A new version of DSMART is being developed that will use soil conceptual information instead of the soil association proportion information currently used (Odgers *et al.* 2014). Odgers is also currently developing new software (PROPR) that will assist with producing soil property rasters. Soil series have been defined for the Fitzroy land system surveys from around 1300 field soil observations. Using this soil series information as a basis with these new software tools it should be possible to derive and map individual soil properties.

DSMART has additional functionality which was not tested in this study. For instance, it has the capability to incorporate additional environmental covariates after the fact and to use known land unit points from detailed land resource mapping in the area in a supervised classification along with expert knowledge of the region. These additional functions could be explored to further enhance the accuracy of the output whilst DSM techniques can be used to enhance existing traditional surveys.

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