National Land & Water Resources Audit
An Initiative of the Natural Heritage Trust

National Land Use Maps: 1992/93, 1993/94, 1996/97, 2000/01, 2001/02 Version 3

BRR 44

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The National Land & Water Resources Audit is an initiative of the Natural Heritage Trust. The Audit provides data, information and nationwide assessments of Australia's land, water and biological resources to support sustainable development.

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Foreword

Land use mapping has many applications relevant to national scale issues, such as supporting information on diversity of environment and economic use of lands, strategic industry-based planning and providing objective assessments on land use and land use change. Land use data also provides background information products to inform decision making and assist in the presentation of policy proposals.

The 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 national land use maps provide an overview of land use throughout Australia, for use at scales up to 1:2,500,000. These were produced from existing national scale data sets and the agricultural land was spatially allocated such that it was consistent with agricultural census data using version two of the Spatial Reallocation of Aggregated Data method (SPREAD II). This repeatable approach allows for the cost effective and timely delivery of broad-scale agricultural activity across extensive areas of agricultural land. The outputs present a time-series profile of land use based on version 5 of Australian Land Use and Management (ALUM) classification.

Dr Cliff Samson
Executive Director
Bureau of Rural Sciences

Executive summary

The goal of this project was to quality assure and publish hard copy versions of the national land use maps produced for the Australian Greenhouse Office for the years 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02. This work builds on the work done by the Bureau of Rural Sciences in developing the *National Land and Water Audit, 1996/97 Land Use of Australia, Version 2* (referred to herein as the *original Audit map*) and a recent project for the Murray Darling Basin (BRS, 2004).

The method of allocating agricultural land has changed from the original Audit map from the Spatial Reallocation of Aggregated Data (SPREAD) algorithm to the Spatial Reallocation of Aggregated Data method version 2 (SPREAD II). The outputs of SPREAD II are more interpretable than SPREAD and the representation of uncertainty is more readily incorporated into analyses that depend on the data.

Qualitative evaluation was performed by members of the Technical Advisory Group for Australian Land Use Mapping. The results of these comments were addressed and some changes were made to the final versions of the maps. Quantitative validation was carried out against the catchment scale land use data for the maps produced for financial years 2000/01 and 2001/02 and the spatial attribute accuracy when compared to the catchment scale land use data (BRS, 2002) is around 50%, though it should be remembered that the catchment scale data is itself subject to some degree of uncertainty. It is expected that the maps for the 1996/97 and 1998/99 will be more accurate since they are temporally closer to the collection dates of the training data.

Recommendations

There are a number of recommendations that are likely to contribute to improvements to the National Land Use Map (NLUM) product:

1. Qualitative assessment suggests that it is important to use control data that is both spatially and temporally close to the area being analysed. Ongoing collection of control site information is recommended to improve the accuracy of maps produced using SPREAD II (collection of this data would also benefit other researches and projects investigating and/or mapping land use and land cover).
2. At present, the normalised difference vegetation index (NDVI) signature of an area of land is characterised by the NDVI profile over the time period of the map being produced. It is recommended that research into the use of longer periods be introduced. This is likely to improve the accuracy of the map for land uses that are part of a rotation system, for example, crop/pasture rotations.
3. The NDVI profile of a given land use is heavily affected by climatic conditions and geography. The incorporation of climatic data and geographic constraints (beyond using contemporary control site information) should be investigated.
4. Research should be conducted into methods for achieving inter-temporal consistency of the maps and how this could be used to improve the maps.
5. Once control sites for the periods corresponding to the collection of MODIS data are established, further investigation on the use of MODIS should be conducted.
6. The current land-use classification scheme is not considered optimal and is likely to be contributing to lower accuracies. More research is required to evaluate optimal classification schemes that meet the need of users and allow reasonable categorisation of land use. Since the algorithm is applied to individual statistical local areas (SLAs), this

research should include investigation into the possibility of customising the metrics used to summarise the NDVI profile for the specific set of land uses that occur within the SLA.

7. Further investigation should be conducted into the use of Advanced Very High Resolution Radiometer (AVHRR) surface temperature data (Ts) and possibly other satellite data.
8. The method used for processing and scaling the agricultural statistics should be further refined.
9. Intensive land uses other than rural residential (such as intensive animal production and defence facilities) should be introduced into the national scale land use maps from catchment scale land use data in future mapping projects. The use of other data sets, such as the digital cadastral databases, to identify areas of intensive land use (and potentially other land uses of interest) should also be investigated.
10. The use of the horticulture and irrigation constraints should be further refined. Potentially other constraints could be introduced, but the impacts of having multiple constraints needs to be better understood and automated checks for consistency between multiple constraints implemented.

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1. Introduction

Background

In 2001 the National Land & Water Resources Audit (NLWRA) funded the development of a national scale land use map, the *National Land and Water Audit, 1996/97 Land Use of Australia, Version 2* (BRS, 2004). This product was produced by the Bureau of Rural Sciences (BRS) using the spatial “SPatial REallocation of Aggregated Data” (SPREAD) algorithm to allocate agricultural land use. One of the outputs from this project was a control site database that has subsequently been used in the production of the maps associated with this project and also maps of the Murray Darling *Land Use Mapping for the Murray-Darling Basin: 1993, 1996, 1998, 2000 maps* (BRS, 2004) on behalf of the Murray Darling Basin Commission.

Over the period 2004 to 2006 the Australian Greenhouse Office (AGO) has funded the development of national land use maps for the financial years 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02. These maps have been produced by the BRS using the SPREAD II algorithm to allocate agricultural land use. The SPREAD and SPREAD II algorithms are quite different, as is described below in section 2.

Objectives of the project

The objectives in this project are:

1. Provision and publication of the national land use maps for the years 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 produced by funding from the AGO.
2. Funding the Quality Assurance (QA) of these maps by members of the Technical Advisory Group for Australian Land Use Mapping (TAGALUM) and consequent clearance of the products by the Executive Steering Committee for Australian Land Use Mapping and Land Management Information (ESCALUM) on behalf of the Australian Collaborative Land Use Mapping Program (ACLUMP).
3. Creation of high quality hard copy maps for distribution to stakeholders.

The national land use maps produced in the AGO project supplement the finer scale, but incomplete and non-temporal catchment scale land use mapping (BRS, 2002).

The requirement for regional land use mapping (both historical and current)

Land use mapping has many applications relevant to national scale issues that include:

- Salinity and hydrological modelling.
- Carbon flow modelling.
- Supporting information on the diversity of the environment and patterns in economic use of land (e.g. risk assessment of land use with climate reliability projections; relating land use to social factors).
- Strategic industry-based planning.
- Integrating with other data sets to allow multi-objective assessment on land use and land use change.

- Background information products to inform decision-making and assist in the presentation of policy proposals.

2. Land use mapping methodology

Overview

Although the process of constructing the maps is similar to that used to construct the 1996/97 Land Use of Australia, Version 2 data set for the Audit (Stewart et al., 2001), the algorithm used to allocate agricultural land uses to agricultural land pixels is very different. In the original methodology the agricultural land uses were determined using the SPREAD algorithm (Walker and Mallawaarachchi, 1998). SPREAD is a nearest neighbour algorithm that produces a single prediction of land use and some quality measures. The new maps are produced using a Markov Chain Monte Carlo algorithm, a Bayesian technique, which generates a probability distribution over the possible land uses for each pixel. This algorithm will be referred to as SPREAD II. The remaining changes to the original methodology involve varying the input data including the introduction of additional data sources.

Both SPREAD and SPREAD II rely on the fact that land uses have different growth characteristics through a one year period so that different agricultural land uses can be characterised by the normalised difference vegetation index (NDVI) profile over that period. Both algorithms allocate land use in accordance with these profiles and subject to the area constraints provided by the agricultural statistics. SPREAD determines a best-case land use allocation for each unknown agricultural land pixel and provides what is, at best, a qualitative guide to reliability. The probability distributions produced by SPREAD II, by contrast, provide a theoretically and intuitively meaningful measure of reliability. The distributions for individual pixels can be used to produce a probability surface for each commodity group and derived probability surfaces can be produced for aggregations of the mapped commodity groups by adding the probability surfaces for the individual commodity groups.

A summary map approximating a maximum likelihood estimate of land use that is consistent with the Agricultural Statistics-based area constraints is derived from the probability surfaces. The level of accuracy below the SLA level is dependant on the success of the algorithm, which is driven by the degree of difference between the NDVI profiles of the various land uses.

Method

Producing a map involves the following steps. See the following sections entitled ‘Input data’ and ‘Parameters used in running SPREAD II’ for methodological details.

1) Make a base land use map showing the non-agricultural land uses and the distribution of agricultural land.

Four thematic layers were constructed in raster form with 0.01 degree pixel size and overlain to make a base land use map showing the non-agricultural land uses and the distribution of agricultural land. The layers were a topographic features layer, a protected areas layer, a tenure layer and a forest type layer.

2) Use the map produced in step 1 to determine target zones to be submitted to SPREAD II for allocation of agricultural land uses

The map created in step 1 is used to identify those pixels which are to be submitted to SPREAD II for allocation of agricultural land uses. These pixels will be referred to as target zones. The target zones are potentially agricultural land, identified on the basis of protected area status, tenure and absence of topographic features such as built up areas, and they are further restricted to those potentially agricultural land pixels with native woody vegetation having a crown cover of 50% or less.

3) Summarise and scale the AgStats data at the SLA level to accord with the area of the target zones determined in step 2.

The AgStats data are processed to derive areas for the dryland and irrigated commodity groups to be mapped by SPREAD II. The areas are scaled to accord with the total area of the target zones in each SLA. SLAs are a standard ABS geographic unit similar to local government areas.

4) Choose a set of control sites to represent the temporal NDVI profiles of each possible land use.

The land cover of an area affects the way it reflects solar radiation. Since land cover is influenced by land use, the temporal NDVI profile of a given pixel can be used in estimating the probability that it is being used for a given land use by comparing it to the NDVI profiles of areas known to have that land use.

5) Summarise the temporal NDVI profiles of each target zone (step 2) and each control site (step 4).

The spectral profiles of the control sites and target zones are summarised using a set of metrics that are useful for discriminating between different land uses.

6) For each target zone (step 2) estimate the probability of observing the metrics calculated in step 5 for that target zone, assuming, in turn, that the target zone is being used for each of the possible land use.

It is through these probabilities that the satellite imagery is assimilated by the SPREAD II algorithm. These probabilities are estimated using a kernel density smoother.

7) Produce probability surfaces for each land use by using a constrained simulation method (SPREAD II) to estimate the probability that each target zone is being used for each land use.

Within each SLA, various constraints are placed on the area of land utilised for each land use. At present, the constraints used are:

- The area of land utilised for each land use must be reasonably close to the area specified by the scaled AgStats data from step 3;
- Land uses with a scaled AgStats area less than 110 ha (approximately the area of one pixel) are ignored;
- Irrigated land uses are constrained to occur within the irrigation mask;
- Horticultural land uses are constrained to occur within the horticulture mask.

While maintaining these constraints, SPREAD II repeatedly allocates a land use to each pixel for a fixed number of iterations. As is typical with this method of estimation, the algorithm is allowed to stabilise for a fixed number of iterations, the results of which are not recorded (referred to as the *burn in period*). After the burn in period, the number of times each pixel is allocated to each land use is counted. At the end of the procedure these counts are divided by the number of iterations for which the algorithm ran (excluding the burn in period) to give the estimated probability distribution over the possible land uses for each pixel.

8) Produce a summary map of agricultural land use.

To produce the agricultural land use allocations for the final map, the average area that each land use occupied through the procedure of step 7 is calculated. These areas are then ordered from smallest to largest. The land use with the smallest average area is then selected, and the pixels with the highest probability of that land use are assigned to that land use. This is then repeated for the land use with the next smallest area, and then repeated until all land uses are allocated.

9) Make the final map.

The summary agricultural land use layer from step 8 is combined with the base land use map from step 1. ALUM, Version 5, land use classes are applied to make the final map. It should be noted that this map has been referred to elsewhere as “the summary map”.

Strengths/Weaknesses of the SPREAD II Algorithm

The form of the outputs of the SPREAD II algorithm offer users a very useable set of inputs into further analyses that meaningfully reflect the uncertainty about the land use of each pixel in the agricultural areas of the map. It should be noted that this uncertainty is not available for non-agricultural pixels. It is easy to incorporate new sources of data into the algorithm in various ways and control the degree of influence that these data have on the process. This makes SPREAD II a very useful tool for integrating various sources and forms of data into a single coherent product.

One weakness of SPREAD II is the construction of the summary map. Because the final map is required to reflect the average areas of each land use as described in step 8 of the algorithm, it is very hard to find *the most likely* map. The approach outlined in step 8 has no formal basis, but seems to produce a reasonable final result. If the map had a specific purpose, then different methods of producing a summary map could be used; for instance, one might allocate the most common land uses first, or alternatively, those that are considered most important.

Outputs

The output, in theory, comprises 43 GIS layers: 42 layers that give the probability of each of the 42 land uses for each pixel, and one summary map derived from the probability layers. (In practice, not all of the probability surfaces are made due to shortcomings of the input data, as explained below.) The summary map can be compared to the probability layers to gain insight into its uncertainty.

There are no berry fruit control sites and consequently this commodity has not been mapped. Berry fruit areas, which are small, were set to zero and the areas of all other commodity groups were scaled to take account of this.

There are no dryland apples control sites and consequently this commodity has been combined with and mapped as irrigated apples.

Agroforestry is incompletely covered by the AgStats data, and variably so from year to year. The AgStats data for the 1992 and 1993 maps have no agroforestry data. For these two years, agroforestry has not been mapped explicitly. In the summary maps it is expected to appear as remnant native cover (ALUMC, Version 5, code 1.3.3), where the height of the trees is 2 m or more and the crown cover exceeds 50%, and as grazing natural vegetation (ALUMC, Version 5, code 2.1.0) otherwise. The AgStats data for the 1996, 1998, 2000 and 2001 maps only includes areas for agroforestry plantations that were established in the year of the census or survey (‘seed sown’ or ‘seedlings planted’ or both) and these areas cannot be disaggregated into dryland and irrigated components. For these four years, agroforestry is expected to appear in the summary maps as remnant native cover (ALUMC, Version 5, code 1.3.3), where the height of the trees is 2 m or more and the crown cover exceeds 50%, as plantation forestry (ALUMC, Version 5, code 3.1.0), where the agroforestry plantations were established in the year of the census or survey, and as grazing natural vegetation (ALUMC, Version 5, code 2.1.0) otherwise.

Input data

The input data used to create the maps are described below. For more on the data sets and methodology used, please see (BRS, 2006)

NDVI imagery

The temporal NDVI profile of each pixel falling in an agricultural area in a given year is characterised by thirteen values representing successive 28 day intervals from splined Advanced Very High Resolution Radiometer (AVHRR) NDVI data covering the period from 1 April in one year to 31 March in the following year. (This period is the old AgStats reporting year.) Each agricultural control site is characterised similarly, but for the year when the documented land use occurred. Cloud correction of the NDVI images was undertaken by the Environmental Resources Information Network (ERIN) of the Department of the Environment and Heritage using a splining methodology similar to that used for the Audit map (Stewart et al, 2001).

AgStats data

Agricultural censuses were conducted by the Australian Bureau of Statistics (ABS) every year for years up to and including the 1996/97 collection. Thereafter, agricultural censuses were conducted every 5 years (starting in 2000/01), with agricultural surveys in the intervening years. Current ABS policy is that AgStats data are reported on SLAs in census years, but are only reported on statistical divisions (SDs) in survey years. The ABS may make special releases of survey data reported on SLAs if the data quality is sufficiently high to support the smaller reporting areas. Hence the 1992/93, 1993/94, 1996/97 and 2000/01 maps are based on census data reported by SLA. The 1998/99 and 2001/02 maps are based on survey data reported by SLA obtained as special releases. In survey years the standard errors are large for certain items.

Modifications made to the AgStats data are the same as carried out during the construction of the Audit map (Stewart et al, 2001) except that, firstly, some edits were made to the AgStats data, prior to scaling, for a small number of SLAs with gross under-reporting of commodities and, secondly, the AgStats scaling regime was changed.

The AgStats processing steps were:

- The AgStats data were first summarised into commodity groups of the ABS level 3 classification with vegetable areas corrected for multiple cropping and orchard tree numbers converted to areas.
- The AgStats area data for pastures, cereals, legumes and oilseeds were then adjusted to compensate for double cropping. Data from the 1996 – 97 Farm Survey (Australian Bureau of Agricultural and Resource Economics, 1997) were used for this purpose. The methodology was the same for all of the maps.
- The AgStats data were then further aggregated to commodity groups of the Audit commodity classification. The methodology was the same for all of the maps.
- The AgStats area data at Audit commodity level were then disaggregated into dryland and irrigated components. AgStats irrigation data were used for this purpose.

- Adjustments were then made to the area data for SLAs in which there was gross under-reporting.
- The AgStats area data, finally, are scaled to accord with the total area of the target zones within the SLA.

Control sites

The control sites used were those in the database of control sites collected for the Audit map (Stewart et al, 2001).

Topographic data

The topographic features layer was constructed from:

- A 1999 update of TOPO-250K (Series 1), a 1:250,000 scale vector topographic data set published by Geoscience Australia (GA);
- A 2005 update of TOPO-250K (Series 2), a 1:250,000 scale vector topographic data set published by GA;
- Catchment scale land use data (BRS, 2002) at scales ranging from 1:25,000 to 1:100,000.

The same topographic features layer was used for all years mapped.

Protected areas data

The protected areas layer was constructed from:

- The Collaborative Australian Protected Areas Database – CAPAD97 – Version 2 (1997), a 1:250,000 scale vector protected areas data set with currency end date 31 December 1997 published by DEH
- The Collaborative Australian Protected Areas Database – CAPAD – 2000, a 1:250,000 scale vector protected areas data set with currency end date 1 February 2000 published by DEH
- The Collaborative Australian Protected Areas Database – CAPAD – 2002, a 1:250,000 scale vector protected areas data set with currency end date 16 October 2002 published by DEH

The 1997 data set was used to construct the 1992/93, 1993/94 and 1996/97 maps. The 2000 data set was used to construct the 1998/99 map. The 2002 data set was used to construct the 2000/01 and 2001/02 maps.

Tenure data

The tenure layer was constructed from:

- Australian Tenure, a 250m raster tenure data set compiled by BRS's National Forest Inventory section in 1997 (additional attribute information compiled by state and territory agencies in 1997 was incorporated, providing a classification of the land use for aboriginal freehold and aboriginal leasehold land as agricultural or non-agricultural);
- The Geoscience Australia 1993 tenure map, and;
- The catchment scale land use data (BRS, 2002).

Forest data

Five different forest type layers were constructed, based respectively on data compiled by the Department of the Environment and Heritage for greenhouse accounting purposes (NCAS, Department of Environment and Heritage, 2004) for the years 1992, 1995, 1998, 2000 and 2002. The forest type layer based on the 1992 data set was used to make the 1992 and 1993 maps; that based on the 1995 data set was used to make the 1996 map; that based on the 1998 data set was used to make the 1998 map; that based on the 2000 data set was used to make the 2000 map; and that based on the 2002 data set was used to make the 2001 map.

Irrigation constraint

An irrigation mask was constructed and used to constrain how much irrigated land use was allocated inside irrigation boundaries published in the 'Australian Irrigation Areas, Version 1a' by the NLWRA and small number of additional irrigation pixels, representing irrigation areas in Victoria, most notably in the Maffra district.

Horticulture constraint

A horticulture mask was constructed and used to constrain how much horticultural land use was allocated in areas identified in the catchment land use data.

Parameters used in running SPREAD II

The parameters when running SPREAD II are as follows:

- The complete set of control sites collected in the production of the Audit map (BRS, 2002) was used to characterise the temporal NDVI profile of each land use in each SLA.
- The set of metrics used to characterise individual control sites and target zones were:
    1. Time of year of maximum NDVI;
    2. Average NDVI;
    3. The difference between the maximum and minimum NDVI in the year.
- The bandwidths of the (Gaussian) kernel density estimator used to derive the probabilities from the metrics were 16, 100 and 100 respectively for metrics 1~3 above.
- The area of land allocated by SPREAD II to each land use was specified to be normally distributed with mean equal to the area of land specified by the scaled AgStats and variance of 40,000 for all SLAs.
- The area allocated to irrigated land uses that can fall inside the irrigation areas identified by the irrigation mask was approximately 70% of the aggregate area of irrigated land uses according to the AgStats. The remaining (approximate) 30% in the rest of the SLA if this were possible (i.e. if 70% of the aggregated area were less than or equal to the area of the irrigation zone). If this were not possible, then approximately all the area in the irrigation zone would be allocated to irrigated land uses.
- The area allocated to horticultural land uses that can fall inside the horticultural areas identified by the horticulture mask was approximately 90% of the aggregate area of irrigated land uses according to the AgStats. The remaining (approximate) 10% in the

rest of the SLA if this were possible (i.e. if 90% of the aggregated area were less than or equal to the area of the irrigation zone). If this were not possible, then approximately all the area in the irrigation zone would be allocated to irrigated land uses.

3. Results

Outputs

The maps produced in this project are a development of the Version 2 Audit map and therefore have been called Version 3. They are supplied as a set of ARC/INFO grids with geographical coordinates referred to GDA 94 and 0.01 degree cell size. For each year there is a set of probability maps, one for each land use, and a single summary map made from the probability maps, which is an approximation to a maximum likelihood land use map (see figures Figure 2 to 7 below, and the legend in Figure 1). The probability maps supplied as floating point grids with cell value between 0 and 1, while the summary map is an integer grid with a value attribute table defining the agricultural commodity group, irrigation status and land use according to the Australian Land Use and Management Classification (ALUMC), Version 5 (Bureau of Rural Sciences, 2002). Version 5 of ALUMC is very similar to, and can readily be derived from, Version 4 which was used in the Audit map (BRS, 2002)[1]. See the page 0 metadata (Appendix 2) and the caveats (Appendix 1) for more information about the mapping outputs.

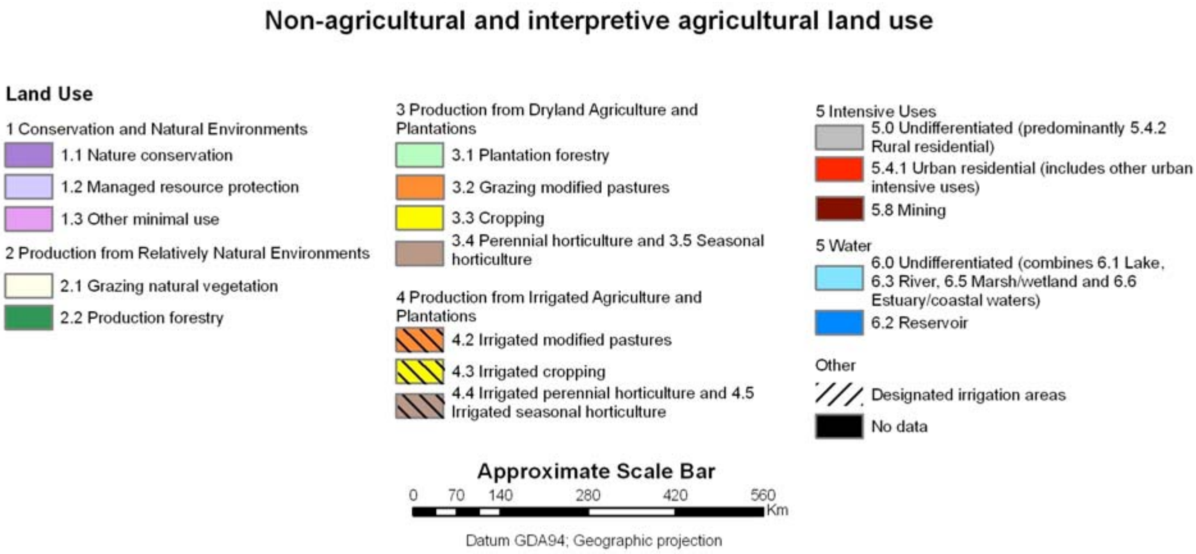

Figure 1: Legend for maps shown in Figure 2 to Figure 7

[1] Visit http://www.affa.gov.au and search the site for 'ALUMC' for information about both Version 4 and Version 5 of the ALUMC.

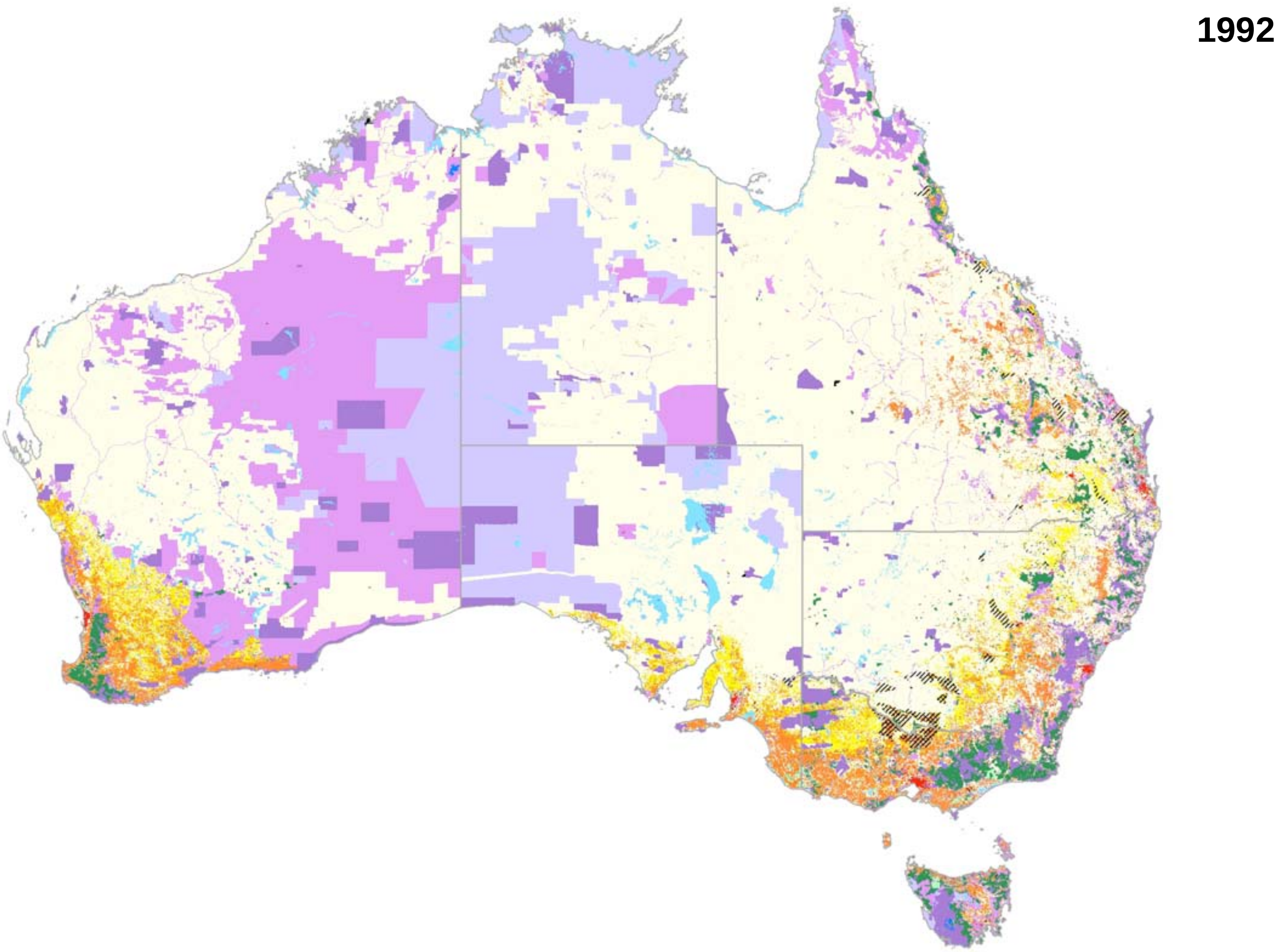

Figure 2: 1992/93 map summarised using land use categories based on the Australian Land Use and Management Classification, Version 5.

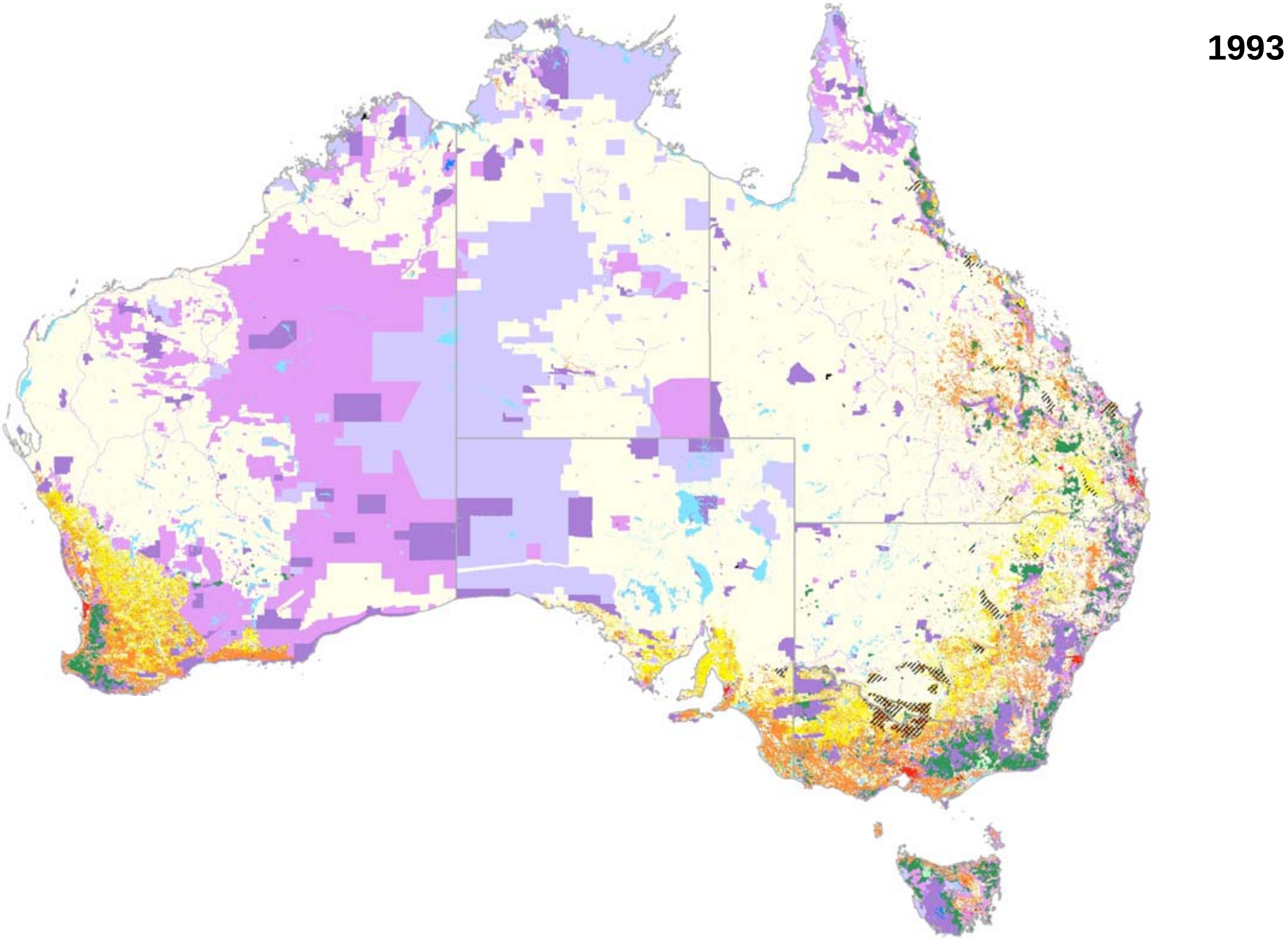

Figure 3:1993/94 map summarised using land use categories based on the Australian Land Use and Management Classification, Version 5.

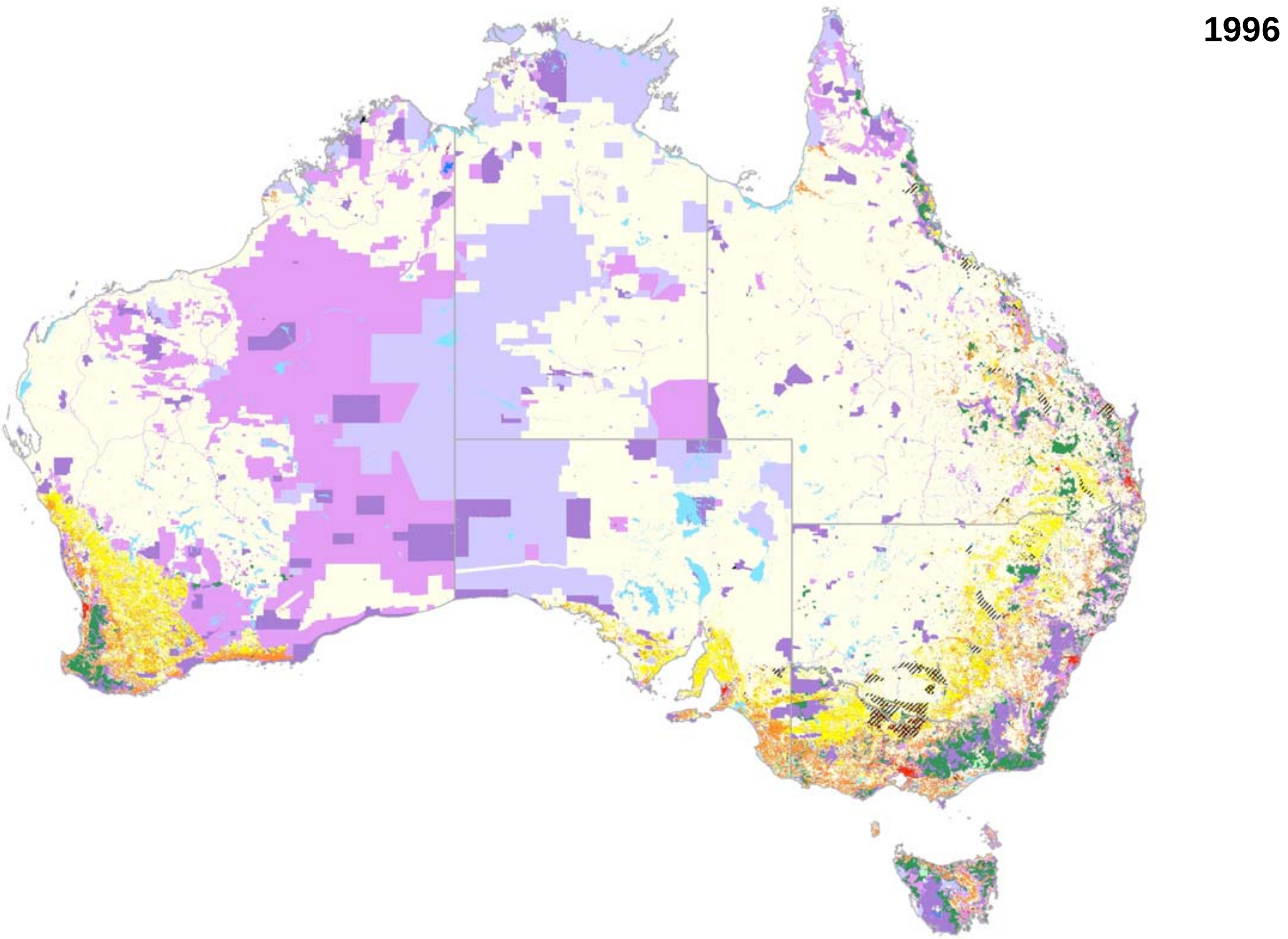

Figure 4:1996/97 map summarised using land use categories based on the Australian Land Use and Management Classification, Version 5.

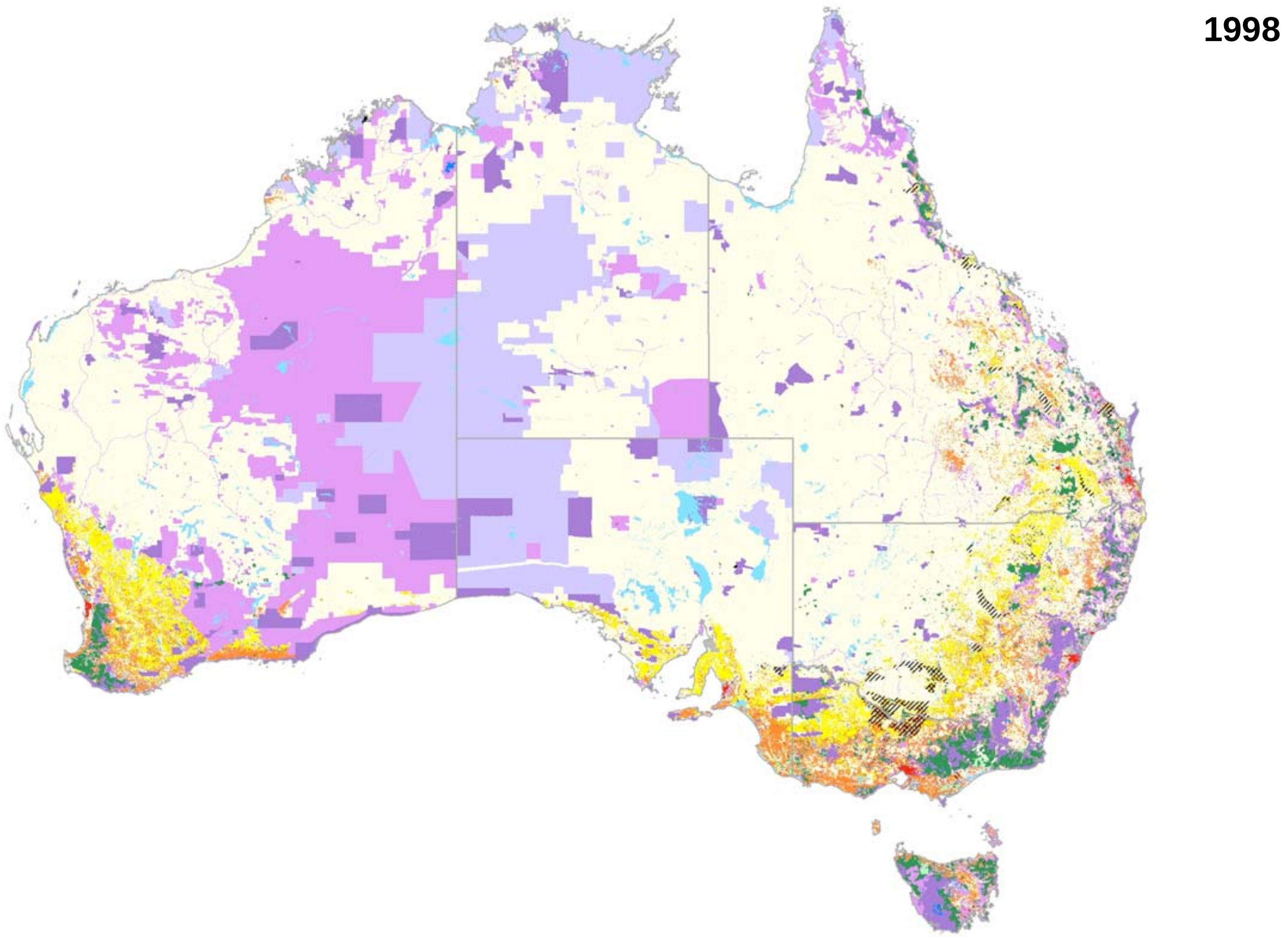

Figure 5: **1998/99 map summarised using land use categories based on the Australian Land Use and Management Classification, Version 5.**

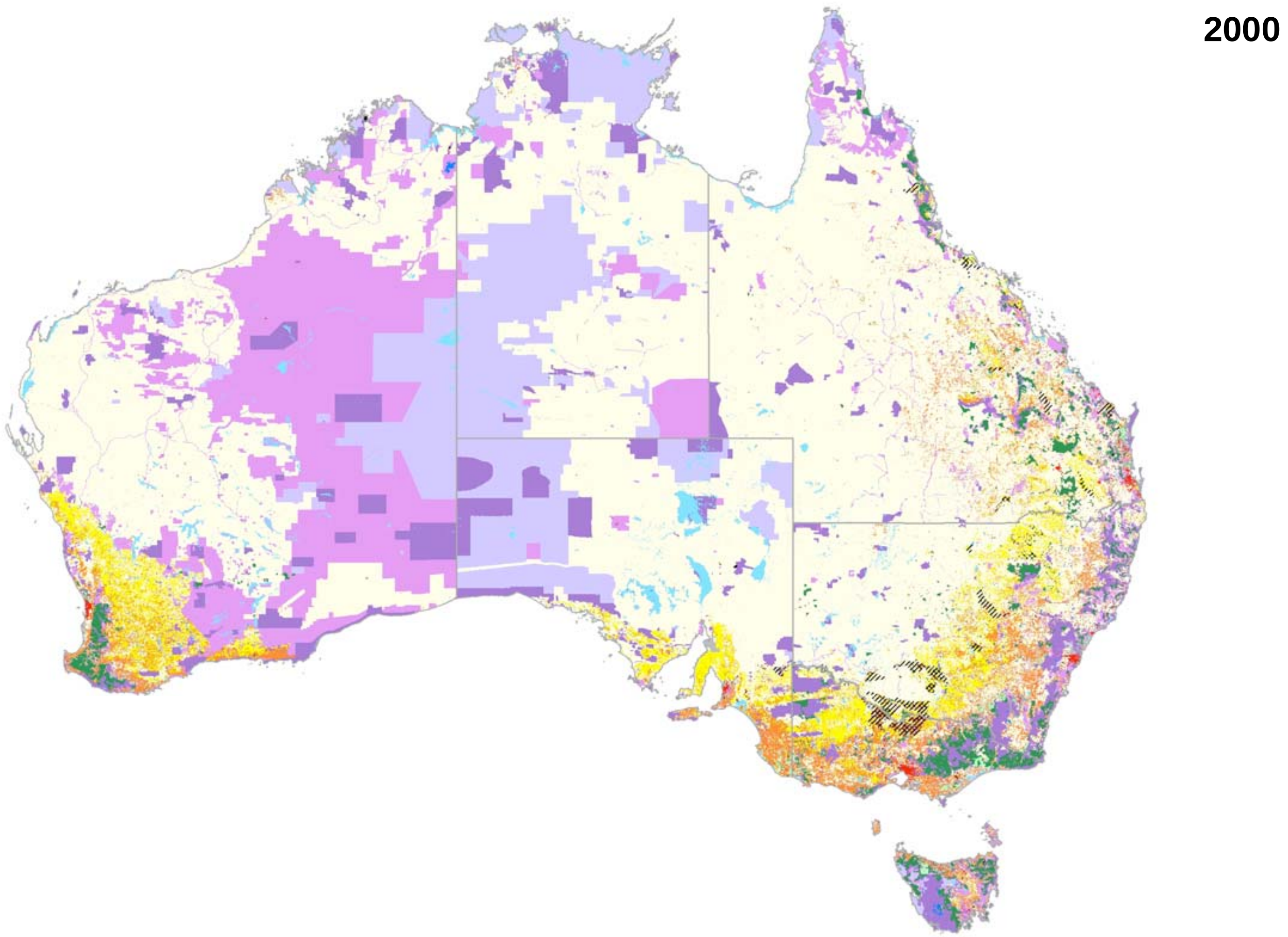

Figure 6: 2001/02 map summarised using land use categories based on the Australian Land Use and Management Classification, Version 5.

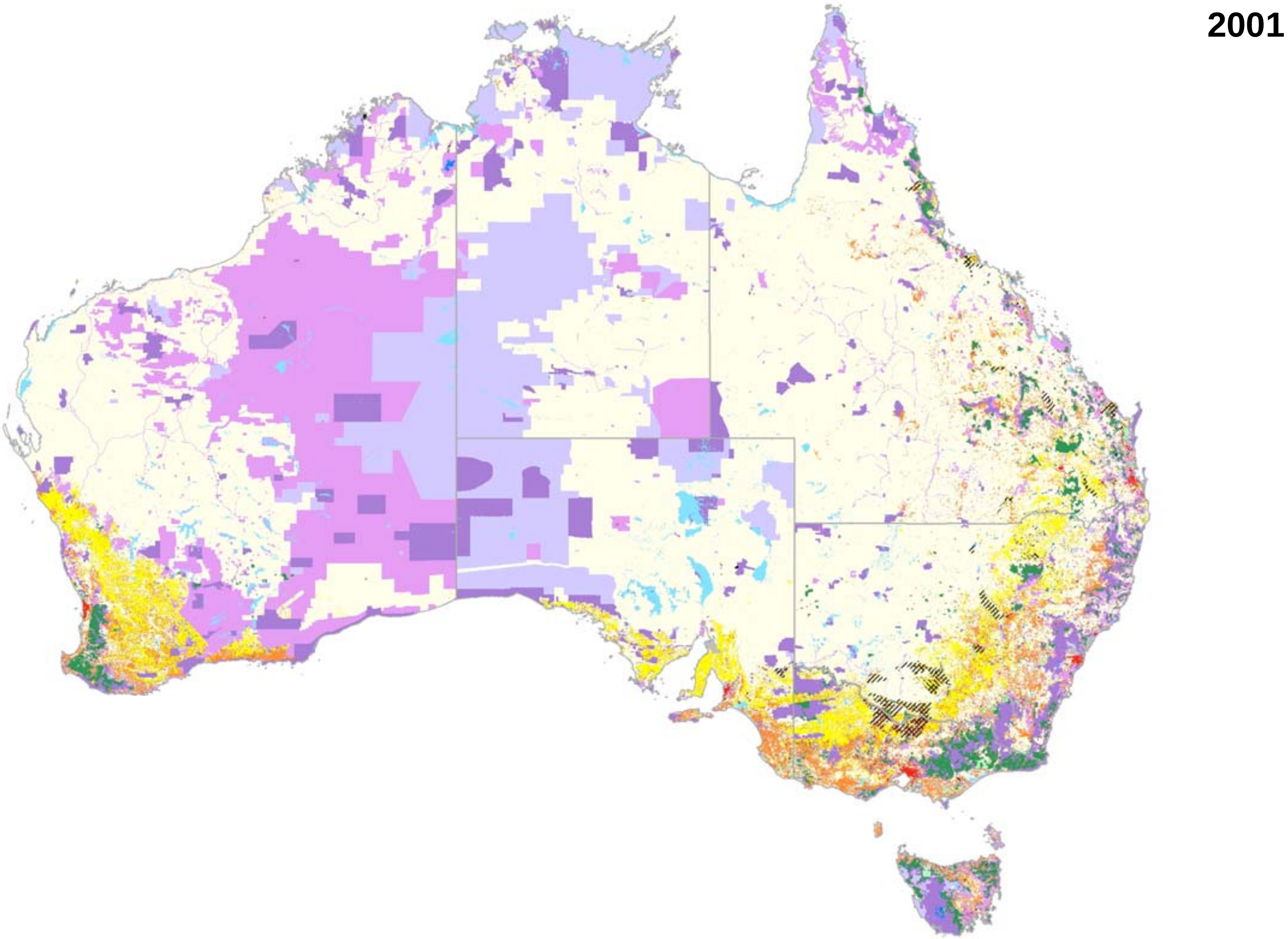

Figure 7: 2002/03 map summarised using land use categories based on the Australian Land Use and Management Classification, Version 5.

4 Results of consultation with members of the Technical Advisory Group for Australian Land Use Mapping

The maps produced for the AGO were reviewed by members of the Technical Advisory Group for Australian Land Use Mapping (TAGALUM). This section presents a summary of the comments received from TAGALUM which are pertinent to the final maps and BRS's response to them. Most of the issues raised in these comments are the subject of the caveats presented in Appendix 1: Caveats for the 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 Land Use Maps of Australia. It is mentioned in the response when the comment is the subject of a caveat.

Responses to comments from NSW – 2000 map only

Large misclassification of land as 2.1.0 where it should be 3.2.0 because the species composition has been extensively changed.

The amount of pasture modification that has occurred in much of the land we have classified as 2.1.0 is almost certainly more than is appropriate for this classification. This reflects the nature of the underlying Agricultural statistics data in which there is a clear distinction between highly modified pastures and moderately modified pastures, but not between moderately modified pastures and minimally modified pastures. When we scale the agricultural statistics, we class both minimally modified and moderately modified pastures as 2.1.0 and hence are almost certainly overstating the area of 2.1.0. This is the subject of a caveat.

Areas of remnant vegetation where the over storey structure is relatively intact and there remains mid- and under- storey layers are either classified as 3.2.0 or 2.1.0 but should be 1.3.3

Errors of this kind have occurred in woodland areas (crown cover between 20% and 50%). We submit all pixels of potentially agricultural land with crown cover less than 50% to SPREAD II for allocation of an agricultural land use. We consider this scheme to be a good compromise as we do not have data that describes the mid and under-storey characteristics which covers the whole country (it may be possible to use NVIS in some areas). It is acknowledged, however, that in some cases our scheme will lead to the misclassification of 1.3.3 as 2.1.0 or 3.2.0 (or, less commonly, other agricultural land uses). This is the subject of a caveat.

Irrigated pastures, irrigated vines, rural residential land, small towns, mining and intensive poultry production are under represented.

The area that has been allocated to irrigated pastures is consistent with the scaled agricultural statistics. In many cases the area of irrigated commodities such as legumes, oilseeds, citrus, cereals (excluding rice) and many others reported in the scaled agricultural statistics were too small to be allocated by SPREAD2.

Rural residential land and mining are determined from rural residential polygons from available catchment scale land use mapping data and mining polygons from TOPO-250K, Series 2. We have only shown small towns for which built-up area polygons are available in TOPO-250K, Series 1 and we have not attempted to show intensive animal production (and a number of other intensive land uses) at all. We hope to improve the under representation of these land uses in the future.

Incorrect distribution of irrigation and mapping of 2.1.0 and dryland horticulture in irrigation areas.

The mapped distribution and abundance of irrigated pastures and irrigated vines reflect the Agricultural statistics data and the discriminating power of SPREAD II. We cannot readily change the former. We may be able to improve the latter in the future, e.g. by obtaining more ground truth data or by improving the operation of the irrigation and horticulture constraints. For example, we have used information on the location of irrigation zones to develop a constraint that encourages SPREAD II to allocate irrigated land uses within irrigation zones, but these irrigation zones do not encompass all areas where irrigation takes place.

Areas around Muswellbrook and research facilities identified as minimal use

The areas referred to have been classified as 1.3.0 though our tenure data indicating that they are institutional crown land. We plan to remedy this error in the future by classifying such pixels as 5.0.0 or 5.5.0. This is the subject of a caveat.

Responses to comments from South Australia – relating variously to some or all of the six maps

Areas with no land use classification

There are small areas around Nepabunna and on Flinders Island with no land use classification. This is because there is no tenure data for the areas concerned. It is hoped that they will be corrected in the future by updating the tenure data.

Under-representation of vine fruits (grapes) and of irrigated pastures

It was suggested that there is under-representation of vine fruits (grapes) in some viticultural areas in all six maps, e.g. in the Clare Valley and around Padthaway and Loxton, and that there is under-representation of irrigated pasture between Mannum and Wellington along the Murray River in the 2000 map. In these regions, the mapped areas of the reportedly under-represented commodities are not significantly different from the areas reported in the Agricultural statistics data at the SLA level. It is possible that these areas are under represented in the agricultural statistics data. Since the distribution of grapes changes from year to year in the maps but would not in reality, it is clear that the mapped distribution of grapes is not correct in at least some of the maps. Since it is possible that the distribution of irrigated pasture will change from year to year, we cannot be certain that the maps are not correct, but this is also possible. This cannot readily be corrected and is covered in the caveats.

Over-representation of horticulture

It was suggested that there are small areas north and south of the Murray River (near Waikerie) that are incorrectly coded as stone fruit, grapes and citrus in the 1998 map. The mapped areas of the reportedly over-represented commodities are not significantly different from the scaled areas. The agricultural statistics data for the relevant SLA are under-reported and have been scaled up using a scale factor of 2.7. Comparison of the 1998/99 Agricultural statistics survey data used to make the 1998/99 map with the 2000/01 Agricultural statistics census data indicates that the over-representation in the 1998/99 map of the horticultural commodities is because of the scaling, which, though appropriate for crops and pastures, is probably not appropriate for horticulture. This error supports a change in the method of scaling of the agricultural statistics data, such that scaling is restricted to areas reported for commodities that normally occupy large areas (crops and pastures) and leaving the areas reported for commodities that normally occupy small areas (horticulture) unscaled.

Missing conservation area

The maps have been made using the CAPAD97, CAPAD2000 and CAPAD2002 protected areas data sets. In CAPAD97 and CAPAD2000, the gazettal year is correctly shown as 1993. In CAPAD2002, the gazettal year is incorrectly shown as 2001. Consequently, in the final maps, the Wahgunyah Conservation Reserve has been correctly omitted from the 1992 map, correctly included in the 1993, 1996, 1998 and 2001 maps but incorrectly omitted from the 2000 map. This is the subject of a caveat.

Introduced conservation area

There is a large protected area, classed as 1.1.4, situated north of the Pooginook Conservation Park. This area is another protected area classed as a ‘natural monument’ in the CAPAD data sets. It has been suggested that this area should be classified as 2.1.0. We have used the classification as 1.1.4 on the grounds that the prime use for protected areas included in the CAPAD data sets can be assumed to be the conservation land use appropriate to the recorded IUCN class – in this case, natural feature protection – and on the grounds that there is merit in methodological consistency. Undoubtedly, there will be protected areas such as this one, where a case could be made for deviating from these grounds.

Missing aboriginal land

The eastern extent of the Pitjantjatjara Lands near Marla, the southern extent of the Maralinga Tjarutja Aboriginal Land and the eastern section of the Yalata Lands are not classified as 1.2.5. This is a problem which derives from the tenure data which may show an early version of these boundaries inappropriate to the currency of our maps. The errors seem to be relatively minor and have not been corrected. It is hoped that they will be corrected in the future through updating the tenure data. This is the subject of a caveat.

Responses to comments from Tasmania – relating to the 1996 and 2000 maps

The main areas of grazing modified pastures and grazing native pastures throughout eastern Tasmania from the 1996 map is a better

representation of their distributions than the 2000 map (according to the state land use map of 2002).

The most likely reason for this is that the control site data are collected in the years 1996-97, 1997-98 and 1998-99. These data are used in the construction of all six maps, which have currencies ranging from 1992-93 to 2001-02. This problem will affect all agricultural land in the map to some extent.

The main cropping areas in northern Tasmania are underestimated.

The area that has been allocated to cropping is consistent with the scaled agricultural statistics and the scaling procedure itself does not appear to have contributed to the under-reporting. Under reporting of cropping in the raw agricultural statistics is likely to be the reason for under representation of these land uses.

There should be more cropping in the Coal River valley area.

The area of cropping is consistent with the agricultural statistics. Under reporting of cropping in the raw agricultural statistics is likely to be the reason for this under representation of cropping.

Tasmania uses forests for winter grazing which are most likely being missed in the land use mapping.

We have no information about the use of native forests on potentially agricultural land and consequently have mapped these as 1.3.3. This is the subject of a caveat.

Remnant native forest around Hobart is overestimated.

The remnant native forest areas have been identified from the forest mask which was based on data compiled by the Department of the Environment and Heritage for greenhouse accounting purposes (NCAS, Department of Environment and Heritage, 2004) for the years 1992, 1995, 1998 and 2002. These data sets provide an internally consistent time series of woody vegetation extent mapping; and therefore provide for a precise determination of change in extent. These data are not the same as the nationally agreed forest extent compiled from State and Territory data by the National Forest Inventory (NFI), which includes a wider range of forest types for the purpose of broader forest assessment and reporting. This may affect the distribution of some land uses. This is the subject of a caveat.

Native pastures are over-estimated in northern Tasmania; there should be more modified pastures in areas shown as 2.1.0 in the north-east of the 1996 map

The allocations are consistent with the agricultural statistics data. In the agricultural statistics data we are able to distinguish the area of highly modified pastures as distinct from other pastures, but we cannot do this for minimally modified pastures. Consequently the area of land that we are allocating as 2.1.0 will probably include moderately modified pasture as well as minimally modified pasture and is therefore significantly larger than it should be. This is the subject of a caveat.

Irrigated areas in the Coal River area and the two other main areas are overestimated, but possibly underestimated in the north-west.

The irrigation allocations are in accord with Agricultural statistics but their distribution within the SLAs may not be correct. We may be able to improve the operation of the irrigation constraint for future editions of the maps, possibly by customising the irrigation constraint for specific regions.

There are some inconsistencies in the estuarine areas – lagoons showing as lakes on the maps

This is a difficulty with the source data set, GA's TOPO-250K, Series 1, in which estuaries are classified as lakes or watercourses. This is the subject of a caveat.

Responses to comments from the Northern Territory – relating to the 1996 and 2000 maps

Other minimal use (1.3.0) and managed resource protection (1.2.0) are very similar land uses in the NT so probably don't need to be in separate categories.

We use 1.2.0 for protected areas included in the CAPAD data sets in the managed resource protection class and 1.3.0 for crown land not used for any specific purpose. It is easier to use the same methodology for the whole country where exceptions are not essential.

There is more variation in the livestock grazing areas (2.1.0) than is indicated by the mapping – on much of the livestock grazing areas, only 10% are useful, e.g. areas of thick vegetation where cattle cannot get in.

Areas such as rocky outcrops and thickets which cannot be grazed by livestock are not differentiated in the data and therefore are indicated as grazing on native vegetation. This is the subject of a caveat.

Wetlands and estuaries are underestimated in the Topo 250 series 1 maps. The series 2 maps pick them up better and using series 2 should improve these areas.

This improvement has not been implemented in the current maps but we hope to implement it in future updates.

Mangoes underestimated

The areas allocated by SPREAD II for perennial horticulture are consistent with the agricultural statistics data. The problem is likely to be under-representation of mangoes (which are classed as stone fruit) in the agricultural statistics data.

Responses to comments from Queensland – relating to the 2000 map

Parcel of 'production forest' on east of Cape York Peninsula (CYP) is incorrect.

This area is shown as multiple use forest on public land in the source tenure data set, which was compiled by BRS in 1997. The 1993 GA tenure map also shows this parcel as public land used as a forestry reserve. The land use – 2.2.0 – has been used, although it is possible that more recent data might support a change.

Sugar is more extensive in some of the regions on the east coast of CYP.

The areas allocated by SPREAD II for sugar cane are consistent with the scaled agricultural statistics data. It was necessary to scale down the agricultural statistics data for some of the relevant SLAs. It is possible that the scaling should not have been applied to the sugar cane areas. Alternatively, the problem may be under-representation of sugar cane in the agricultural statistics data.

Region of cropping in central Queensland is questionable.

In the region in question, the areas allocated for cropping are consistent with the agricultural statistics data. The cropping reported in Agricultural statistics is mainly dryland cereals excluding rice but also includes dryland oilseeds, dryland legumes and dryland cotton.

Many of the 'other minimal use' areas seem unusual and are probably grazed. / Other areas in south-east Queensland shown as 'other minimal use' are often 'grazing' and possibly 'rural residential'. / The distinction between grazing and 'other minimal use' in the Cape York Peninsula needs local knowledge.

The 1.3.3 land use class has been assigned where native forest or woodland falls on public land with no other special use or where native forest (crown cover > 50%) falls on potentially agricultural land. Data for rural residential land has been introduced, where available, and has led to correct classification of some of the areas erroneously classified as 1.3.0. However, errors in our 1.3.3 class will still arise from three sources, which are the subject of caveats. 1) the rigidly applied assumption that grazing occurs up to but not beyond a crown cover of 50%; 2) attribute errors in the input data sets used to define the distribution of native forest and woodland (the Department of Environment and Heritage forest data compiled for greenhouse accounting); and 3) attribute errors in the input data sets used to define the crown cover of native forest and woodland (the Carnahan data sets).

In indicated cropping regions of central and south-east Queensland, overall extent and distribution of dryland and irrigated appear correct but both regions should probably be less patchy

In both regions the areas allocated by SPREAD II for cropping are in accord with the agricultural statistics data. If the allocations are too patchy, this could either be due to under-representation in the agricultural statistics data or to poor spatial disaggregation by SPREAD II. If the latter is the problem, improved control site collections could lead to improvements in future versions of the maps

These areas in south-east Queensland that are shown as ‘irrigated cropping’ are actually ‘grazing’, ‘other minimal use (defence)’ and ‘rural residential’.

This error resulted from faulty behaviour of SPREAD II and missing defence reserve polygons. The faulty behaviour of SPREAD II was corrected before construction of the final maps. Some defence reserve polygons were incorporated, but some small ones were not included. Despite the missing defence reserve polygons, attribute errors in this region are very much reduced in the final maps. It is hoped that the small defence polygons not included in these maps can be included in a later edition of the maps. The tenure issue is the subject of a caveat.

Responses to comments from Victoria – relating to the 1996 and 2000 maps

Many areas in Victoria that are shown as ‘grazing natural vegetation’ probably ought to be shown as ‘grazing modified pastures’.

This problem was also noted by reviewers in NSW, Tasmania and WA. In the section dealing with comments from NSW, the response headed ‘Large misclassification of land as 2.1.0 where it should be 3.2.0 because the species composition has been extensively changed’ and, in the section dealing with comments from Tasmania, the response headed ‘Native pastures are over-estimated in northern Tasmania; there should be more modified pastures in areas shown as 2.1.0 in the north-east of the 1996 map’ deal with alternative statements of this problem and are applicable to all states and territories, including Victoria. This is the subject of a caveat.

Responses to comments from Western Australia – relating to the 1996 and 2000 maps

Many areas in the south-western agricultural area of Western Australia that are shown as ‘grazing natural vegetation’ would generally be expected to be classified as ‘grazing modified pastures’ or more specifically as ‘native/exotic pasture mosaic’.

This problem was also noted by reviewers in NSW, Tasmania and Victoria. In the section dealing with comments from NSW, the response headed ‘Large misclassification of land as 2.1.0 where it should be 3.2.0 because the species composition has been extensively changed’ and, in the section dealing with comments from Tasmania, the response headed ‘Native pastures are over-estimated in northern Tasmania; there should be more modified pastures in areas shown as 2.1.0 in the north-east of the 1996 map’ deal with alternative statements of this problem and are applicable to all states and territories, including Western Australia. This is the subject of a caveat.

Areas that should be classified as 'remnant native cover' have been shown as 'grazing natural vegetation'.

This problem was also noted by the reviewer in NSW. In the section dealing with comments from NSW, the response headed 'Areas of remnant vegetation where the over storey structure is relatively intact and there remains mid- and under- storey layers are either classified as 3.2.0 or 2.1.0 but should be 1.3.3' deals with a more specific case of this problem but the response is applicable to the general case and to all states and territories, including Western Australia. This is the subject of a caveat.

Areas of the rangelands, many of which carry very sparse native vegetation and may have been burnt in recent times, have been classified 1.3.0 (other minimal use) but would be expected to be classified as 1.3.3 (remnant native cover).

This problem results from the assumption that crown land (other than defence reserves) not in protected areas and with no woody vegetation (i.e. the crown cover is less than 20% or the height is less than 2 m) should be shown as ALUMC, Version 5, class 1.3.0 (other minimal use). It is likely, however, that many of these areas have remnant native vegetation that may or may not have been burnt and should be classed as 1.3.3 (remnant native cover). This problem is the subject of a caveat. It may be possible to remedy this problem in the future by introducing additional data.

Through the production of the 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 land use maps, several improvements to the SPREAD II algorithm were made. Further improvements are possible and will be pursued into the future. The following conclusions and recommendations can be made from the work done in this project and the one currently being finalised for the AGO (BRS, 2006).

Conclusions

Output land-use maps generated by the project are statistically and spatially consistent with ABS Agricultural Statistics at the SLA level due to the spatial constraint to census agricultural data. Verification and accuracy testing of the finer-scale NLUM SPREAD allocation data suggests that, at the primary level of classification, spatial accuracies at 1km resolution are around 50%. Accuracy testing has been performed against the Catchment Scale Land Use (CLUM) data for the years 2000/01 and 2001/02. The testing was only performed for these years due to the limited amount of CLUM data available over the period of the maps. Qualitative assessment of the maps suggests that the best results were achieved in 1996/97, which coincides with the period over which the control site information was collected. Unfortunately there was no catchment scale land used data collected for these periods and hence quantitative validation was not possible. It is expected, however, that the accuracy of the maps produced for these years will be higher than that quoted for the years for which quantitative assessment was performed. Inconsistencies in the exact time of mapping for the two methods are also likely to artificially reduce the accuracy results. Analyses of SPREAD II probability surfaces show that the level of correct allocation increases with the probability values and that accuracy results are improved by using a large suite of NDVI signatures for a particular commodity.

Qualitative evaluation of the maps suggests that it is important to use training data which is temporally close to the period being analysed. It is expected that the main reason for this is differences in climatic conditions that have a strong bearing on the NDVI signatures of a given land use. Since climatic conditions also vary geographically, it is also likely to be important to use control sites that are geographically close to an area being analysed. Due to the small number of control sites available, it has not been possible to formally investigate this.

Mapping has been done at the level of Audit commodity classes and there are a number of problems with this in relation to attempts to characterise the NDVI phenology of the Audit classes. One problem is that these classes may often contain a number of different land cover types with variable phenology and hence NDVI signatures. For example, cereals include wheat, barley, grain sorghum and maize; legumes include soybeans, peanuts and lupins; oilseeds include canola and sunflowers, and these specific crops have differing NDVI characteristics. Another problem is that crop-types falling in different classes can have similar profiles. An example of this is that wheat, lupins and canola have time-series NDVI signatures that are fairly indistinguishable. This issue may be addressed to some extent by having a very large number of control sites, but attempting to identify such crop types at the current Audit commodity class level will continue to be difficult and is likely to be contributing to lower accuracies.

The method used to scale the agricultural statistics has improved over the course of this work, but further improvements are possible. Discrepancies occur in AgStats data due to the fact that the outputs of a farm business are always reported against a single SLA, though some of the farm land may be located in neighbouring SLAs. It is likely that discrepancies of this kind affect large farms to a much greater extent than small farms. Therefore, the AgStats scaling procedure may accord better with reality if only the areas of crops and pastures were scaled with the areas of horticultural commodities left unscaled. This should be investigated and implemented in future mapping projects if confirmed. Continued introduction of data on intensive uses as it becomes available from catchment scale data, or from digital cadastral databases, will also improve the scaling of the agricultural statistics.

It is hoped that the accuracy of the NLUM mapping product will be significantly enhanced in the future by using data from the new MODIS sensor. These data have improved spatial and radiometric characteristics. At present, however, there are no control sites available for the period for which these data have been collected.

The operation of the irrigation and horticulture constraints could probably be improved by using SLA-specific operating parameters. For example, for the SLA containing the Ord River Irrigation Scheme, the proportion of irrigated land to be allocated within the irrigation area should be set to a very high percentage (around 100%) while for SLAs in Tasmania, this setting should be much lower (perhaps around 60%). This improvement should be introduced in future mapping projects.

There are opportunities to further refine the use of SPREAD II for making national or regional scale land use maps. For example, SPREAD II could be used to make time series of maps that are temporally consistent, other sources of satellite imagery could be incorporated, or metrics that take account changes in NDVI over multiple years could be introduced.

Recommendations

There are a number of recommendations that are likely to contribute to improvements to the NLUM product:

1. Qualitative assessment suggests that it is important to use control data that is both spatially and temporally close to the area being analysed. It is recommended that there be ongoing collection of control site information to improve the accuracy of maps produced using SPREAD II (collection of this data would also benefit other researches and projects investigating and/or mapping land use and land cover).
2. At present, the normalised difference vegetation index (NDVI) signature of an area of land is characterised by the NDVI profile over the time period of the map being produced. It is recommended that research into the use of longer periods be introduced. This is likely to improve the accuracy of the map for land uses that are part of a rotation system, for example, crop/pasture rotations.
3. The NDVI profile of a given land use is heavily affected by the climatic conditions and geography. Investigation into the incorporation of climatic data and geographic constraints (beyond using contemporary control site information) should be investigated.
4. Research should be conducted into methods for achieving inter-temporal consistency of the maps and how such consistency could be used to improve the maps.
5. Once control sites for the periods corresponding to the collection of MODIS data are established, further investigation on the use of MODIS should be conducted.
6. The current land-use classification scheme is not considered optimal and is likely to be contributing to lower accuracies. More research is required to evaluate optimal classification schemes that meet the need of users and allow reasonable categorisation of land use. Since the algorithm is applied to individual statistical local areas (SLAs), this research should include investigation into the possibility of customising the metrics used to summarise the NDVI profile for the specific set of land uses that occur within the SLA.

7. Further investigation should be conducted into the use of Advanced Very High Resolution Radiometer (AVHRR) surface temperature data (Ts) and possibly other satellite data.
8. The method used for processing and scaling the agricultural statistics should be further refined.
9. Intensive land uses other than rural residential (such as intensive animal production and defence facilities) should be introduced into the national scale land use maps from catchment scale land use data in future mapping projects. The use of other data sets, such as the digital cadastral databases, to identify areas of intensive land use (and potentially other land uses of interest) should also be investigated.
10. The use of the horticulture and irrigation constraints should be further refined. Potentially other constraints could be introduced, but the impacts of having multiple constraints needs to be better understood and automated checks for consistency between multiple constraints implemented.

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Appendix 1: Caveats for the 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 Land Use Maps of Australia

1. The purpose of these maps is to provide nation-wide representations of major commodity types for mapping and display, and spatial input to numerical models.

2. Finer resolution land use data are available for many areas of Australia and, when appropriate, should be used in preference to these maps.

3. The land use maps should be used at an appropriate scale (nominally 1:2,000,000). For the agricultural land uses, the summary maps cannot be expected to have high attribute accuracy on a pixel-by-pixel basis (each pixel is ~ 1.1km). The method used does not impose temporal stability and changes in individual pixel land use assignments should not be used to directly infer land use transitions.

4. Attribute accuracy is likely to be particularly low for pixels in the summary maps representing agricultural land used for more than one commodity group. This can occur where different commodity groups are close in space (strip cropping in particular and small scale planting in general) or in time (multiple cropping). Attribute accuracy is generally dependant on how distinct the commodity appears in the satellite image. The most distinct commodities include primary level classifications and some homogeneous irrigated agricultural types.

5. Agricultural census data and, in the case of the 1998 and 2001 maps, agricultural survey data supplied by the Australian Bureau of Statistics (ABS) provide the areas of each commodity group in each Statistical Local Area (SLA) that were built into the maps. It should be noted that the ABS data were processed on the basis of various assumptions during construction of the maps, as discussed in the project report entitled 'Final Report: 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 Land Use of Australia, Version 3' compiled by BRS in 2006. The maps should therefore be used with appropriate caution. In relation to the 1998 and 2001 maps, it should, further, be noted that the agricultural survey data include many records with large relative standard error, which may exceed 50%. This is because the ABS designs its agricultural surveys to be reported on larger areas than SLAs and only releases agricultural survey data at SLA level by special request. The 1998 and 2001 maps should therefore be used with additional caution.

6. The ABS agricultural census and survey data provide a clear distinction between grazing of highly modified pastures, such as sown pastures, and grazing of pastures that are not highly modified. The highly modified pastures can be subdivided into dryland and irrigated types. The data do not, however, provide a clear distinction between grazing of moderately modified pastures, whose composition deviates significantly from native pasture, and grazing of minimally modified pastures, whose composition does not deviate significantly from native pasture. It is likely that the satellite imagery would not provide a clear discrimination between moderately modified and minimally modified pasture in any case. Consequently, in the construction of the maps, pastures were mapped using three map units: dryland highly modified pastures, irrigated highly modified pastures and all other pastures. In terms of the Australian Land Use and Management Classification

(ALUMC), Version 5, these three map units were classified, respectively, as 3.2.0 (grazing modified pastures), 4.2.0 (irrigated modified pastures) and 2.1.0 (grazing natural vegetation). Users of the maps should be aware that a significant proportion of the area classified as 2.1.0 comprises pastures whose composition deviates from native pasture more than it should according to ALUMC guidelines.

7. In the construction of the maps it has been assumed that farmland, as defined by tenure, with native forest cover will be used for agricultural pursuits if the crown cover is less than 50% and will not be used for agricultural pursuits if the crown cover exceeds 50%. Reality, however, does not conform to this rigid demarcation. Some forest areas with crown covers as high as 80% are grazed and, on the other hand, some woodland with crown cover between 20% and 50% is not used for agricultural pursuits, nor for any other purposes. Users of the maps should be aware that for some land classified, in terms of the ALUMC, Version 5, as 1.3.3 (remnant native cover), the prime use from time to time should be classified as 2.1.0 (grazing natural vegetation); and that for some land with classifications such as 2.1.0 (grazing natural vegetation) or 3.2.0 (grazing modified pastures) the prime use should actually be classified as 1.3.3 (remnant native cover).

8. In constructing the maps, the distribution of woody vegetation (1992, 1995, 1998, 2000 and 2002) was modelled using the data compiled by the Department of the Environment and Heritage for greenhouse accounting purposes (NCAS, Department of Environment and Heritage, 2004). These data sets provide an internally consistent time series of woody vegetation extent mapping; and therefore provide for a precise determination of change in extent. These data are not the same as the nationally agreed forest extent compiled from State and Territory data by the National Forest Inventory (NFI), which includes a wider range of forest types for the purpose of broader forest assessment and reporting. This may affect the distribution of some land uses.

9. In the construction of the maps, the native forest crown cover was determined using the Carnahan Vegetation data sets representing present and pre-European vegetation in Australia (Geoscience Australia). These data sets show data captured from low resolution (1:5 million scale) source material. Users of the maps should be aware that this is expected to contribute to errors in the distribution of some land uses such as remnant native cover.

10. Non-perennial and perennial hydrographic features have not been distinguished. Users of the maps should be aware that grazing might have been the dominant land use, from time to time, in some areas classified as 'lake', 'river' or 'marsh/wetland'.

11. In the construction of the maps, areas of crown land (other than defence reserves) not in protected areas and with no woody vegetation (i.e. the crown cover is less than 20% or the height is less than 2 m) have been shown as ALUMC, Version 5, class 1.3.0 (other minimal use), but it is likely that many of these areas have remnant native vegetation that may or may not have been burnt and should be classed as 1.3.3 (remnant native cover).

12. Some known errors and omissions in the maps are the following:
    - Areas of institutional crown land have been misclassified. They have been shown as ALUMC, Version 5, class 1.3.0 (other minimal use) rather than class 5.5.0 (services) or 5.0.0 (intensive uses).
    - The Wahgunyah Conservation Reserve (a small protected area in South Australia classed as a ‘natural monument’ and, as such, falling in ALUMC, Version 5, class

1.1.4) has been omitted from the 2000 map due to an error in one of the input data sets.

- The eastern extent of the Pitjantjatjara Lands near Marla, South Australia, the southern extent of the Maralinga Tjarutja Aboriginal Land in South Australia and the eastern section of the Yalata Lands in South Australia are not classified as ALUMC, Version 5, class 1.2.5, due to errors in one of the input data sets.
- Some small defence reserves and facilities have been omitted from the maps due to errors in one of the input data sets.
- Estuaries are classified as ALUMC, Version 5, class 6.1 (lake) or class 6.3 (river) rather than as class 6.6 (estuary/coastal waters). Only mangroves and saline coastal flats are classed as 6.6. This reflects the classification structure of the input data.

Appendix 2: Page 0 Metadata for 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 Land Use Maps of Australia

Data Set Title
1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 Land Use of Australia, Version 3

Custodian
Bureau of Rural Sciences (BRS)

Jurisdiction
Australia

Description
Abstract
The 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 Land Use of Australia, Version 3, is a series of land use maps of Australia for the years 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02. The non-agricultural land uses are based on existing digital maps covering four themes: protected areas, topographic features, tenure and forest. Time series data at relatively high temporal resolution were available for the protected areas and forest themes. The agricultural land uses are based on the Australian Bureau of Statistics' agricultural censuses and surveys for the years mapped. The spatial distribution of agricultural land uses is interpretive and has been determined using AVHRR satellite imagery with ground control data. The maps are supplied as a set of ARC/INFO grids with geographical coordinates referred to GDA94 and 0.01 degree cell size. For each of the years mapped there is a set of probability maps, one for each agricultural land use, and a single summary map showing the non-agricultural land uses and a likely arrangement of the agricultural land uses. The arrangement of agricultural land uses in the summary map was determined from the probability maps using some simple rules to make an approximation to a maximum likelihood land use map. As supplied, the probability maps are floating point grids with cell value between 0 and 1 and no value attribute table while the summary map is an integer grid with a value attribute table with attributes defining the agricultural commodity group, irrigation status and land use according to the Australian Land Use and Management Classification (ALUMC), Version 5 (http://www.daff.gov.au). Prospective users of the data should note the caveats and additional metadata, which are included in the document entitled 'User Guide and Caveats: 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 Land Use of Australia, Version 3' (Bureau of Rural Sciences, 2006c). The caveats are also available as a separate document entitled 'Caveats: 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 Land Use of Australia, Version3' (Bureau of Rural Sciences, 2006a).

Search Words

AGRICULTURE
AGRICULTURE Crops
AGRICULTURE Horticulture
AGRICULTURE Irrigation
BOUNDARIES
BOUNDARIES Administrative
BOUNDARIES Biophysical
BOUNDARIES Cultural
FLORA
FLORA Exotic
FLORA Native
FORESTS
FORESTS Agroforestry
FORESTS Natural
FORESTS Plantation
HUMAN ENVIRONMENT
LAND
LAND Conservation
LAND Conservation Reserve
LAND Cover
LAND Ownership
LAND Use
VEGETATION
VEGETATION Structural
WATER
WATER Lakes
WATER Surface
WATER Wetlands

North Bounding Latitude
-9.995

South Bounding Latitude
-44.005

East Bounding Longitude
154.005

West Bounding Longitude
112.505

Data Currency
Beginning Date
1992-04-01

Ending Date
2002-03-31

Data Set Status
Progress
Complete

Maintenance and Update Frequency
As required

Access

Stored Data Format
DIGITAL ARC/INFO 9.1 under SunOS

Available Format Type
DIGITAL - ARC/INFO raster

Access Constraint
Access is unrestricted. Users of the data set are asked to acknowledge, in any visual or published material, that it was derived and compiled by BRS and to make known to BRS any errors, omissions or suggestions for improvement.

Data quality
Lineage

I. For each year mapped, four thematic layers were constructed in raster form with 0.01 degree pixel size and overlain to determine the non-agricultural land uses and the distribution of agricultural land. The layers were a topographic features layer, a protected areas layer, a tenure layer and a forest type layer. They were based on a 1999 update of TOPO-250K (Series 1) and a 2005 update of TOPO-250K (Series 2), 1:250,000 scale vector topographic data sets published by Geoscience Australia (GA); the Collaborative Australian Protected Areas Database data sets for 1997, 2000 and 2002, 1:250,000 scale vector protected areas data sets published by the Department of Environment and Heritage (DEH); Australian Tenure, a 250m raster tenure data set compiled by BRS in 1997; agricultural land use status information for aboriginal freehold and leasehold land from state and territory agencies; forest extent data compiled by the Department of Environment and Heritage for greenhouse accounting purposes for 1992, 1995, 1998, 2000 and 2002 - 25m raster data; crown cover data from Vegetation: Present (1988) and Vegetation: Pre-European Settlement (1788) published by GA; land use data from the collaborative 'Land Use Mapping at Catchment Scale' project managed by BRS (Bureau of Rural Sciences, 2002) and from the collaborative 'Land Use Data Integration Case Study - Lower Murray NAP Region' project managed by BRS and from the agricultural Land Cover Change: 1995 Land Cover data set compiled by BRS; and plantation forest data from BRS's Plantations 2001 data set.

II. The spatial distribution of specific agricultural land uses for each of the six years was determined using SPREAD II, developed by Simon Barry of BRS. SPREAD II, like the SPREAD (SPatial REallocation of Aggregated Data) algorithm of Walker and Mallawaarachchi (1998), uses time series NDVI data with control sites (ground control data comprising records of the agricultural land uses that existed at specific points in specific years) to spatially disaggregate agricultural census or survey data. The SPREAD II methodology is statistically based, using a Bayesian technique - a Markov chain Monte Carlo (MCMC) algorithm. It has been implemented in R. NDVI images were obtained from Advanced Very High Resolution Radiometer (AVHRR) data processed to correct for cloud cover by DEH.

Control site data were collected by State and Territory agencies for the Audit (project BRR5) and relate to the years 1996, 1997 and 1998. The irrigation status of most control sites is known and the method was used to determine the distribution, not only of commodity groups, but also of their irrigation status. Agricultural census and survey data reported on Statistical Local Areas (SLAs) were obtained from the Australian Bureau of Statistics. Modifications made to the agricultural census and survey data are the same as carried out during the construction of the 1996/97 Land Use of Australia, Version 2 (Stewart et al, 2001). The irrigation boundaries data set published by the Audit, the Australian Irrigation Areas, Version 1a, with some additional polygons incorporated for irrigation districts in Victoria, served as an irrigation constraint to refine the prior probabilities used in the MCMC algorithm. A horticulture mask constructed using some of the data sets listed in section I served as a horticulture constraint to refine the prior probabilities used in the MCMC algorithm. For each of the six years, SPREAD II generated outputs comprising the 42 probability maps described in the abstract and a summary agricultural land use map (the agricultural component of the summary map described in the abstract).

III. Land uses were assigned to pixels in the summary grids with the aid of a macro, which assigns land use categories from the Australian Land Use Management Classification Version 5 (http://www.daff.gov.au/ - search site for ALUMC) according to the attributes of the four layers overlaid in step I and of the summary agricultural land use map made in step II.

Positional Accuracy
The data type and stated positional accuracy of the major existing data sets used to determine the non-agricultural land uses and the distribution of agricultural land (as discussed in the lineage section) are as follows:
. CAPAD data sets - vector data, spatial errors are in the range 1m to 500m
. TOPO-250K - vector data, error less than 160m for at least 90% of well-defined points
. Australian Tenure - 250m raster data, spatial errors, in the main, do not exceed 125m
. Forest extent data compiled by the Department of Environment and Heritage for greenhouse accounting purposes, positional accuracy unknown but average errors assumed to be comparable in size to pixel size The input NDVI imagery and the output probability and summary grids have 0.01 degree pixel size. Therefore, spatial errors, in the main, should not exceed 1 - 2 km.

Attribute Accuracy
Non-agricultural land uses were assigned, initially, on the basis of existing data sets showing topographic features, protected areas, tenure and forest type. Specific agricultural land uses were then assigned by automated interpretation of NDVI images. Accuracy of assignments based on existing data

sets depends mainly on the attribute accuracy of the underlying data sets but also on the validity of the rules used for land use assignment. The attribute accuracy of the underlying data sets has not been tested except for the topographic features data set (TOPO-250K) for which the range of allowable attribute errors is from 0.5% to 5% at a 99% confidence level. However, the attribute accuracy of the other three underlying data sets is expected to be high, with consequent high accuracy in non-agricultural land use assignments. The accuracy of the specific agricultural land use allocations based on automated interpretation of NDVI images is variable. The probability grids give an indication of the accuracy of the agricultural land use allocations.

Logical Consistency
The attribute combination corresponding to each land use assignment in the summary grid was tested by inspection to verify that these automated assignments were as intended and were logically consistent.

Completeness
Coverage and classification are complete. Verification of spatial and attribute data are in progress.

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Additional Metadata

Bureau of Rural Sciences, 2002, 'Land use mapping at catchment scale: principles, procedures and definitions', Edition 2, Bureau of Rural Sciences, Canberra.

Bureau of Rural Sciences, 2006a, 'Caveats: 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 land use of Australia, version 3', Bureau of Rural Sciences, Canberra.

Bureau of Rural Sciences, 2006b, 'Final report: 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 land use of Australia, version 3', Bureau of Rural Sciences, Canberra.

Bureau of Rural Sciences, 2006c, 'User guide and caveats: 1992/93, 1993/94, 1996/97, 1998/99, 2000/01 and 2001/02 land use of Australia, version 3', Bureau of Rural Sciences, Canberra.

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