South Australian Land Cover Layers: an Introduction and Summary Statistics

Nigel Willoughby, David Thompson, Matt Royal and Matt Miles

Department for Environment and Water

April 2018

DEW Technical report 2018/01

Department for Environment and Water

GPO Box 1047, Adelaide SA 5001

Telephone National (08) 8463 6946

International +61 8 8463 6946

Fax National (08) 8463 6999

International +61 8 8463 6999

Website www.environment.sa.gov.au

Disclaimer

ISBN 978-1-925668-13-1

Preferred way to cite this publication:

Willoughby, N., Thompson, D., Royal, M. and Miles, M. (2018). South Australian Land Cover Layers: an Introduction and Summary Statistics, DEW Technical report 2018/01, Government of South Australia, Department for Environment and Water, Adelaide.

Download this document at https://data.environment.sa.gov.au/Content/Publications/SA-Land-Cover-Layers-Technical-Summary.pdf

Foreword

The Department for Environment and Water (DEW) contributes to the management of South Australia's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW’s strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

John Schutz
A/CHIEF EXECUTIVE
DEPARTMENT FOR ENVIRONMENT AND WATER

Acknowledgements

Many people and organisations contributed to the land cover mapping project technically and financially. Contributions to the land cover mapping were made by all of the South Australian Natural Resources Management Boards, the South Australian Department for Environment and Water (DEW), the Environment Protection Authority, the Native Vegetation Council, Commonwealth Department of the Environment, Geoscience Australia and the Arthur Rylah Institute. Brad Page and Annelise Wiebkin (DEW but now with the Department of Primary Industries and Regions, South Australia) conceived the project and drove it through the early stages. Several other DEW staff were instrumental in establishing this project including Keith Smith, Kristian Peters, Renata Rix and Tim Bond. Matt White, Graeme Newell (both Arthur Rylah Institute) and Peter Griffioen (Ecoinformatics) undertook the land cover modelling. Tim Croft (T&M Ecologists) provided tens of thousands of training points. Many tens of thousands of training points were provided by the other contributors to the project. Data publishing and licensing support from Xen Markou, Chris Roberts, and Robin Green (all DEW).

Daniel Rogers (DEW) provided principal oversight throughout and technical review of the land cover mapping project and this report. Feedback on earlier drafts of this report was also provided by Kirsty Bevan, Michelle Bald, Sandy Carruthers, Trevor Hobbs and Colin Cichon (all DEW).

Kenneth Clarke (The University of Adelaide) reviewed an earlier version of this report, suggesting several key areas for improving rigour and clarity.

Contents

List of figures

List of tables

1 Summary

The purpose of this report is to introduce the South Australian Land Cover Layers by presenting summary statistics, large scale trends and limitations. The South Australian Land Cover Layers provide a consistent through time, whole-of-state, spatial land cover data set. Native vegetation cover in South Australia was previously estimated from data that were becoming dated and were limited in their spatial and temporal coverage. Other land cover trends were informed by theme or industry-based data approaches, based on various mapping methods. In 2015 DEW together with the South Australian Natural Resources Management (NRM) Boards and the Australian Government Department for Environment, sought improved knowledge of native vegetation extent through a research collaboration with the Victorian Department of Environment, Land, Water and Planning's research institute (the Arthur Rylah Institute), Ecoinformatics and Geoscience Australia. The research collaboration aimed to model native vegetation, and other land cover classes, across South Australia in six epochs between 1987 and 2015 (mostly five years per epoch). The results of this collaboration are now available as a dataset called the 'South Australian Land Cover Layers'. These layers are used to present information on land cover and land cover change at three broad scales across South Australia: whole-of-state; systems; and natural resources management regions. The 'systems' scale is presented in three natural groupings of natural resources management regions, from wetter to drier:

- High-rainfall
  - Adelaide and Mount Lofty Ranges
  - Kangaroo Island
  - South East
- Low-rainfall
  - Eyre Peninsula
  - Northern and Yorke
  - South Australian Murray-Darling Basin
- Arid
  - Alinytjara Wilurara
  - South Australian Arid Lands

Trends in land cover change according to this dataset include:

- In the high rainfall system:
  - increase in plantation (hardwood)
  - increase in various other high intensity land uses
    - orchards/vineyards in Adelaide and Mount Lofty Ranges and South East
    - irrigated non-woody in the South East
    - plantation (softwood) on Kangaroo Island and in the South East
    - urban area in Adelaide and Mount Lofty Ranges
  - decrease in wetland vegetation
  - decrease in dryland agriculture on Kangaroo Island
- In the low-rainfall system:
  - increase in woody native vegetation (although low confidence increase in Northern and Yorke NRM Region)
  - trends that are due, in part, to classification limitations
    - increase in dryland agriculture

- decrease in non-woody native vegetation

- In the arid system the land cover classes fluctuate between epochs and thus appear stable (low confidence in any overall trend)
- Changes, where they occur, are diffuse in nature (e.g. Figures 21 and 27), with the trends becoming most evident when analysing over relatively large areas

The new land cover layers suggest that native vegetation per cent cover is considerably higher than the previous dataset (South Australian Vegetation) suggested. For example, in the Adelaide and Mount Lofty Ranges NRM Region, the area covered by native vegetation is estimated at 32% whereas previous datasets suggested it was 13%. This change is only due to the new method of mapping and delineation of native vegetation. For example, using this new method, all linear (e.g. roadside and riparian) vegetation is now mapped. The results may lead to discussion regarding the various definitions of native vegetation that are used in South Australia and in some cases lead to variations in natural resources management planning and reporting.

The new dataset also enables the trend in native vegetation cover to be determined. At all scales investigated, native vegetation per cent cover was either stable or decreasing.

Summary information for each NRM Region is given in Figure 1a) showing estimated 2015 per cent cover for all land cover classes, and Figure 1b) showing estimated per cent cover change over the period 1990 to 2015.

Figure 2 shows the 2015 land cover layer for all of South Australia. At this scale several key features of South Australian land cover are evident:

- non-woody vegetation dominating the arid areas of the state
- large wetland areas in the north-east of the state: ephemeral braided channel wetland system associated with the Diamantina River and with Coongie Lakes
- the salt lakes across the arid zone of the state
- large areas of woody native vegetation as a band across the state immediately north of the broadacre system
- the broadacre system as a yellow band of dryland agriculture across temperate South Australia including several large areas of native vegetation such as Hincks, Hambidge and Ngarkat Conservation Parks and Billiatt Wilderness Protection Area
- plantation areas in the south east of the state, on Kangaroo Island and to a lesser extent in the Mount Lofty Ranges
- the urban areas around Adelaide

The new datasets provide a step-change in the levels of information regarding trends in land cover in South Australia, including the native vegetation, forestry, agriculture and urban land cover classes. However, like all models, the limits of the most likely layers from the SA Land Cover Layers 1987–2015 must be understood for their utility and value to be realised in any particular application.

As the land cover layers continue to be used to analyse the history and dynamics of South Australian land cover, iterative improvements to the modelled layers and summary statistics derived from the modeled layers (such as this report) should be expected. Such improvements are encouraged through open access to data. The data available at Data SA will always reflect the most recent versions, with the associated metadata (DEWNR 2017b) providing details and dates of updated data (this report is based on October 2017 release data). It is therefore important to ensure any analysis or presentation of results records the date of data download or viewing.

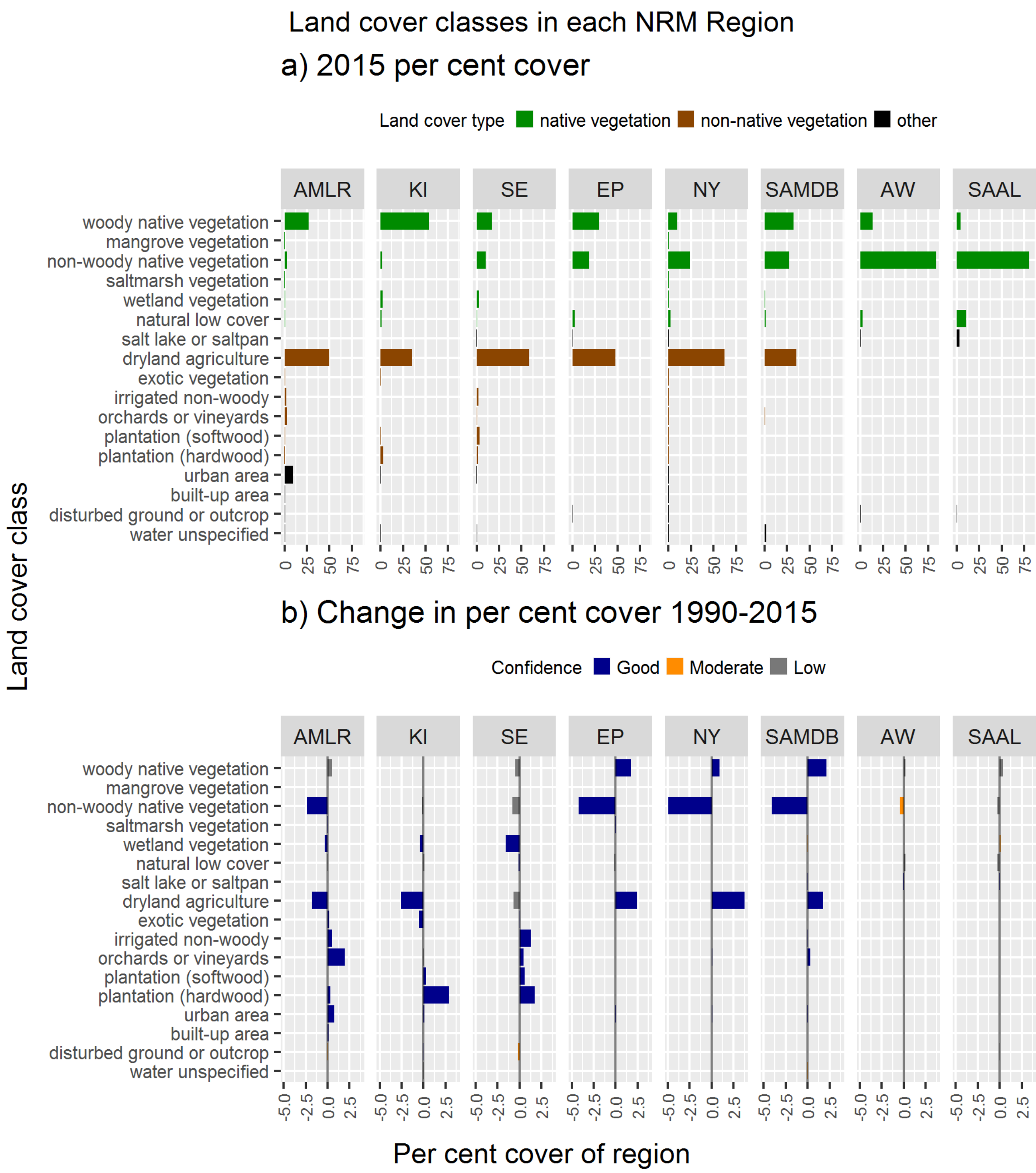

Figure 1 Results for each NRM Region: estimated per cent cover in 2015 and change between 1990 and 2015. Per cent cover is per cent of the region

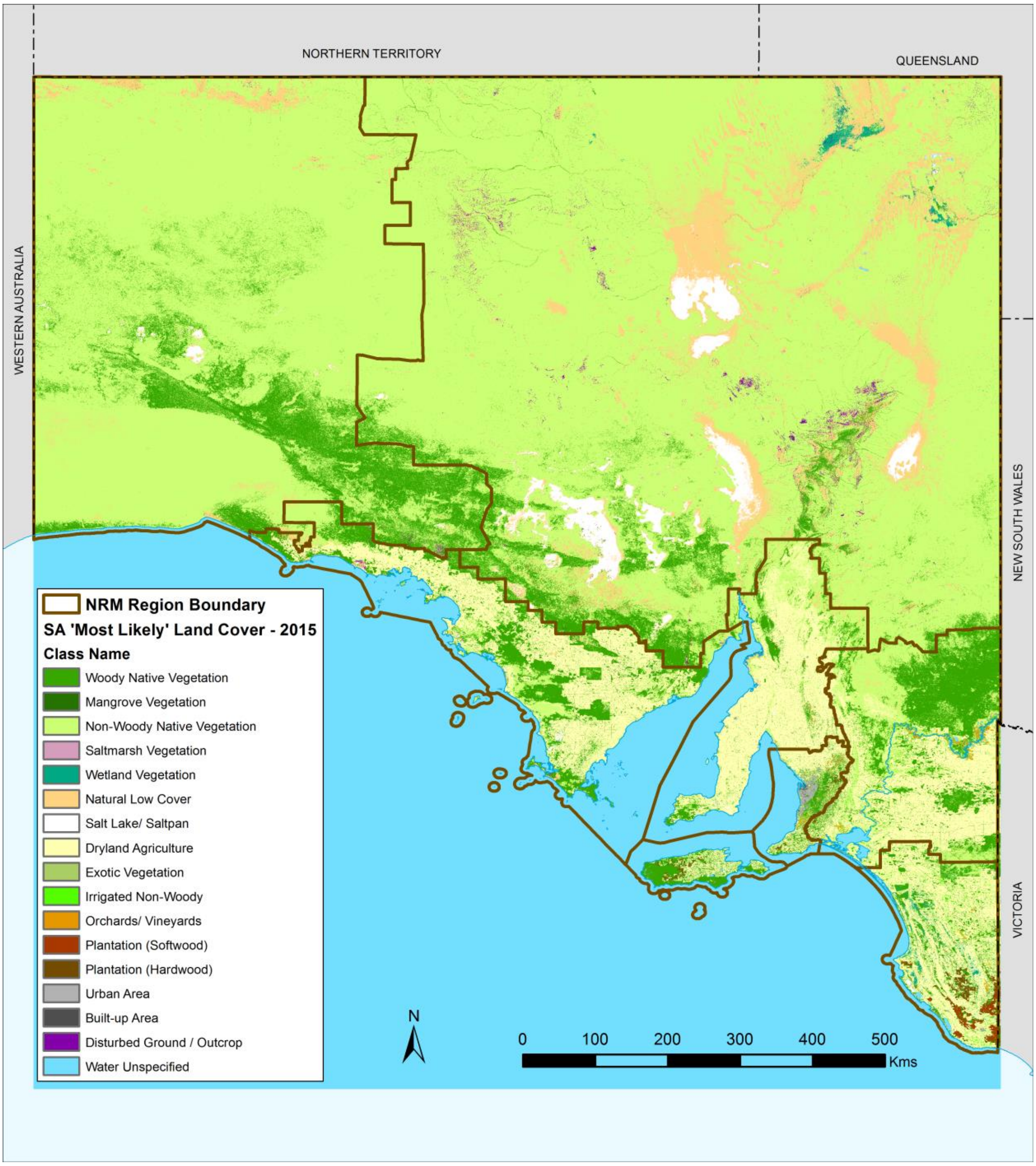

Figure 2 Land cover class map for all of South Australia (2010-2015 epoch)

2 Introduction

Native vegetation information is used by the Department for Environment and Water (DEW), regional Natural Resources Management Boards and the Environment Protection Authority for a range of natural resources management activities including state-wide, regional and sub-regional planning and reporting, evaluation of investment activities, and supporting landscape management. Government of South Australia agencies in general, local governments, industry and the public also have an interest in land cover and land cover change.

Until 2016 there has been no consistent through-time, whole-of-state, spatial land cover information. Previously, native vegetation cover for the state has been estimated based on information in the Native Vegetation Floristic Areas mapping known as 'SAVeg' (DEWNR 2017a). The nature of the SAVeg dataset meant that South Australian vegetation extent estimates were based on data that were becoming dated and were limited in their spatial and temporal coverage (e.g. O'Connor 2009; Pisanu 2010). For example, the SAVeg data had:

- a single layer representing native vegetation across all of South Australia (i.e. not tied to any particular time period)
- approximately 89% coverage of South Australia
- multiple dates in the single layer dependent on when each part of the state was mapped
- problems with edge-matching between areas that were mapped at different times and/or for different reasons
- been based on a range of different methodologies
- been based on subjective decisions regarding the boundaries of native vegetation.

In 2015 DEW together with the South Australian NRM Boards and the Australian Government Department for Environment, sought improved knowledge of native vegetation extent through a research collaboration with the Victorian Department of Environment, Land, Water and Planning's research institute (the Arthur Rylah Institute), Ecoinformatics and Geoscience Australia. The research collaboration aimed to model native vegetation, and other land cover classes, across South Australia between 1987 and 2015. The results of this collaboration are now available as a dataset called the 'South Australian Land Cover Layers'. This new dataset uses Landsat satellite imagery and local calibration (or training) data to quantify trends in land cover classes in six epochs from 1990 to 2015. It comprises:

- 55 statewide 'continuous' layers - one for each land cover class. These contain likelihood measures (between 0 and 100) that a pixel is that land cover class (DEWNR 2017c)
- 55 'confidence' layers. For each of the continuous layers there is a confidence measure (DEWNR 2017c)
- **most likely layers**. Summary layers displaying the most likely land cover class for each pixel in each epoch. These layers can be viewed on-line at NatureMaps with a metadata record available at LocationSA (DEWNR 2017b)

Collectively, these new datasets provide a step-change in the levels of information regarding trends in land cover in South Australia, including native vegetation. However due diligence is required to ensure understanding of what these datasets do well, and where they may have limitations. As an initial description of the datasets and a first look at changes in land cover classes through time, this document is one component of that due diligence. The focus is on the most likely layers as they are the main product that most people will use.

2.1 Purpose

The purpose of this report is to introduce the South Australian Land Cover Layers by presenting summary statistics, large scale trends and limitations. Specifically, this document:

- presents summary statistics of land cover and land cover change from the most likely layers (one layer for each of six epochs) - a key set of layers in the new dataset
- compares native vegetation per cent cover estimates obtained from two distinct data sources:
  - the standard data source on vegetation cover in South Australia over the last few decades: SAVeg (DEWNR 2017a)
  - the most likely layers from the SA Land Cover Layers 1987–2015 (DEWNR 2017b)
- provides an example of how the most likely layers can be used to report on the State NRM Plan Guiding Target: *Increase extent and improve condition of native vegetation* (Government of South Australia 2012)
- discusses known limitations of the data, and analysis, encountered while undertaking these tasks.

3 Methods

3.1 South Australian Land Cover Layers

The South Australian Land Cover Layers are spatially explicit models of predicted land cover, with an emphasis on native vegetation. The layers cover all of South Australia in six 5-year epochs (Table 1). The methods used to develop the layers followed are described in White and Griffioen (2016) and repeated here briefly:

- a dataset of land cover class training points were generated across South Australia covering the time period 1990 to 2015:
  - roughly 90% of these data were used as training points to develop the model
  - roughly 10% of these data were held-back as test points to assess the model at a later stage
- a series of independent spatial layers were obtained (see Table 2) to form the basis of the model for each epoch:
  - Landsat images for 5-year periods from 1985 onwards
  - various other datasets supplemented the Landsat images
- stratified random forests were used to produce a single model predicting the relative likelihoods of each land cover class
- the model was applied to the independent spatial layers for each epoch to create continuous layers of likelihood for each land cover class across South Australia in each epoch
- a series of rules were applied to these continuous layers to generate a single 'most-likely' layer in each epoch (see below)
- each layer was assessed against the held-back data

The full set of 38 independent variables used in the generation of the continuous layers are given in (Table 2). For full descriptions, refer to White and Griffioen (2016).

Table 1 Definition of epochs, including number of training and test points

Epoch	Years	End year of epoch	Training points	Test points
1	1987-1990	1990	43893	4879
2	1990-1995	1995	56570	6286
3	1995-2000	2000	52027	5785
4	2000-2005	2005	43588	4838
5	2005-2010	2010	44190	4910
6	2010-2015	2015	49825	5539

Table 2 Independent variables used in the generation of the land cover layers (White and Griffioen 2016)

Variable	Satellite	Pixel resolution	Season used	Statistics
Landsat B1	Landsat	25m	Summer, Spring, Autumn, Winter	25th, 50th, 75th percentiles for each epoch
Landsat B2	Landsat	25m	Summer, Spring, Autumn, Winter	25th, 50th, 75th percentiles for each epoch
Landsat B3	Landsat	25m	Summer, Spring, Autumn, Winter	25th, 50th, 75th percentiles for each epoch
Landsat B4	Landsat	25m	Summer, Spring, Autumn, Winter	25th, 50th, 75th percentiles for each epoch
Landsat B5	Landsat	25m	Summer, Spring, Autumn, Winter	25th, 50th, 75th percentiles for each epoch
Landsat B7	Landsat	25m	Summer, Spring, Autumn, Winter	25th, 50th, 75th percentiles for each epoch
Enhanced Vegetation Index	Landsat	25m	Summer, Spring, Autumn, Winter	Median for each epoch
Normalised Difference Moisture Index	Landsat	25m	Summer, Spring, Autumn, Winter	Median for each epoch
Normalised Difference Soil Index	Landsat	25m	Summer, Spring, Autumn, Winter	Median for each epoch
Normalised Difference Vegetation Index	Landsat	25m	Summer, Spring, Autumn, Winter	Median for each epoch
Soil Adjusted Total Vegetation Index	Landsat	25m	Summer, Spring, Autumn, Winter	Median for each epoch

Variable	Satellite	Pixel resolution	Season used	Statistics
Specific Leaf Area Vegetation Index	Landsat	25m	Summer, Spring, Autumn, Winter	Median for each epoch
Normalised Difference Burn Ratio	Landsat	25m	Summer, Spring, Autumn, Winter	Median for each epoch
Normalised Difference Wetness Index	Landsat	25m	Summer, Spring, Autumn, Winter	Median for each epoch
Spectral Bathymetry	Landsat	NA	Summer	Median for each epoch
Horizontal Transmit - Vertical Receive Polarisation (HV)	ALOS PALSAR (L-band)	25m	N/A	Minimum, Maximum, Median for 2005-2010 epoch
Horizontal Transmit - Vertical Receive Polarisation (HV)	ALOS PALSAR (L-band)	25m	N/A	Minimum, Maximum, Median for 2005-2010 epoch
Water Observations from Space	Landsat	25m	N/A	% of images detecting water
Alos Ratio	ALOS PALSAR (L-band)	25m	N/A	N/A
Landsat B1	Landsat	225m	Summer	Median
Landsat B2	Landsat	225m	Summer	Median
Landsat B3	Landsat	225m	Summer	Median
Landsat B4	Landsat	225m	Summer	Median
Landsat B5	Landsat	225m	Summer	Median
Landsat B7	Landsat	225m	Summer	Median
NDVI_Delta	Landsat	25m	Summer	Each epoch
Band1_MaxDiff	Landsat	25m	Summer	Each epoch
Band2_MaxDiff	Landsat	25m	Summer	Each epoch
Band3_MaxDiff	Landsat	25m	Summer	Each epoch
Band4_MaxDiff	Landsat	25m	Summer	Each epoch
Band5_MaxDiff	Landsat	25m	Summer	Each epoch
Band7_MaxDiff	Landsat	25m	Summer	Each epoch
Band1_MinDiff	Landsat	25m	Summer	Each epoch
Band2_MinDiff	Landsat	25m	Summer	Each epoch
Band3_MinDiff	Landsat	25m	Summer	Each epoch
Band4_MinDiff	Landsat	25m	Summer	Each epoch

Variable	Satellite	Pixel resolution	Season used	Statistics
Band5_MinDiff	Landsat	25m	Summer	Each epoch
Band7_MinDiff	Landsat	25m	Summer	Each epoch

3.2 Most likely layers

3.2.1 Modelled land cover classes

This report uses October 2017 release of the most likely layers (DEWNR 2017b).

The most likely layers (one for each epoch, see Table 1) include 18 land cover classes (as defined in Table 3, including a 'no data/unclassified' class). These are derived from 44 of the continuous layers using a rule set provided in White and Griffioen (2016). The rule set does not simply take the most likely from any of the continuous layers but instead takes a more nuanced approach including:

- inertia based on land cover class in earlier and later epochs - i.e. a pixel is unlikely to take a land cover class for only one epoch if that pixel is a single land cover class in all other epochs. There are exceptions to this for initial and final epochs
- 'high-level' decisions that limit the options for the 'lower-level' final decision on the most likely class e.g. initial classification as land or water; vegetation or not vegetation informs later class assignment. Thus, if a pixel was classified at a high-level as, say, vegetation, it could not be classified at a lower-level as, say, built-up area.

For the full rule set, refer to White and Griffioen (2016).

The relationship of the 18 land cover classes in the most likely layers to 44 continuous layers is given in Table 4.

Table 3 Description of land cover classes in the most likely layer

Land cover class	Description
woody native vegetation	Woody native vegetation generally > 1 m tall (e.g. eucalypt forests and woodlands, wattle shrublands, hop-bush shrublands)
mangrove vegetation	Mangrove dominated forest
non-woody native vegetation	Non-woody native vegetation generally < 1 m tall (e.g. grasslands including herbs and low shrubs such as chenopods)
saltmarsh vegetation	Low native vegetation in areas with saline soils dominated by samphire species
wetland vegetation	Non-woody native vegetation occurring in association with wetlands (e.g. emergent vegetation, lignum)
natural low cover	Very sparse native vegetation (e.g. gibber plains, post-fire heath, coastal dunes, beaches. Large fluctuations can occur - usually with low native vegetation)
salt lake or saltpan	Salt lakes and salt pans

Land cover class	Description
dryland agriculture	Non-native vegetation that is used for dryland cropping and/or grazing
exotic vegetation	Any form of (generally woody) vegetation dominated by non-native species and not classified to the other non-native vegetation classes
irrigated non-woody	Irrigated pasture or crops (e.g. irrigated cropping/ pasture, grassed reserves, golf courses)
orchards or vineyards	Irrigated woody crops (e.g. grapes, citrus, stone fruit)
plantation (softwood)	Pine plantations
plantation (hardwood)	Plantations other than pine (often Tasmanian blue gum)
urban area	A mix of vegetation and built surfaces (e.g. roads, gardens, houses, street trees)
built-up area	Dominated by built surfaces (e.g. roads, buildings)
disturbed ground or outcrop	Disturbed ground or outcrop (e.g. open-cut mines)
water unspecified	Open water bodies
no data or unclassified	Areas not classified (e.g. far out into marine areas or no data on all satellite inputs)

Table 4 Continuous layers used in production of the most likely layer

Land cover class	Land cover type	Continuous band	Continuous name
woody native vegetation	native vegetation	41	`treed_native`
woody native vegetation	native vegetation	43	`treed_native_roadside`
woody native vegetation	native vegetation	45	`treed_native_paddock`
woody native vegetation	native vegetation	47	`sheoke_KI`
woody native vegetation	native vegetation	49	`peppermintbox`
woody native vegetation	native vegetation	51	`salt_Pbark`
woody native vegetation	native vegetation	75	`native_shrublands`
mangrove vegetation	native vegetation	15	`mangrove`
non-woody native vegetation	native vegetation	99	`Grasslandpasture_native`

Land cover class	Land cover type	Continuous band	Continuous name
non-woody native vegetation	native vegetation	101	IronGrass
non-woody native vegetation	native vegetation	103	hummockGrass
saltmarsh vegetation	native vegetation	13	saltmarsh
wetland vegetation	native vegetation	81	land_vegetated_herb_wet
wetland vegetation	native vegetation	85	herb_wet_Native
wetland vegetation	native vegetation	87	herb_wet_Native_perennial
wetland vegetation	native vegetation	89	herb_wet_Native_occasional
wetland vegetation	native vegetation	91	herb_wet_native_occ_EPBC
wetland vegetation	native vegetation	93	gahnia
natural low cover	native vegetation	21	rock
natural low cover	native vegetation	23	sand
natural low cover	native vegetation	29	bareground
salt lake or saltpan	other	11	saline_lake
salt lake or saltpan	other	27	saltpan
dryland agriculture	non-native vegetation	97	herb_dry_crop
dryland agriculture	non-native vegetation	105	grasslandpasture_Not_native
exotic vegetation	non-native vegetation	59	pHalapensis
exotic vegetation	non-native vegetation	61	pradiata
exotic vegetation	non-native vegetation	69	windbreak
exotic vegetation	non-native vegetation	71	willows
exotic vegetation	non-native vegetation	77	woody_NotTreed_NotNative

Land cover class	Land cover type	Continuous band	Continuous name
irrigated non-woody	non-native vegetation	83	herb_wet_NotNative
orchards or vineyards	non-native vegetation	65	orchard
plantation (softwood)	non-native vegetation	57	plantation_pine
plantation (hardwood)	non-native vegetation	63	plantation_BlueGum
urban area	other	67	treed_NotNative_urban
built-up area	other	25	built
disturbed ground or outcrop	other	31	coal
disturbed ground or outcrop	other	33	disturbed
water unspecified	other	1	water
water unspecified	other	3	water_deep
water unspecified	other	5	marine_grass
water unspecified	other	7	marine_bareground
water unspecified	other	9	reef
no data or unclassified	no data/ unclassified	NA	NA

3.2.2 Validation of model inputs and outputs

The rule set for assembling the most likely layers from the continuous layers proceeded through several iterations where each set of outputs were evaluated for accuracy by project teams and regional stakeholders using available aerial imagery and local knowledge. Many land cover classes such as forestry and irrigated horticulture, along with spectrally distinct classes such as salt lakes and water were consistently well represented by the model. Classes with spectral similarity and/or overlapping definitions were not consistently well represented by the model. The less well represented classes were subject to post-processing rectification.

3.2.3 Post-processing

This section outlines briefly post-processing steps undertaken with the aim of increasing the accuracy of the most likely layers. More detailed methods, and other data handling procedures, are outlined by Thompson and Royal (2017).

3.2.3.1 Non-woody native vegetation

The most substantial post-processing was applied to non-woody native vegetation as visual inspection identified many instances of classification to non-woody native vegetation within areas that appeared to be dryland agriculture throughout the period 1990-2015 (visual inspection can be undertaken using resources such as https://earthengine.google.com/timelapse/). The over-estimation of non-woody native vegetation appeared to be most concerning in large areas of relatively flat broadacre farming. All most likely layer non-woody native vegetation pixels underwent further processing with a biophysical 'filter'. New continuous layers for each of the five continuous layers that make up dryland agriculture and non-woody native vegetation were built, using the original training points but using biophysical rather than landsat data as predictive layers.

There were five continuous layers (see Table 4) involved:

- `Grasslandpasture_native`, `IronGrass` and `hummockGrass` classed as non-woody native vegetation in the most likely layers
- `grasslandpasture_Not_native` and `herb_dry_crop` classed as dryland agriculture in the most likely layers

The process by which these were re-scaled to dampen non-woody native vegetation and boost dryland agriculture in the most likely layers was:

- run maxent (Phillips *et al.* 2006) using the original training points and several climate, topography and soils layers to create new biophysical-derived layers.
- multiply the original landsat-derived continuous layers by the new biophysical-derived continuous layer to create a new biophysical-and-landsat-informed continuous layer
- choose the most likely value from the new set of continuous layers for each of the original non-woody native vegetation pixels.

This process successfully decreased (but did not completely remove) over-estimation of non-woody native vegetation in the most likely layers, particularly at the expense of dryland agriculture. The biophysical layers used were:

- mean annual rainfall (Hijmans *et al.* 2005)
- mean annual temperature (Hijmans *et al.* 2005)
- topographic wetness index, TWI (CSIRO 2015)
- soil texture index, STI (CSIRO 2015)
- soil pH (CSIRO 2015)
- water observations from space (wofs) (Geoscience Australia 2015)

The two climate layers are self-explanatory. Hobbs *et al.* (2017) explain the derivation of the other layers, repeated in the following paragraphs.

TWI is a measure of soil wetness resulting from local water redistribution patterns (~3 km maximum radius), lower values represent drier water-shedding areas and higher values represent wetter run-on or flood out areas (CSIRO 2015). It does not represent water flowing into landscapes from major drainage lines where the catchment area is beyond the local 25 km^2 area.

STI is used to differentiate functional soil types (e.g. heavy clays through to deep sands). Data on the proportion of sand in the 0-15 cm, 15-30 cm, 30-60 cm, 60-100 cm soil profiles (CSIRO 2015) was used to create a continuous soil texture index for the upper 1m soil profile (rather than many discrete soil group classifications) using the formula:

$$STI_{0\text{-}100cm} = Sand_{0\text{-}15cm} \times Sand_{15\text{-}30cm} \times Sand_{30\text{-}60cm} \times Sand_{60\text{-}100cm}$$

The STI is weighted towards higher proportions of sand in uppermost soil layers (e.g. 0-15 cm layer represent 15% of the soil profile but contributes 25% of the index weight) which provides an ecological surrogate for increased rainfall absorption and lower runoff values from deeper sandy soils.

The average pH of soils for the upper 1 m soil profile was calculated from pH data (CSIRO 2015) in the 0-15 cm, 15-30 cm, 30-60 cm, 60-100 cm soil profiles using the formula:

$pH_{0\text{-}100cm} = (pH_{0\text{-}15cm} + pH_{15\text{-}30cm} + pH_{30\text{-}60cm} + pH_{60\text{-}100cm}) / 4$

The index is slightly weighted by the pH values in the uppermost soil layers (e.g. 0-15 cm layer represent 15% of the soil profile but contributes 25% of the index weight) to reflect its likely influence on plant species and the typically higher proportions of plant roots in upper soil layers.

The occurrence of water covering landscapes is readily identified by sensors on the Landsat satellite. Geoscience Australia (2015) has collated all imagery between 1987–2015, and calculated the percent of time any cell has water covering it into a 'water observations from space' or 'wofs' layer. While the return frequency of Landsat means that some short-term flooding events are not captured in this data, it does identify persistence or frequently water-covered areas.

3.2.3.2 Other post-processing

Besides the non-woody native vegetation post-processing, several other post-processing steps were undertaken:

- within the intertidal zone non-native land cover classes were converted to water unspecified (but native vegetation land cover classes in the intertidal and marine zone were kept) - termed 'intertidal reclass zone' in Figure 4
- within the pastoral zone and National Parks and Wildlife Act Reserves in the agricultural zone - termed 'pastoral plus reserves reclass zone' in Figure 4:
  - dryland agriculture pixels were converted to natural low cover (e.g. Figure 3)
  - irrigated non-woody pixels were converted to non-woody native vegetation
  - orchards/ vineyards pixels converted to woody native vegetation
- mangrove vegetation pixels were converted to woody native vegetation in areas more than 300 m from the coast. This occurred particularly along the River Murray - termed 'mangrove reclass zone' in Figure 4
- in areas outside the agricultural zone and not within a 1000 m buffer of built-up areas defined in Geoscience Australia (2016) - termed 'built-up area reclass zone' in Figure 4:
  - urban pixels were converted to woody native vegetation
  - built up pixels were converted to woody native vegetation.

This enabled clearly inappropriate classes to be globally rectified in the most likely layers. Figure 4 shows the boundaries used for each of the post-processing steps. Further refinement to these model limitations may occur in the future.

The most likely layers were clipped to the low water mark for analyses in this report. The approximate area across South Australia of the land cover classes in the most likely layers is given in Table 7.

3.2.4 Accuracy

Approximately 10% of the original training points were retained as 'test-points' to assess model performance (see Table 1). Generating kappa statistics from these test data suggests the most likely layers are between 88.48 % and 92.11 % better than might have been obtained by chance (Thompson and Royal 2017).

Table 5 gives the kappa statistic for the most likely layer in each epoch. Table 6 provides an example of how training points classed as non-woody native vegetation were misclassified into other classes across all epochs. Full confusion matrix, accuracy and kappa statistics per epoch are generated by Thompson and Royal (2017).

Table 5 Kappa statistic generated for each epoch in the most likely layers

Epoch	Years	kappa
1	1987-1990	0.898
2	1990-1995	0.918
3	1995-2000	0.885
4	2000-2005	0.912
5	2005-2010	0.921
6	2010-2015	0.905

Table 6 How points classed as non-woody native vegetation were originally classified (across all epochs)

Original classification	Count of points classified as non-woody native vegetation	Percent
woody native vegetation	320	5.59
mangrove vegetation	0	0.00
non-woody native vegetation	5142	89.90
saltmarsh vegetation	11	0.19
wetland vegetation	7	0.12
natural low cover	47	0.82
salt lake or saltpan	0	0.00
dryland agriculture	64	1.12
exotic vegetation	1	0.02
irrigated non-woody	34	0.59
orchards or vineyards	10	0.17
plantation (softwood)	0	0.00
plantation (hardwood)	0	0.00
urban area	4	0.07
built-up area	0	0.00
disturbed ground or outcrop	80	1.40
water unspecified	0	0.00

3.2.5 Land cover types

Each of the land cover classes were assigned to one of three land cover types (Table 7).

Table 7 Land cover classes in the most likely layer and their approximate area in South Australia

Land cover class	Land cover type	Hectares
woody native vegetation	native vegetation	10,421,000
mangrove vegetation	native vegetation	17,000
non-woody native vegetation	native vegetation	69,519,000
saltmarsh vegetation	native vegetation	35,000
wetland vegetation	native vegetation	242,000
natural low cover	native vegetation	6,683,000
salt lake or saltpan	other	1,740,000
dryland agriculture	non-native vegetation	8,525,000
exotic vegetation	non-native vegetation	12,000
irrigated non-woody	non-native vegetation	71,000
orchards or vineyards	non-native vegetation	55,000
plantation (softwood)	non-native vegetation	102,000
plantation (hardwood)	non-native vegetation	31,000
urban area	other	99,000
built-up area	other	8,000
disturbed ground or outcrop	other	382,000
water unspecified	other	151,000

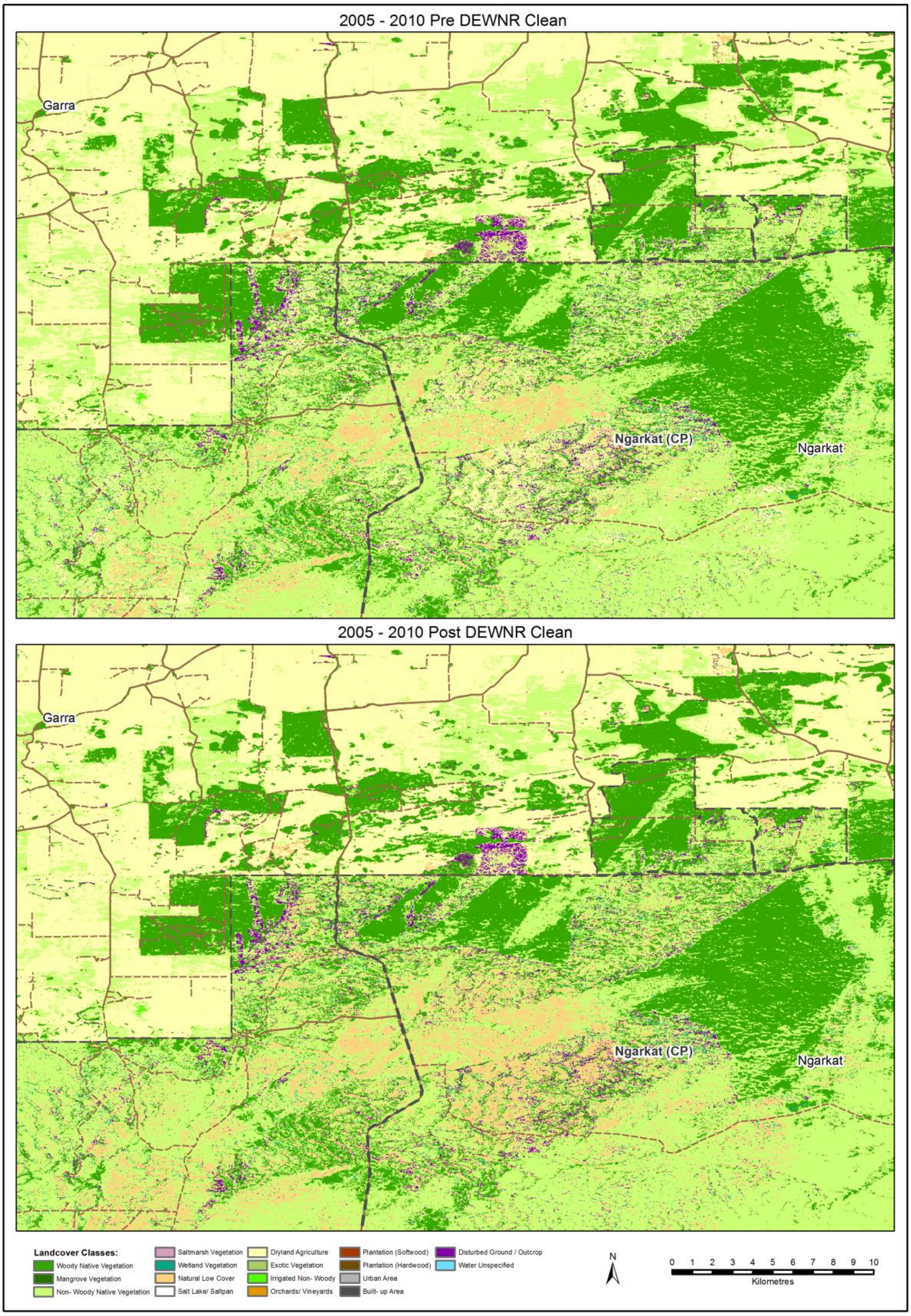

Figure 3 Example of post-processing reclassification from dryland agriculture to natural low cover in Ngarkat Conservation Park.

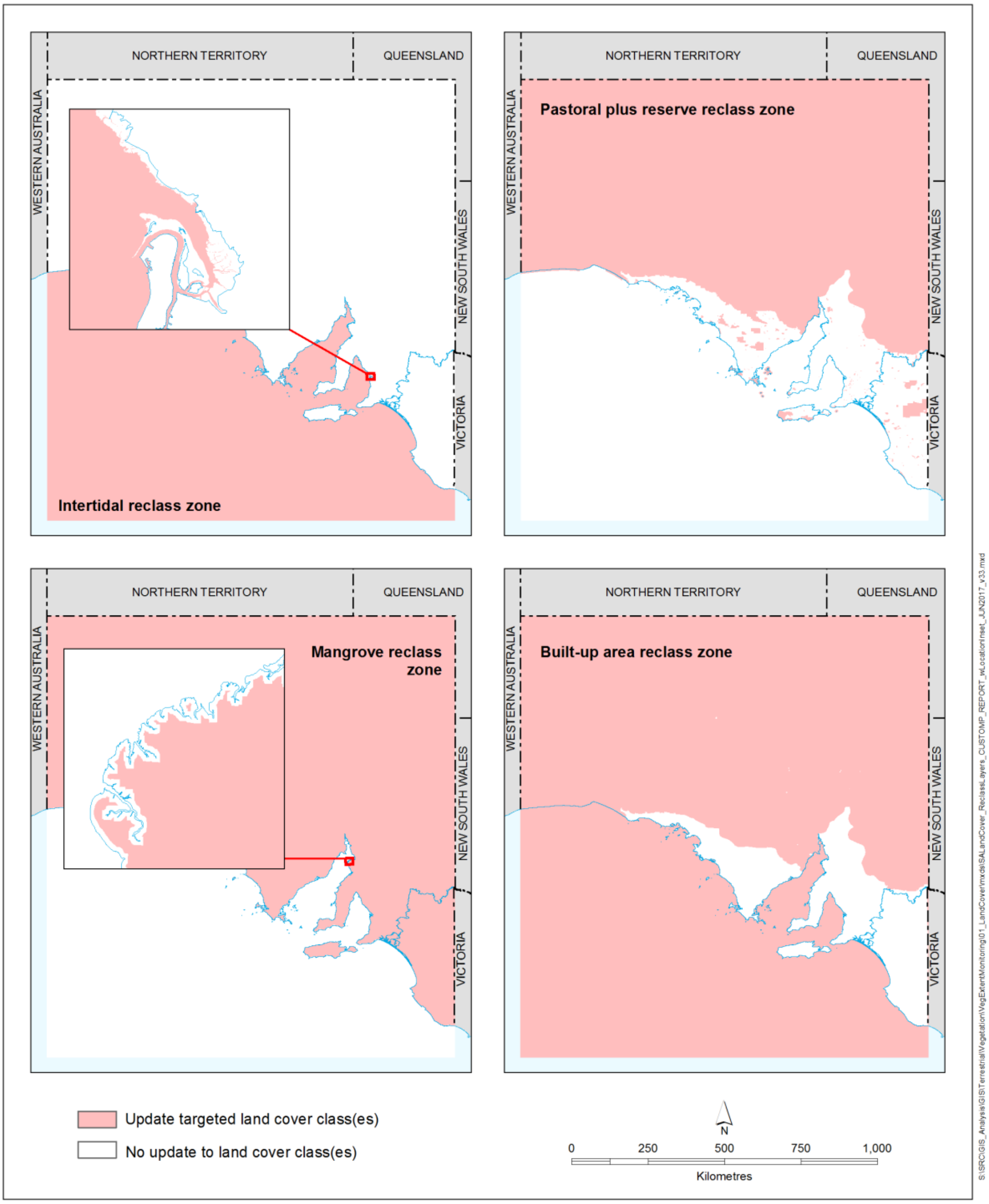

Figure 4 Zones over which post-processing reclassification occurred

3.3 Analysis

The methods used to analyse trends in the the most likely layers are deliberately simple as this is an introductory exploration of the potential of these data while still providing good indications of any trends in the data.

3.3.1 Per cent cover

Area summaries were generated at three spatial scales: whole-of-state, system ('arid', 'low-rainfall' agricultural and 'high-rainfall' agricultural), and natural resources management region (Table 8 defines systems based on natural resources management regions). At each of these scales the area of each land cover class in each epoch was determined (Table 1 defines the epochs). Figure (5) shows the natural resources management regions and their classification to each system.

Per cent cover statistics were calculated per epoch as the amount of a land cover class in an area × 100 / Total hectares of that area. Thus, per cent cover always refers to the percentage of a land cover class within a spatial area (not as a percentage of its value in 1990 or 2015).

To remove implausible variability visible in the per cent cover of some land cover classes (see Limitations), any per cent cover estimates were taken from Bayesian linear regression (see [trends]) through the data points rather than the points themselves. While this approach is an easily digestible method it does have some drawbacks:

- the sum of changes across land cover types or classes is unlikely to equal zero
- in some instances the trend in per cent cover of a land cover class is clearly non-linear (e.g. plantation (hardwood) on Kangaroo Island - see Figure 6)

In any instance where the regression model suggested negative per cent cover of a land cover class the estimate was instead set to zero.

Table 8 South Australian NRM regions including the abbreviations used throughout this document, assignation to agricultural or arid zones, total area in hectares and native vegetation per cent cover based on the previously used SAVeg (DEWNR 2017a)

NRM Region	NRM	System	Total Area (hectares)	SAVeg native vegetation per cent cover
Adelaide and Mt Lofty Ranges	AMLR	High-rainfall	663,000	13
Alinytjara Wilurara	AW	Arid	28,055,000	100
Eyre Peninsula	EP	Low-rainfall	5,175,000	46
Kangaroo Island	KI	High-rainfall	440,000	52
Northern and Yorke	NY	Low-rainfall	3,461,000	37
South Australian Arid Lands	SAAL	Arid	51,993,000	94

NRM Region	NRM	System	Total Area (hectares)	SAVeg native vegetation per cent cover
South Australian Murray-Darling Basin	SAMDB	Low-rainfall	5,626,000	53
South East	SE	High-rainfall	2,678,000	17

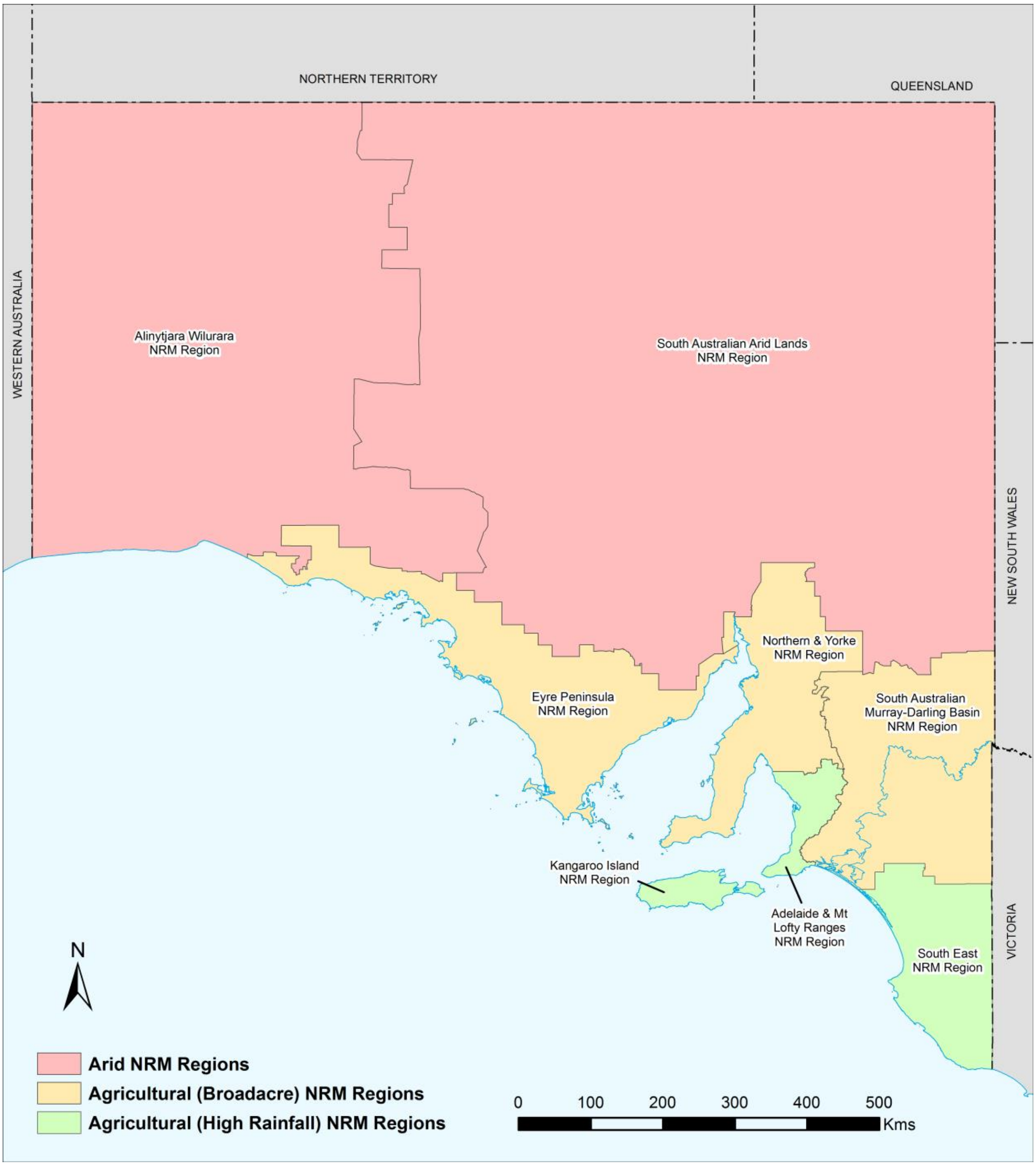

Figure 5 NRM regions and their classification as arid or agricultural zone

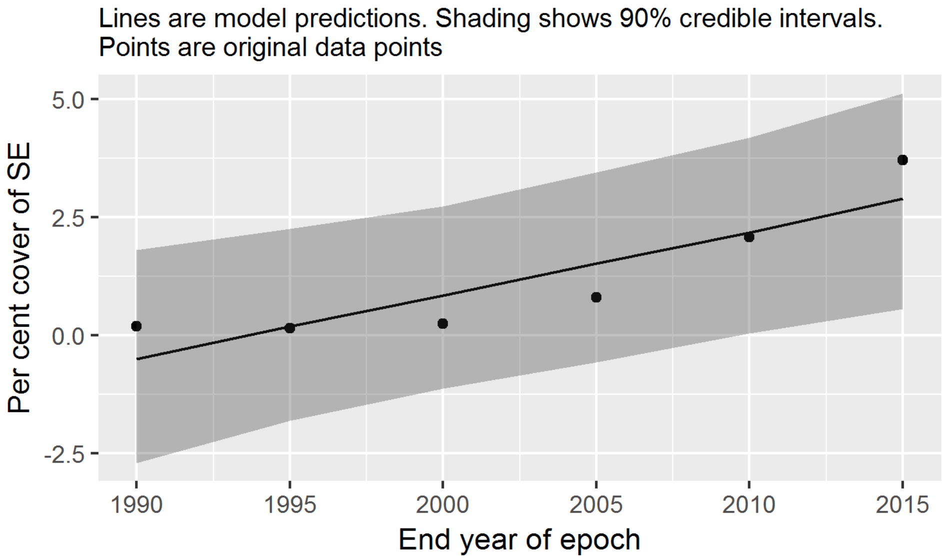

Figure 6 Example of poorly fitting linear model that suggests negative per cent cover of plantation (hardwood) on KI during the first epoch

3.3.2 Trend

At each level of the two spatial scales (whole-of-state, system and natural resource management region [8 levels]), Bayesian regression was used to test the effect of Epoch on land cover class per cent cover.

The following values were estimated from the posterior distribution resulting from the Bayesian analysis:

- slope
- value in the first and last epochs
- change between 1990 and 2015 (overall change)

Analyses were run using the rstanarm package (Stan Development Team 2016) in R (R Core Team 2017).

Confidence was assigned based on the likelihood of the slope being positive or negative. Where the likelihood reached: 90% the confidence was considered 'good'; 80% the confidence was considered 'moderate'; and any values below 80% then confidence was considered 'low'.

3.3.3 Condition

Native vegetation per cent cover in 2015, at each scale (whole-of-state, zone and natural resources management region), was classified to one of several condition classes. The thresholds for each class were based on the work of, particularly, McIntyre and Hobbs (1999; 2000) but also others (e.g. Andrén 1994; Radford and Bennett 2004; Radford *et al.* 2005), as follows:

- Intact: >90% remaining native vegetation. Generally low modification of remaining habitat with high levels of connectivity

- Variegated: 60-90% remaining native vegetation. Low to high levels of modification of remaining habitat with generally high levels of connectivity but species sensitive to habitat modification may experience fragmentation
- Fragmented: 10-60% remaining native vegetation. Low to high levels of modification of remaining habitat with generally low levels of connectivity but mobile species may still experience high levels of connectivity
- Relictual: less than 10% remaining native vegetation. Highly modified remaining habitat with no to low connectivity of remaining habitat.

3.3.4 Native vegetation in protected areas

Native vegetation in protected areas was calculated by overlaying the Collaborative Australian Protected Area Database (CAPAD) for 2016 (DoEE 2016) with the 2015 most likely layer using land cover types (native vegetation, non-native vegetation and other). Protected areas in CAPAD include:

- Conservation Park
- Conservation Reserve
- Forest Reserve
- Game Reserve
- Heritage Agreement
- Indigenous Protected Area
- National Park
- National reserve systems addition - gazettal in progress
- Private Nature Reserve
- Recreation Park
- Regional Reserve
- Wilderness Protection Area

3.4 SAVeg

Until the availability of the SA Land Cover Layers 1987–2015, native vegetation per cent cover was determined from the Native Vegetation Floristic Areas mapping for South Australia, also known as 'SAVeg' (DEWNR 2017a). SAVeg native vegetation per cent cover was calculated as the area of native vegetation according to SAVeg within each natural resources management region × 100 / Total area of that natural resources management region. Water bodies were excluded from these calculations.

Comparisons of native vegetation per cent cover made with SAVeg against those made with the SA land cover layers were only undertaken at the scale of natural resources management regions.

3.5 Software

In keeping with the Premier's digital by default declaration this report has been generated using open data, public licence software and reproducible research tools. This report and the information on the associated report card were prepared using R (R Core Team 2017), RStudio (RStudio Team 2016) and rmarkdown (Allaire *et al.* 2017). The R packages used in the creation of this report and report card are given in Table 9.

Table 9 R (R Core Team 2017) packages used in the production of this report

Package	Citation
bookdown	Xie (2016)
broom	Robinson (2017)
forcats	Wickham (2017a)
gridExtra	Auguie (2016)
knitr	Xie (2017)
modelr	Wickham (2017b)
readxl	Wickham and Bryan (2017)
rgdal	Bivand *et al.* (2017)
rstan	Guo *et al.* (2017)
rstanarm	Gabry and Goodrich (2017)
scales	Wickham (2016)
tidyverse	Wickham (2017c)

4 Results

These results are presented by land cover type (native vegetation, non-native vegetation and other) and then the 18 land cover classes at each scale and alphabetically within each scale, thus: State, Arid, High-rainfall, Low-rainfall, AMLR, AW, EP, KI, NY, SAAL, SAMDB and SE.

4.1 Whole-of-state

4.1.1 Land cover type

Figure 7 shows the results of trend analyses for land cover types in South Australia. The Appendix has more detail on results from the per cent cover trend analysis (Table 12).

In 2015, 88.35% of South Australia was native vegetation. Between 1990 and 2015 native vegetation per cent cover has been decreasing across South Australia. The estimated loss of 497,616 ha (0.51% of the area of South Australia) over that period had good confidence.

In 2015, the land cover type non-native vegetation covered 9.21% of South Australia. Between 1990 and 2015 non-native vegetation per cent cover has been increasing across South Australia. The estimated gain of 482,660 ha (0.49% of the area of South Australia) over that period had good confidence.

Based on these data, the condition of native vegetation per cent cover in South Australia was variegated in 2015.

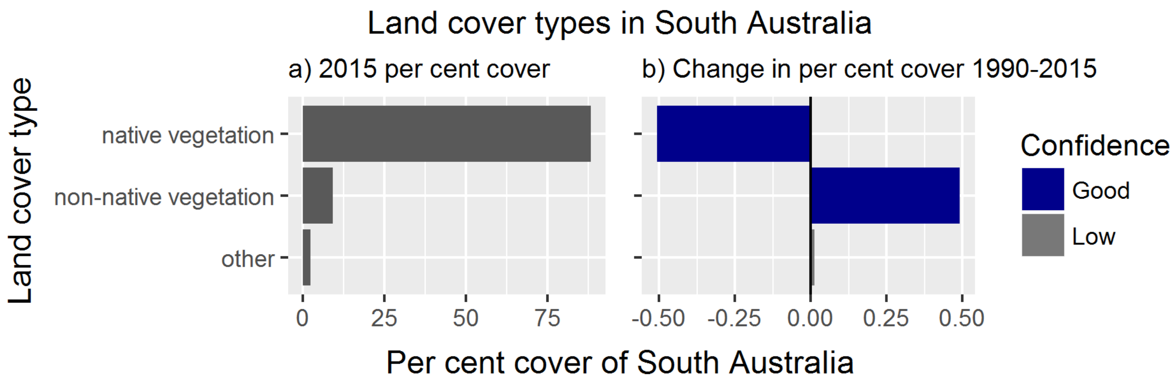

Figure 7 Per cent cover of types in South Australia

4.1.2 Land cover class

In 2015 the dominant land cover class(es) in South Australia were non-woody native vegetation (70.43%), woody native vegetation (10.88%), dryland agriculture (8.85%) and natural low cover (6.76%) (Figure 8a). The Appendix has more detail on results from the per cent cover trend analysis (Table 13), including a plot of the regressions for each land cover class (Figure 50).

Across South Australia, non-woody native vegetation was the land cover class that changed the most between 1990 and 2015, with a decrease of approximately 0.91% of South Australia or about 890,010 hectares.

Figure 8b shows change in each land cover class as a per cent of South Australia. Between 1990 and 2015 the most significantchanges in land cover in South Australia (with some confidence or better) occurred in the classes non-woody native vegetation (-0.91%), woody native vegetation (0.5%) and dryland agriculture (0.31%). The amount that each land cover class contributed to these changes are presented in Figure 9. Note that Figure 9 uses only the single data points in 1990 and 2015 and thus will not necessarily indicate the same quantity of change given in (Table 13).

The large change observed in natural low cover was too variable to have confidence in the overall pattern.

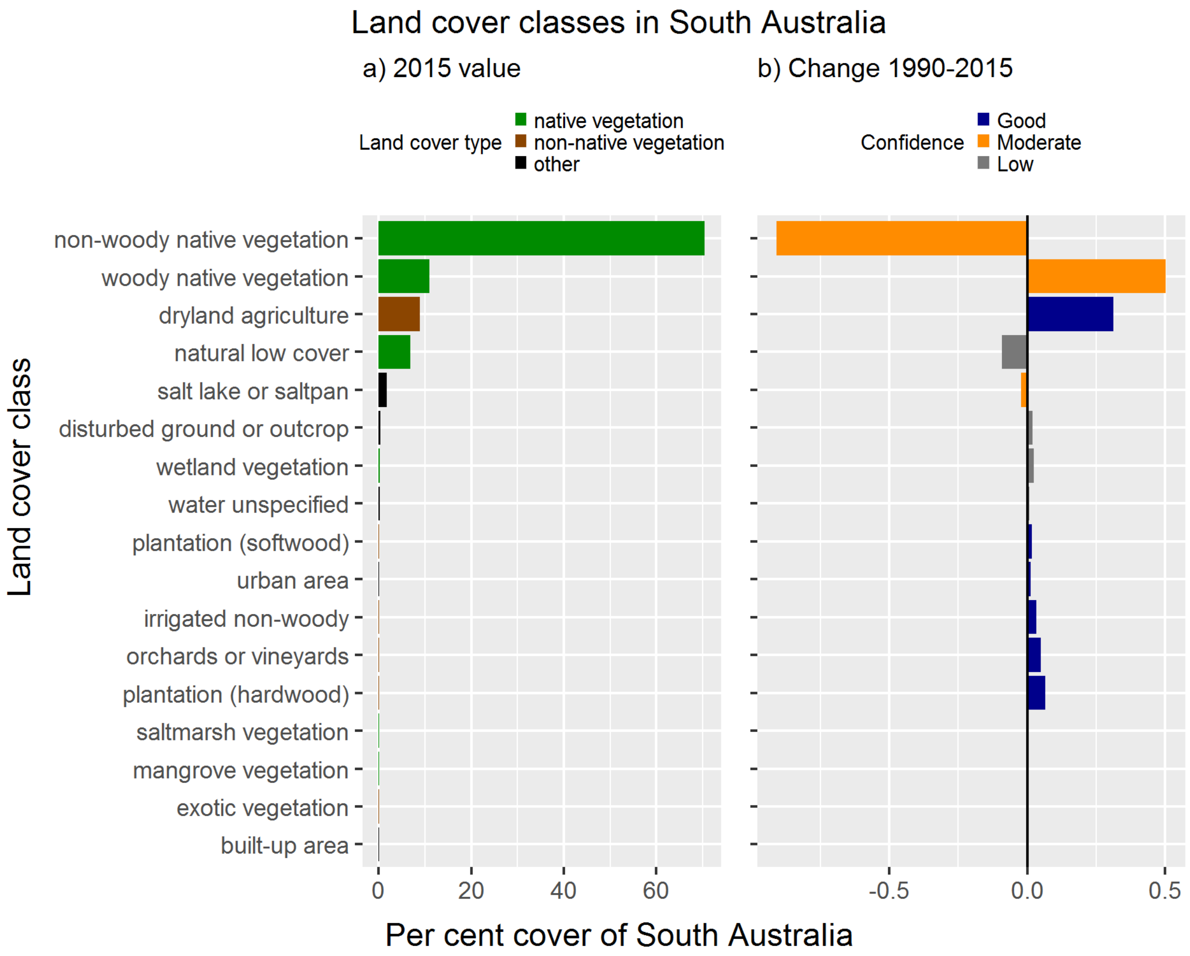

Figure 8 Per cent cover of classes in South Australia: a) as at 2015, and b) change between 1990 and 2015

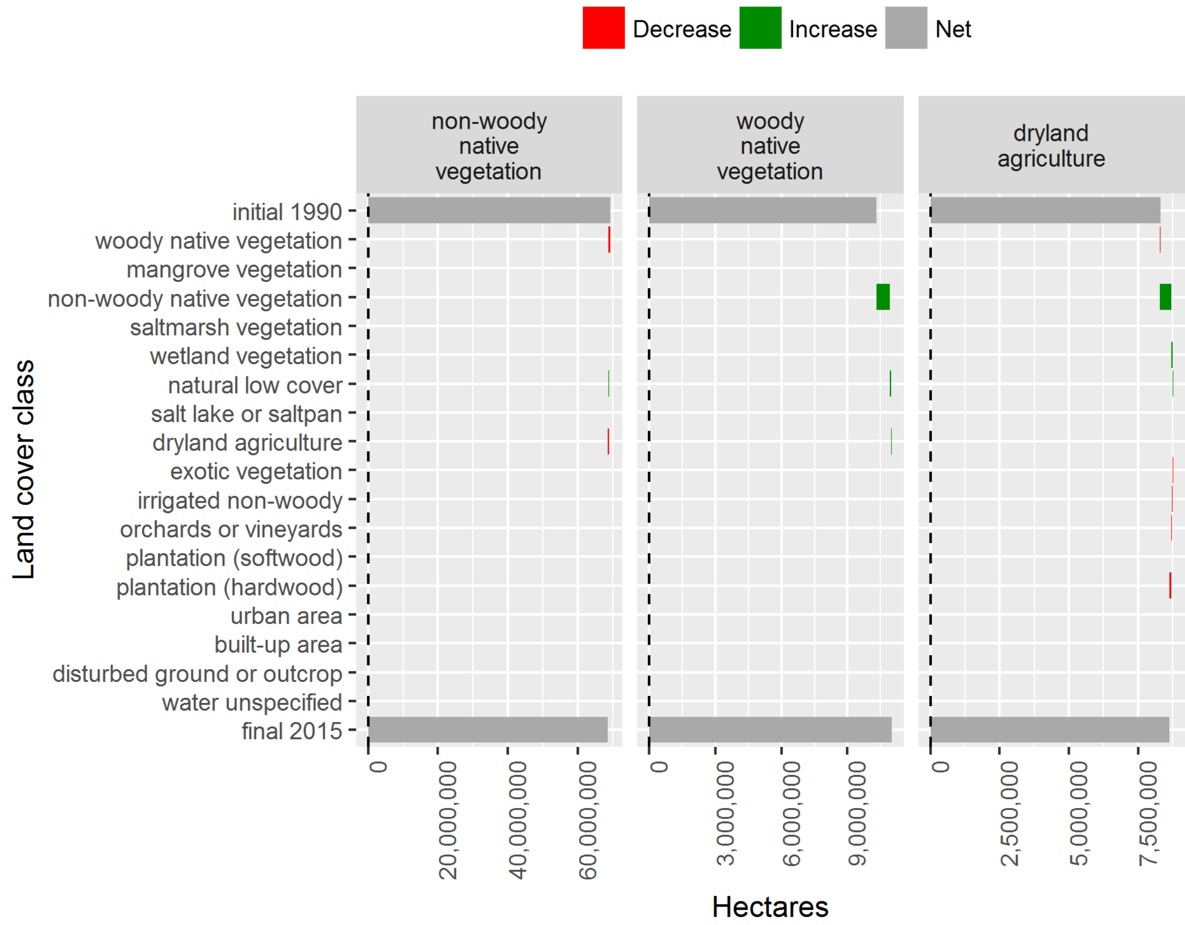

Figure 9 Large changes in land cover classes non-woody native vegetation (-0.91%), woody native vegetation (0.5%) and dryland agriculture (0.31%) in South Australia - contributions to change

4.2 High-rainfall system

4.2.1 Land cover type

Figure 10 shows the results of trend analyses for land cover types in the high-rainfall system. The Appendix has more detail on results from the per cent cover trend analysis (Table 14).

In 2015, 34.71% of the high-rainfall system was native vegetation. Between 1990 and 2015 native vegetation per cent cover has been stable across the high-rainfall system. The estimated loss of 101,266 ha (2.68% of the area of the high-rainfall system) over that period had moderate confidence.

In 2015, the land cover type non-native vegetation covered 61.59% of the high-rainfall system. Between 1990 and 2015 non-native vegetation per cent cover has been increasing across the high-rainfall system. The estimated gain of 94,887 ha (2.51% of the area of the high-rainfall system) over that period had good confidence.

Based on these data, the condition of native vegetation per cent cover in the high-rainfall system was fragmented in 2015.

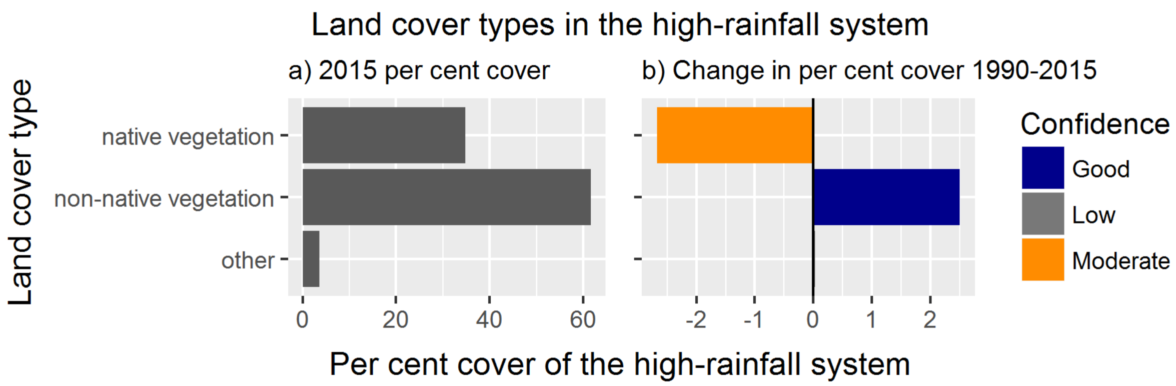

Figure 10 Per cent cover of types in the high-rainfall system

4.2.2 Land cover class

In 2015 the dominant land cover class(es) in the high-rainfall system were dryland agriculture (54.2%), woody native vegetation (23.08%), non-woody native vegetation (7.96%) and plantation (softwood) (2.84%) (Figure 11a). The Appendix has more detail on results from the per cent cover trend analysis (Table 15), including a plot of the regressions for each land cover class (Figure 51).

Figure 11b shows change in each land cover class as a per cent of the high-rainfall system. Between 1990 and 2015 the most significantchanges in land cover in the high-rainfall system (with some confidence or better) occurred in the classes plantation (hardwood) (1.63%), wetland vegetation (-1.22%) and irrigated non-woody (0.97%). Large changes were observed in non-woody native vegetation and dryland agriculture although changes in the cover of these classes through time were too variable to have confidence in the overall pattern.

Across the high-rainfall system, plantation (hardwood) was the land cover class that changed the most between 1990 and 2015, with an increase of approximately 1.63% of the high-rainfall system or about 61,640 hectares.

The amount that each land cover class contributed to the large changes in land cover classes is shown in Figure 12. Note that Figure 12 uses only the single data points in 1990 and 2015 and thus will not necessarily indicate the same quantity of change given in Table 15.

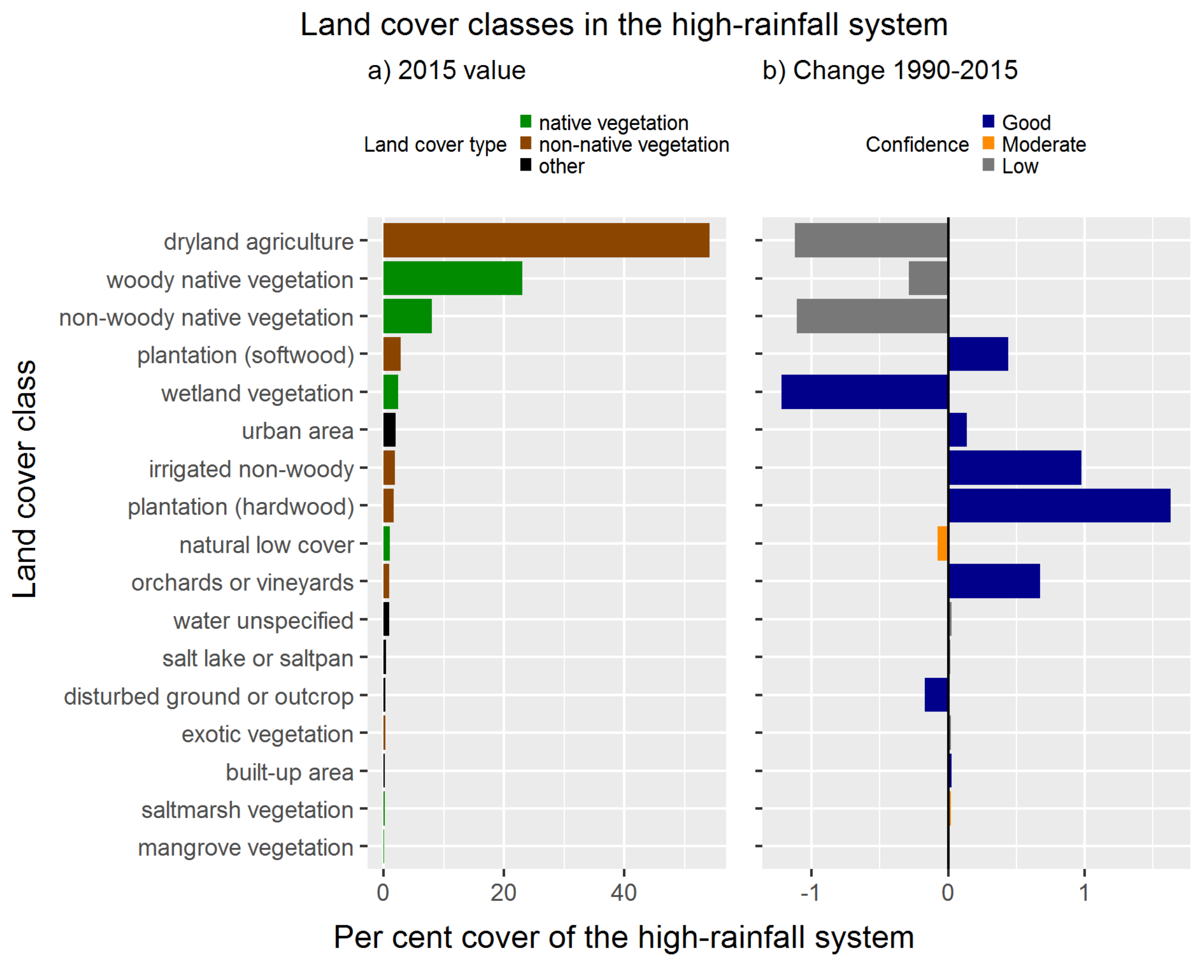

Figure 11 Per cent cover of classes in the high-rainfall system: a) as at 2015, and b) change between 1990 and 2015

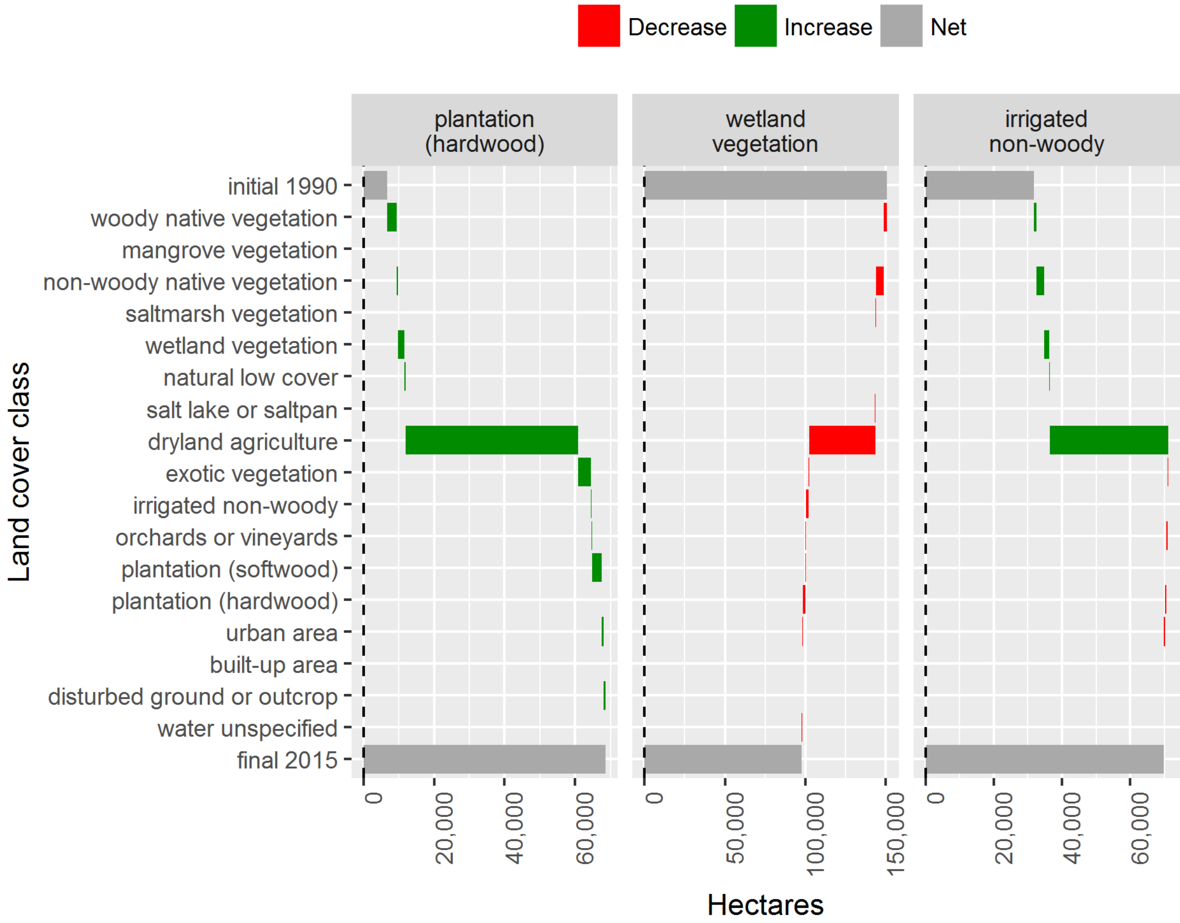

Figure 12 Large changes in land cover classes plantation (hardwood) (1.63%), wetland vegetation (-1.22%) and irrigated non-woody (0.97%) in the high-rainfall system - contributions to change

4.3 Low-rainfall system

4.3.1 Land cover type

Figure 13 shows the results of trend analyses for land cover types in the low-rainfall system. The Appendix has more detail on results from the per cent cover trend analysis (Table 16).

In 2015, 51.52% of the low-rainfall system was native vegetation. Between 1990 and 2015 native vegetation per cent cover has been decreasing across the low-rainfall system. The estimated loss of 383,843 ha (2.69% of the area of the low-rainfall system) over that period had good confidence.

In 2015, the land cover type non-native vegetation covered 46.96% of the low-rainfall system. Between 1990 and 2015 non-native vegetation per cent cover has been increasing across the low-rainfall system. The estimated gain of 383,950 ha (2.69% of the area of the low-rainfall system) over that period had good confidence.

Based on these data, the condition of native vegetation per cent cover in the low-rainfall system was fragmented in 2015.

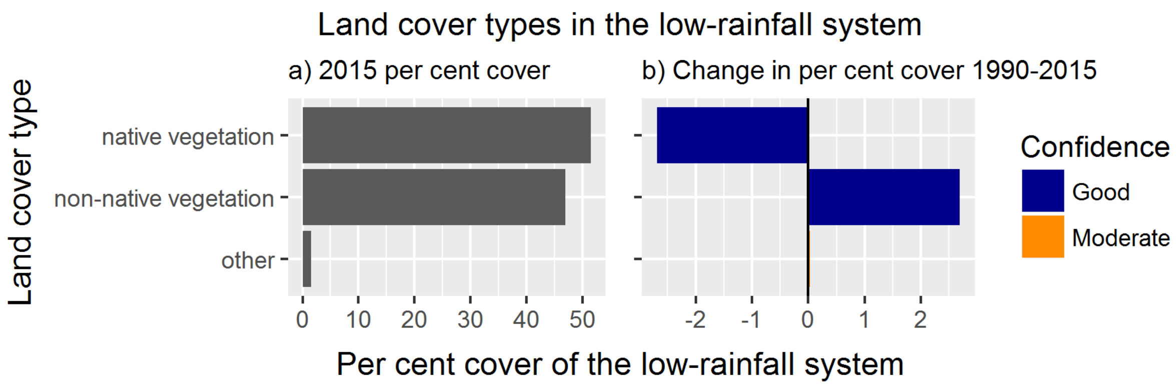

Figure 13 Per cent cover of types in the low-rainfall system

4.3.2 Land cover class

In 2015 the dominant land cover class(es) in the low-rainfall system were dryland agriculture (46.47%), woody native vegetation (25.7%), non-woody native vegetation (23.18%) and natural low cover (2.03%) (Figure 14a). The Appendix has more detail on results from the per cent cover trend analysis (Table 17), including a plot of the regressions for each land cover class (Figure 52).

Figure 14b shows change in each land cover class as a per cent of the low-rainfall system. Between 1990 and 2015 the most significantchanges in land cover in the low-rainfall system (with some confidence or better) occurred in the classes non-woody native vegetation (-4.38%), dryland agriculture (2.49%) and woody native vegetation (1.7%). The variability in each individual land cover class was small enough that there was at least some confidence in any large overall change.

An example of loss of non-woody native vegetation to dryland agriculture between the first and the last epoch is provided in Figure 15.

The amount that each land cover class contributed to the large changes in land cover classes is shown in Figure 16. Note that Figure 16 uses only the single data points in 1990 and 2015 and thus will not necessarily indicate the same quantity of change given in Table 17.

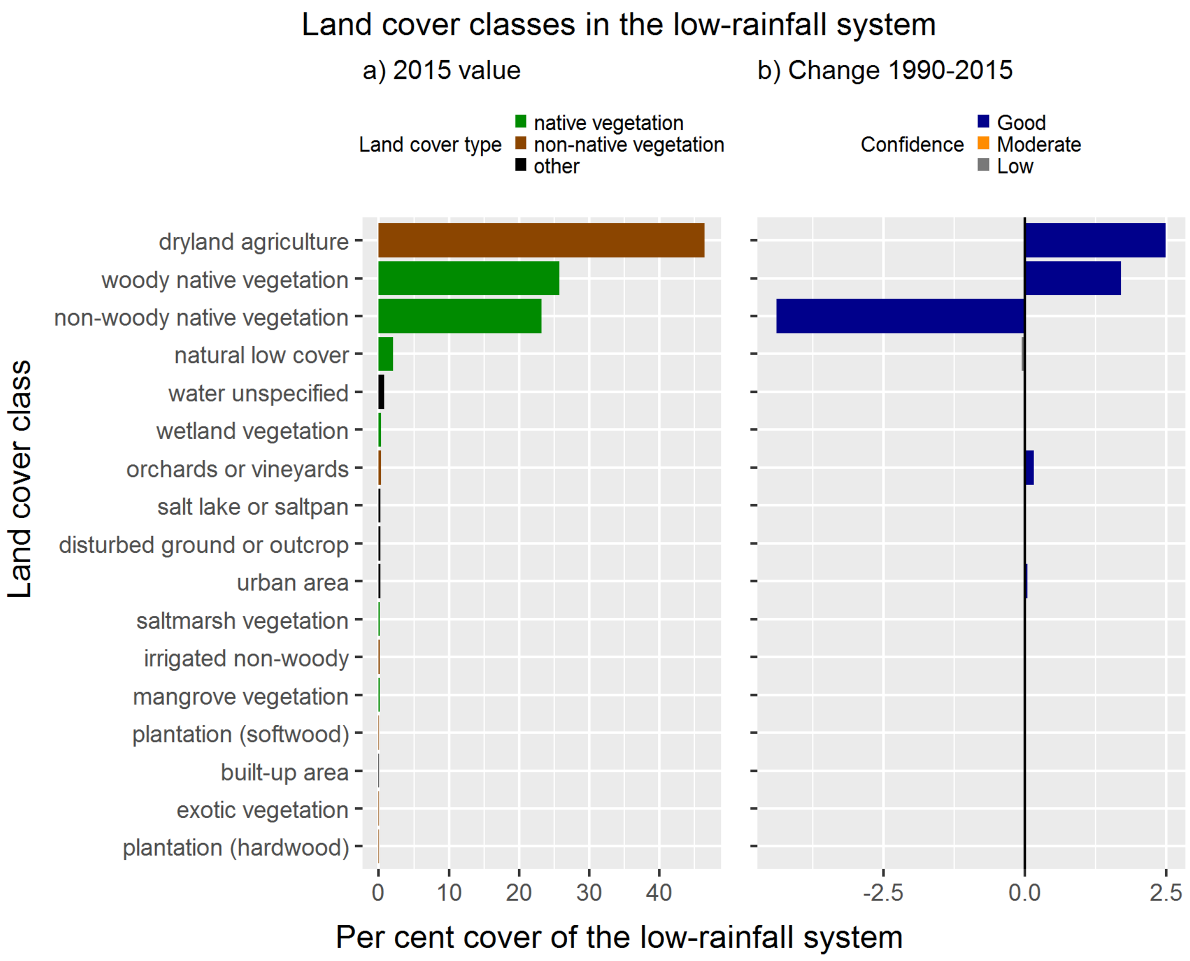

Figure 14 Per cent cover of classes in the low-rainfall system: a) as at 2015, and b) change between 1990 and 2015

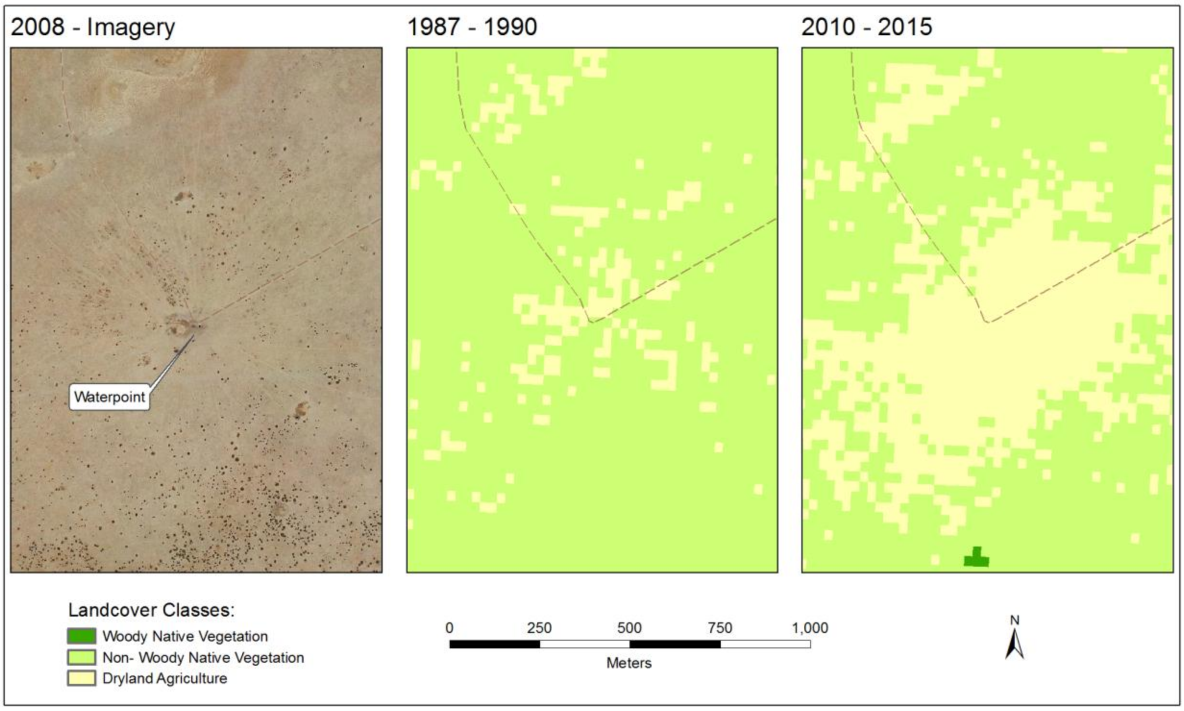

Figure 15 An example of the most likely layers suggesting change from non-woody native vegetation to dryland agriculture - in this case surrounding a water point - between the first and the last epoch

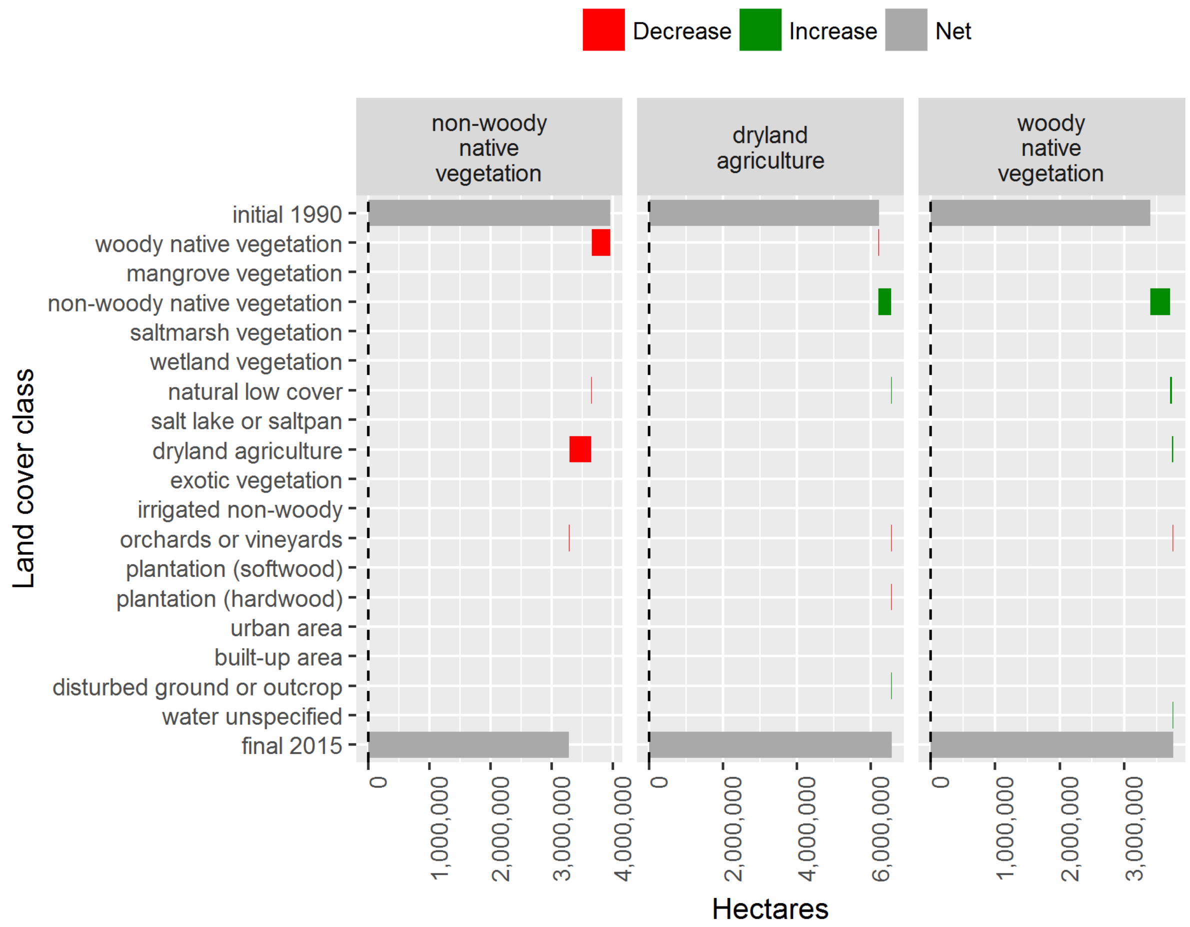

Figure 16 Large changes in land cover classes non-woody native vegetation (-4.38%), dryland agriculture (2.49%) and woody native vegetation (1.7%) in the low-rainfall system - contributions to change

4.4 Arid system

4.4.1 Land cover type

Figure 17 shows the results of trend analyses for land cover types in the arid system. The Appendix has more detail on results from the per cent cover trend analysis (Table 18).

In 2015, 97.45% of the arid system was native vegetation. Between 1990 and 2015 native vegetation per cent cover has been stable across the arid system. The estimated loss of 9,378 ha (0.01% of the area of the arid system) over that period had low confidence.

In 2015, the land cover type non-native vegetation covered 0.01% of the arid system. Between 1990 and 2015 non-native vegetation per cent cover has been stable across the arid system. The estimated gain of 824 ha (0% of the area of the arid system) over that period had low confidence.

Based on these data, the condition of native vegetation per cent cover in the arid system was intact in 2015.

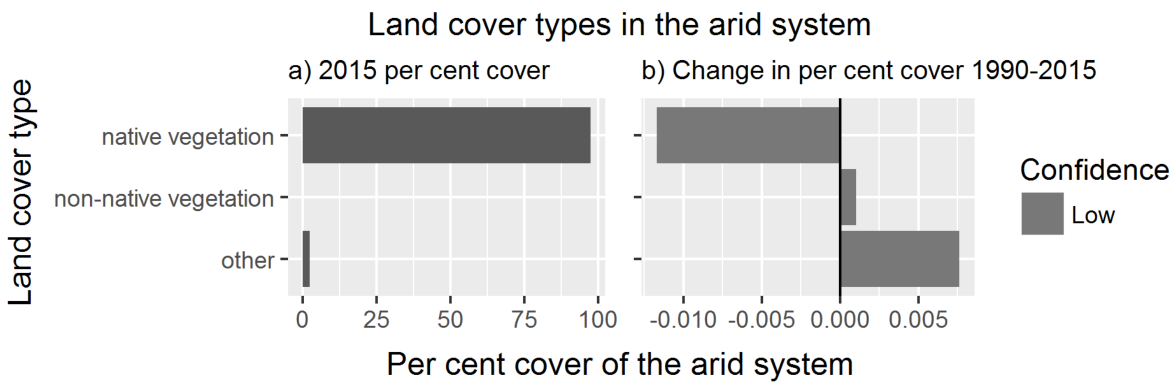

Figure 17 Per cent cover of types in the arid system

4.4.2 Land cover class

In 2015 the dominant land cover class(es) in the arid system were non-woody native vegetation (81.75%), natural low cover (7.87%) and woody native vegetation (7.64%) (Figure 18a). The Appendix has more detail on results from the per cent cover trend analysis (Table 19), including a plot of the regressions for each land cover class (Figure 53).

Figure 18b shows change in each land cover class as a per cent of the arid system. Between 1990 and 2015 the most significantchange in land cover in the arid system (with some confidence or better) occurred in the class woody native vegetation (0.33%). Large changes were observed in non-woody native vegetation and natural low cover although changes in the cover of these classes through time were too variable to have confidence in the overall pattern.

The large fluctuations in land cover classes, leading to low confidence in any overall trends, reinforces the dynamic nature of the arid zone of South Australia.

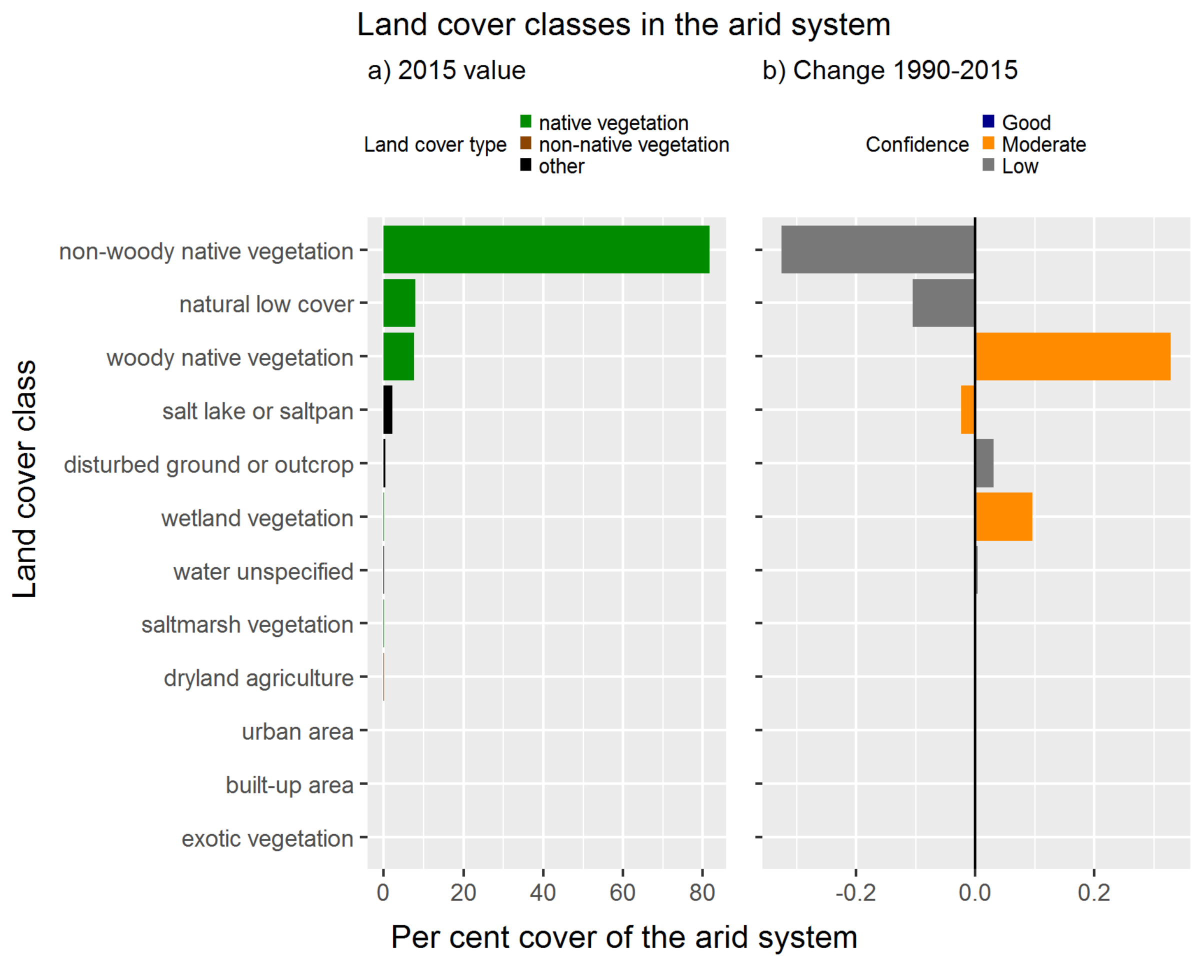

Figure 18 Per cent cover of classes in the arid system: a) as at 2015, and b) change between 1990 and 2015

4.5 Adelaide and Mount Lofty Ranges Natural Resources Management Region

4.5.1 Land cover type

Figure 19 shows the results of trend analyses for land cover types in the AMLR NRM Region. The Appendix has more detail on results from the per cent cover trend analysis (Table 20).

In 2015:

- 32% of the AMLR NRM Region was native vegetation. Between 1990 and 2015 native vegetation per cent cover has been decreasing across the AMLR NRM Region. The estimated loss of 14,009 ha (2.11% of the area of the AMLR NRM Region) over that period had good confidence.
- the land cover type non-native vegetation covered 56.16% of the AMLR NRM Region. Between 1990 and 2015 non-native vegetation per cent cover has been stable across the AMLR NRM Region. The estimated gain of 7,639 ha (1.15% of the area of the AMLR NRM Region) over that period had moderate confidence.
- the land cover type 'other' covered 11.8% of the AMLR NRM Region. Between 1990 and 2015 other per cent cover has been increasing across the AMLR NRM Region. The estimated gain of 5,705 ha (0.86% of the area of the AMLR NRM Region) over that period had good confidence.

Based on these data, the condition of native vegetation per cent cover in the AMLR NRM Region was fragmented in 2015.

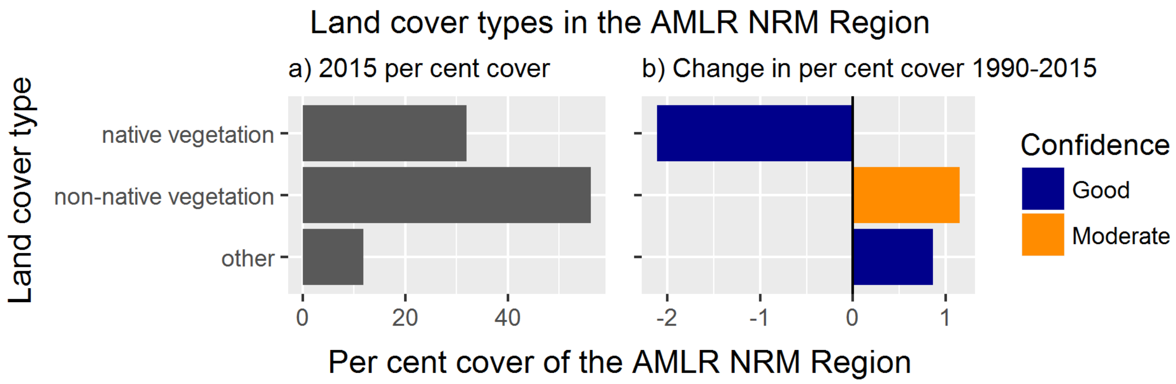

Figure 19 Per cent cover of types in the AMLR NRM Region

4.5.2 Land cover class

In 2015 the dominant land cover class(es) in the AMLR NRM Region were dryland agriculture (49.66%), woody native vegetation (26.86%), urban area (9.44%) and orchards or vineyards (2.73%) (Figure 20a). The Appendix has more detail on results from the per cent cover trend analysis (Table 21), including a plot of the regressions for each land cover class (Figure 54).

Figure 20b shows change in each land cover class as a per cent of the AMLR NRM Region. Between 1990 and 2015 the most significantchanges in land cover in the AMLR NRM Region (with some confidence or better) occurred in the classes non-woody native vegetation (-2.32%), orchards or vineyards (1.94%) and dryland agriculture (-1.76%). The variability in each individual land cover class was small enough that there was at least some confidence in any large overall change.

Across the AMLR NRM Region, non-woody native vegetation was the land cover class that changed the most between 1990 and 2015, with a decrease of approximately 2.32% of the AMLR NRM Region or about 15,370 hectares.

As can be seen in Figure 21, parts of the AMLR NRM Region have seen changes in land cover, particularly non-woody native vegetation (-2.32%), orchards or vineyards (1.94%) and dryland agriculture (-1.76%), between the first and last epoch.

The amount that each land cover class contributed to the large changes in land cover classes is shown in Figure 22. Note that Figure 22 uses only the single data points in 1990 and 2015 and thus will not necessarily indicate the same quantity of change given in Table 21.

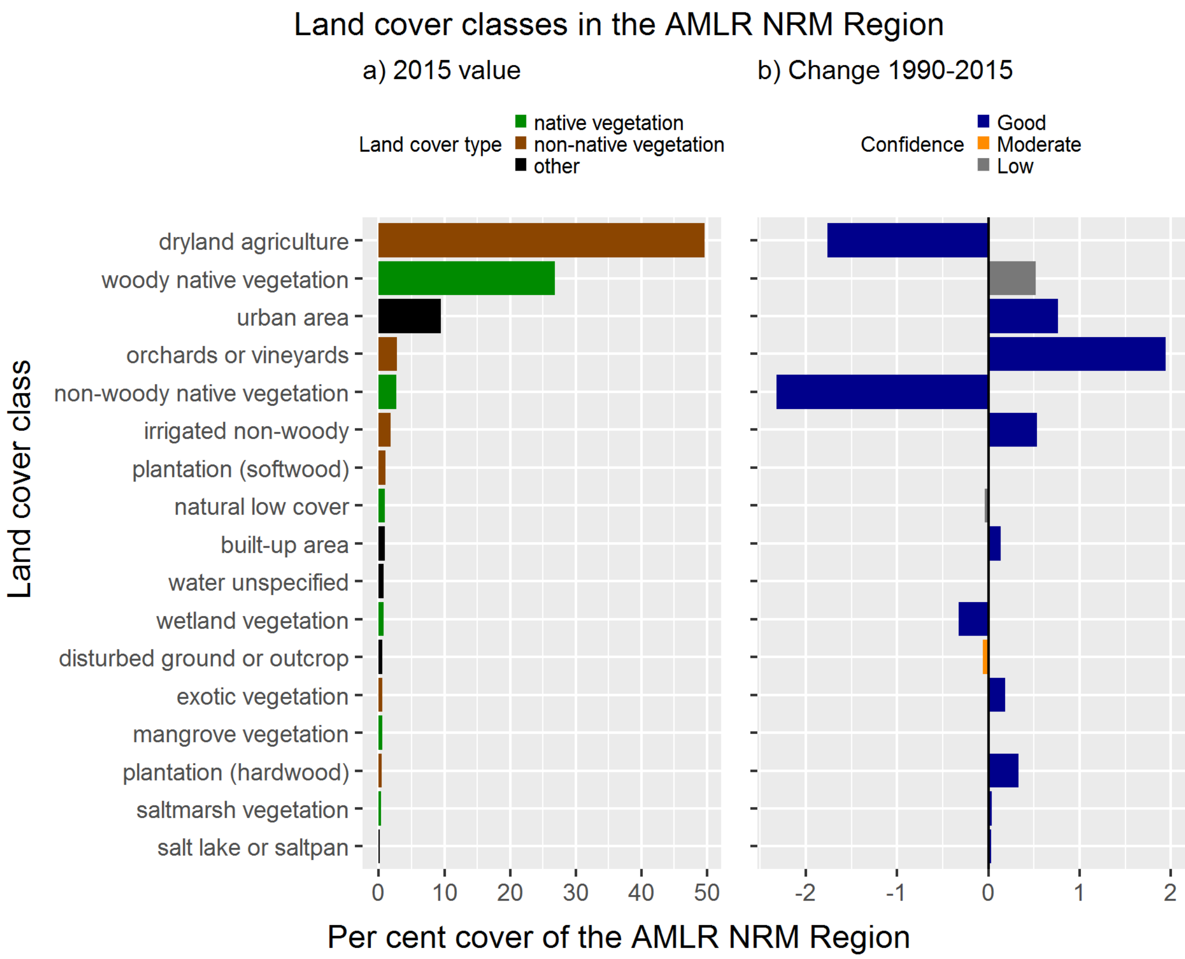

Figure 20 Per cent cover of classes in the AMLR NRM Region: a) as at 2015, and b) change between 1990 and 2015

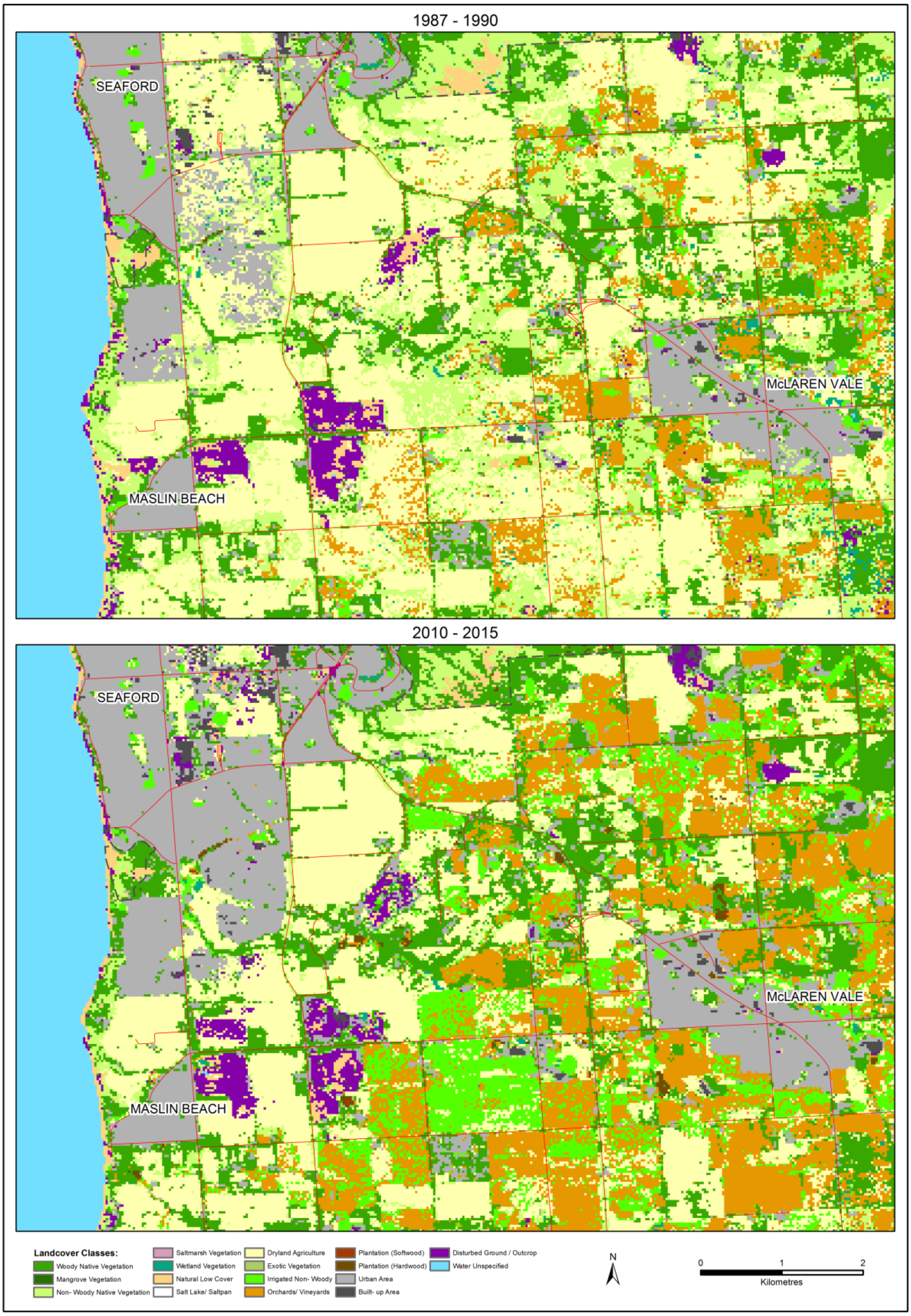

Figure 21 The most likely land cover classes for a small area of the the AMLR NRM Region, in the first and last epochs. The large land cover changes are visible (i.e. changes in non-woody native vegetation (-2.32%), orchards or vineyards (1.94%) and dryland agriculture (-1.76%))

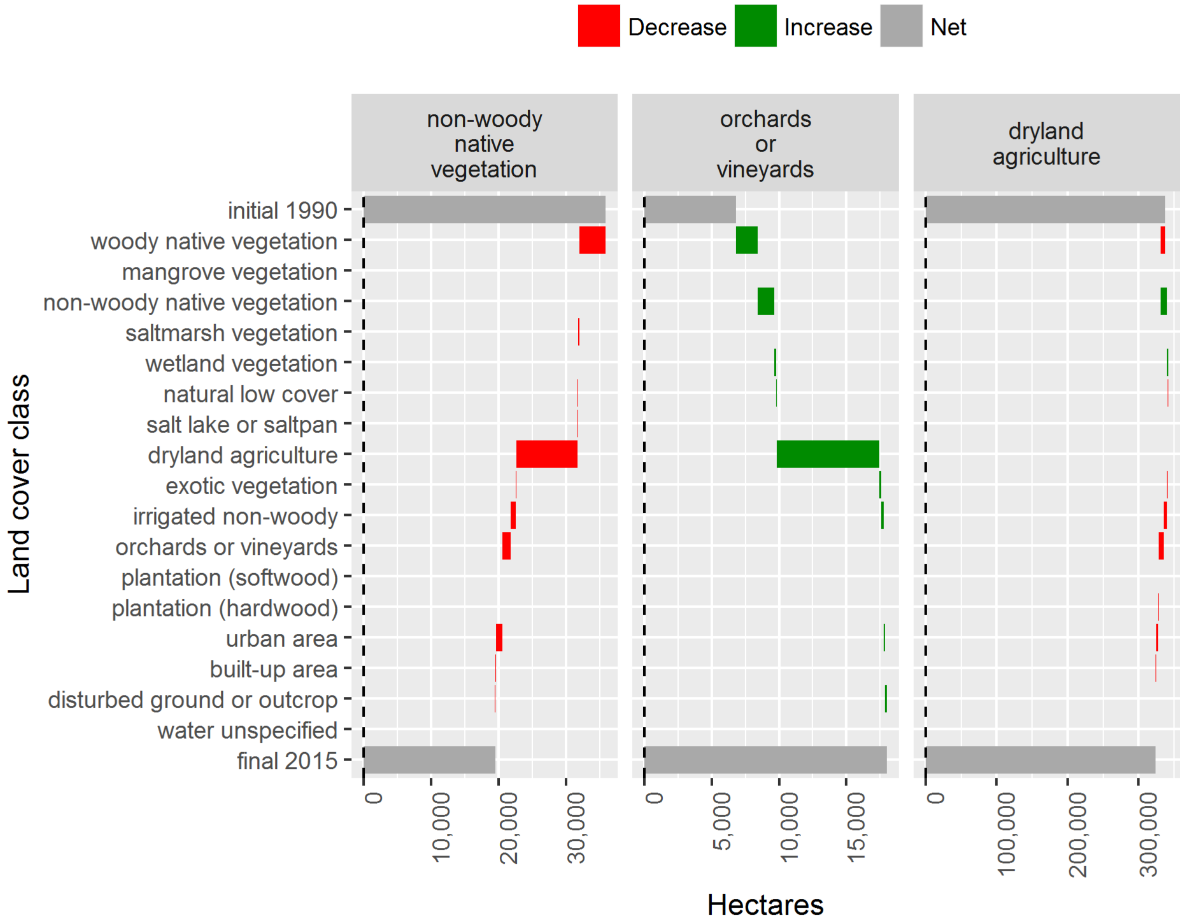

Figure 22 Large changes in land cover classes non-woody native vegetation (-2.32%), orchards or vineyards (1.94%) and dryland agriculture (-1.76%) in the AMLR NRM Region - contributions to change

4.6 Alinytjara Wilurara Natural Resources Management Region

4.6.1 Land cover type

Figure 23 shows the results of trend analyses for land cover types in the AW NRM Region. The Appendix has more detail on results from the per cent cover trend analysis (Table 22).

In 2015:

- 99.64% of the AW NRM Region was native vegetation. Between 1990 and 2015 native vegetation per cent cover has been decreasing across the AW NRM Region. The estimated loss of 15,065 ha (0.05% of the area of the AW NRM Region) over that period had good confidence.
- the land cover type non-native vegetation covered 0.01% of the AW NRM Region. Between 1990 and 2015 non-native vegetation per cent cover has been stable across the AW NRM Region. The estimated loss of 26 ha (0% of the area of the AW NRM Region) over that period had low confidence.

- the land cover type 'other' covered 0.35% of the AW NRM Region. Between 1990 and 2015 other per cent cover has been increasing across the AW NRM Region. The estimated gain of 15,480 ha (0.06% of the area of the AW NRM Region) over that period had good confidence.

Based on these data, the condition of native vegetation per cent cover in the AW NRM Region was intact in 2015.

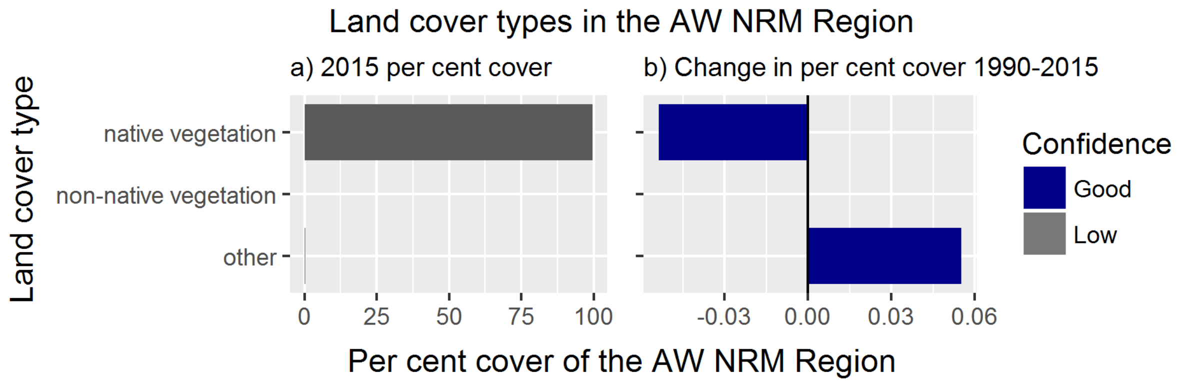

Figure 23 Per cent cover of types in the AW NRM Region

4.6.2 Land cover class

In 2015 the dominant land cover class(es) in the AW NRM Region were non-woody native vegetation (84.22%) and woody native vegetation (13.18%) (Figure 24a). The Appendix has more detail on results from the per cent cover trend analysis (Table 23), including a plot of the regressions for each land cover class (Figure 55).

Figure 24b shows change in each land cover class as a per cent of the AW NRM Region. Between 1990 and 2015 the most significantchanges in land cover in the AW NRM Region (with some confidence or better) occurred in the classes non-woody native vegetation (-0.45%) and salt lake or saltpan (0.04%). The large change observed in woody native vegetation was too variable to have confidence in the overall pattern.

As for the arid zone as a whole, large fluctuations in land cover classes in the AW NRM Region led to low confidence in any overall trends.

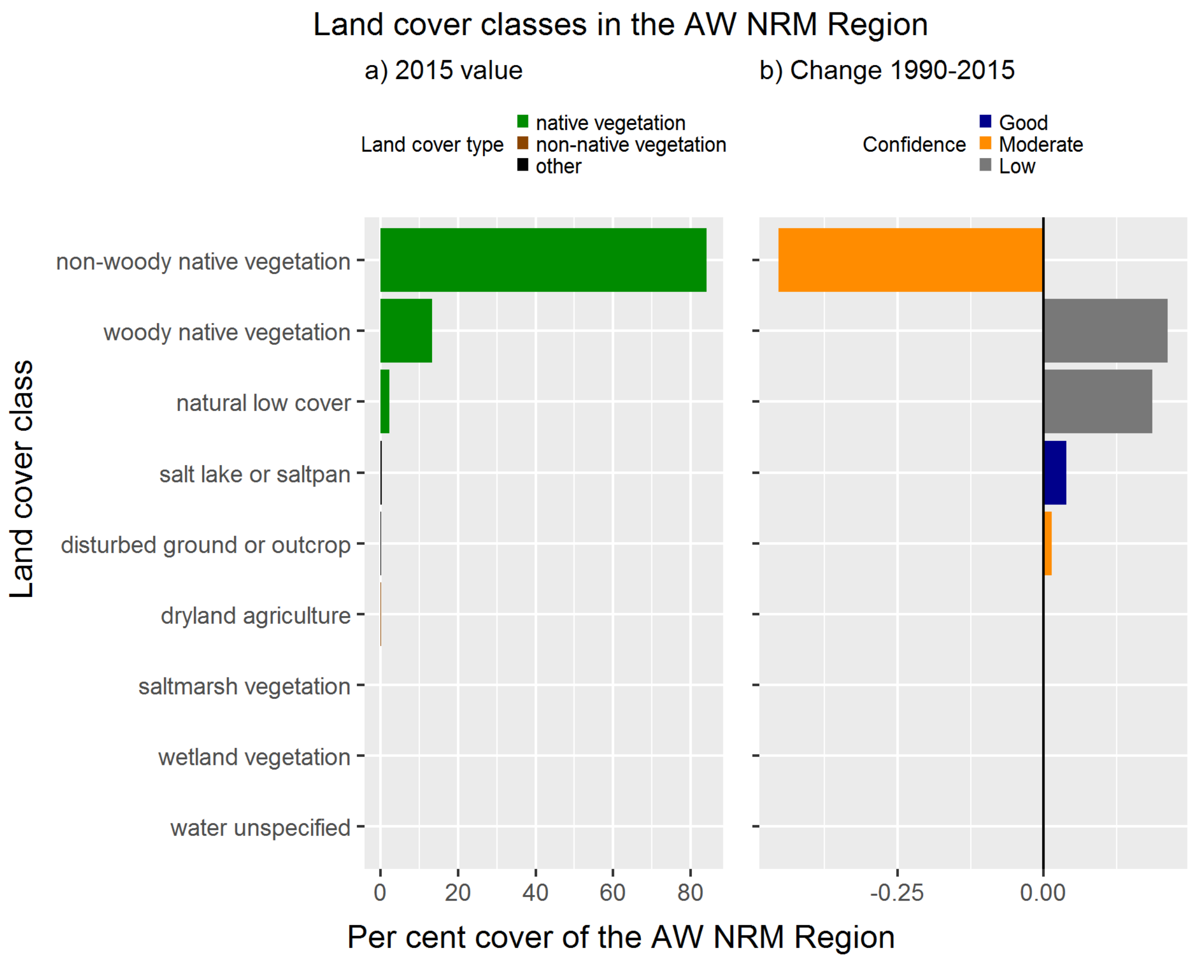

Figure 24 Per cent cover of classes in the AW NRM Region: a) as at 2015, and b) change between 1990 and 2015

4.7 Eyre Peninsula Natural Resources Management Region

4.7.1 Land cover type

Figure 25 shows the results of trend analyses for land cover types in the EP NRM Region. The Appendix has more detail on results from the per cent cover trend analysis (Table 24).

In 2015:

- 51.05% of the EP NRM Region was native vegetation. Between 1990 and 2015 native vegetation per cent cover has been decreasing across the EP NRM Region. The estimated loss of 134,614 ha (2.6% of the area of the EP NRM Region) over that period had good confidence.
- the land cover type non-native vegetation covered 47.76% of the EP NRM Region. Between 1990 and 2015 non-native vegetation per cent cover has been increasing across the EP NRM Region. The estimated gain of 127,634 ha (2.47% of the area of the EP NRM Region) over that period had good confidence.
- the land cover type ‘other’ covered 1.11% of the EP NRM Region. Between 1990 and 2015 other per cent cover has been stable across the EP NRM Region. The estimated gain of 1,895 ha (0.04% of the area of the EP NRM Region) over that period had low confidence.

Based on these data, the condition of native vegetation per cent cover in the EP NRM Region was fragmented in 2015.

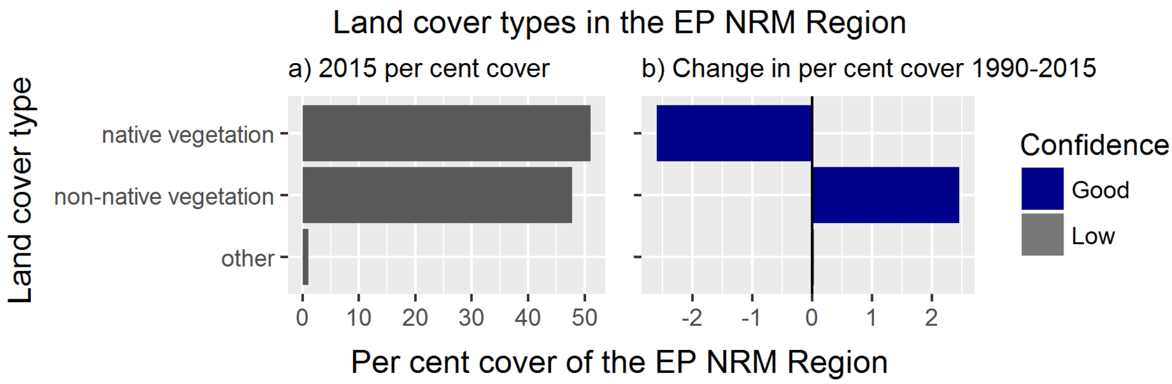

Figure 25 Per cent cover of types in the EP NRM Region

4.7.2 Land cover class

In 2015 the dominant land cover class(es) in the EP NRM Region were dryland agriculture (47.75%), woody native vegetation (29.71%), non-woody native vegetation (18.28%) and natural low cover (2.65%) (Figure 26a). The Appendix has more detail on results from the per cent cover trend analysis (Table 25), including a plot of the regressions for each land cover class (Figure 56).

Figure 26b shows change in each land cover class as a per cent of the EP NRM Region. Between 1990 and 2015 the most significantchanges in land cover in the EP NRM Region (with some confidence or better) occurred in the classes non-woody native vegetation (-4.23%), dryland agriculture (2.49%) and woody native vegetation (1.74%). The large change observed in natural low cover was too variable to have confidence in the overall pattern.

Across the EP NRM Region, non-woody native vegetation was the land cover class that changed the most between 1990 and 2015, with a decrease of approximately 4.23% of the EP NRM Region or about 219,160 hectares. The decline in non-woody native vegetation was roughly matched by an increase in woody native vegetation and dryland agriculture. This pattern was also observed in the other broadacre natural resources management regions (NY and SAMDB).

As can be seen in Figure 27, parts of the EP NRM Region have seen changes in land cover, particularly non-woody native vegetation (-4.23%), dryland agriculture (2.49%) and woody native vegetation (1.74%), between the first and last epoch.

The amount that each land cover class contributed to the large changes in land cover classes is shown in Figure 28. Note that Figure 28 uses only the single data points in 1990 and 2015 and thus will not necessarily indicate the same quantity of change given in Table 25.

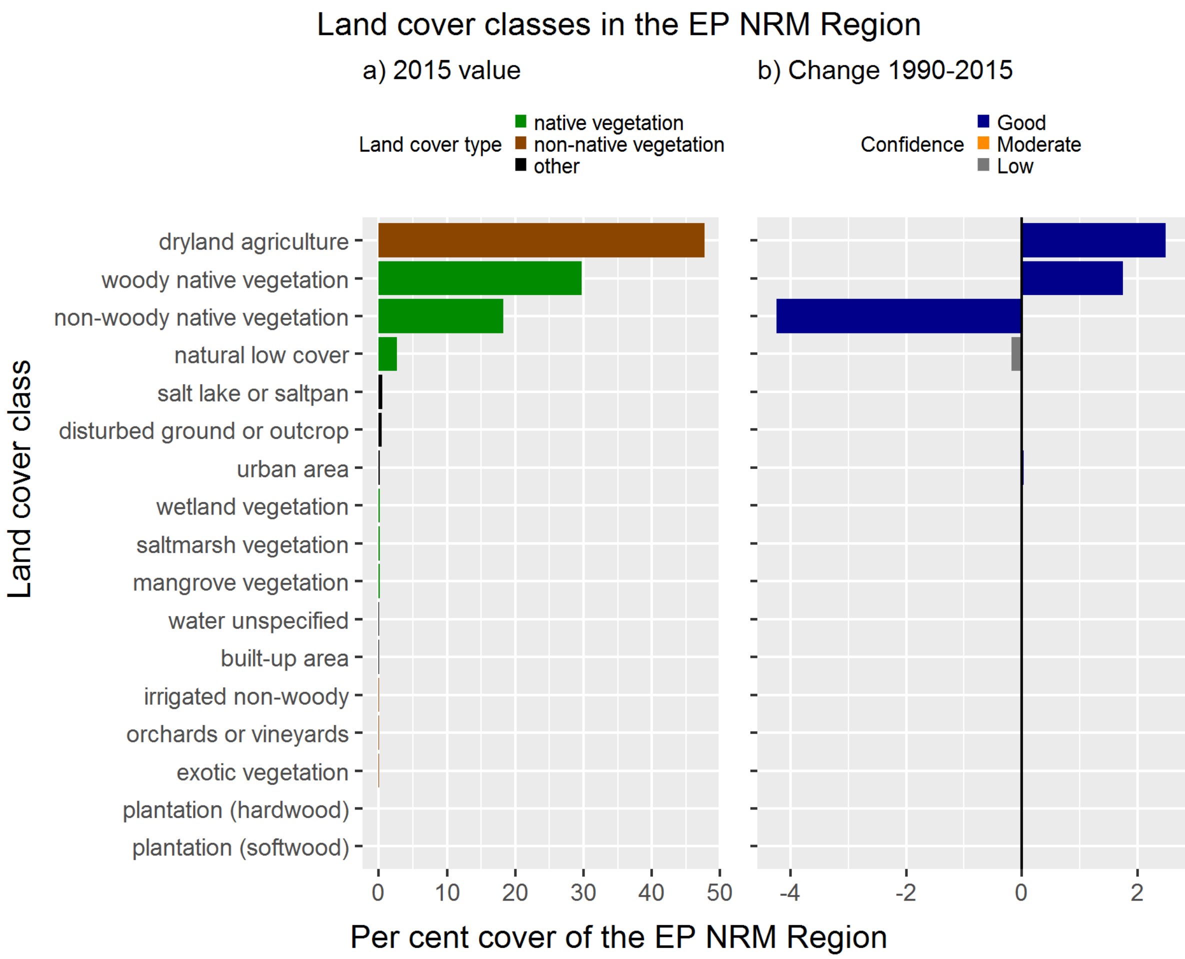

Figure 26 Per cent cover of classes in the EP NRM Region: a) as at 2015, and b) change between 1990 and 2015

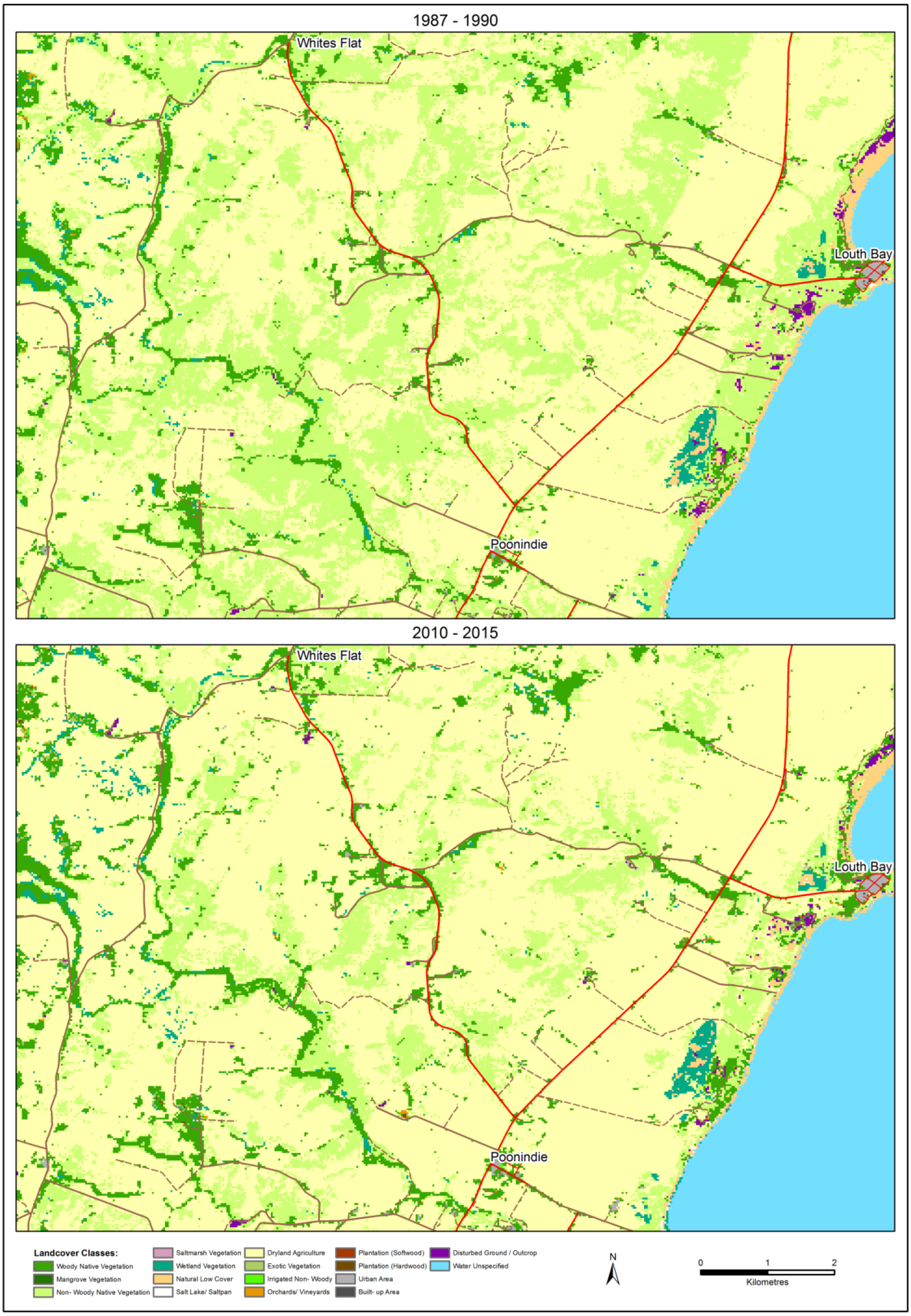

Figure 27 The most likely land cover classes for a small area of the the EP NRM Region, in the first and last epochs. The large land cover changes are visible (i.e. changes in non-woody native vegetation (-4.23%), dryland agriculture (2.49%) and woody native vegetation (1.74%))

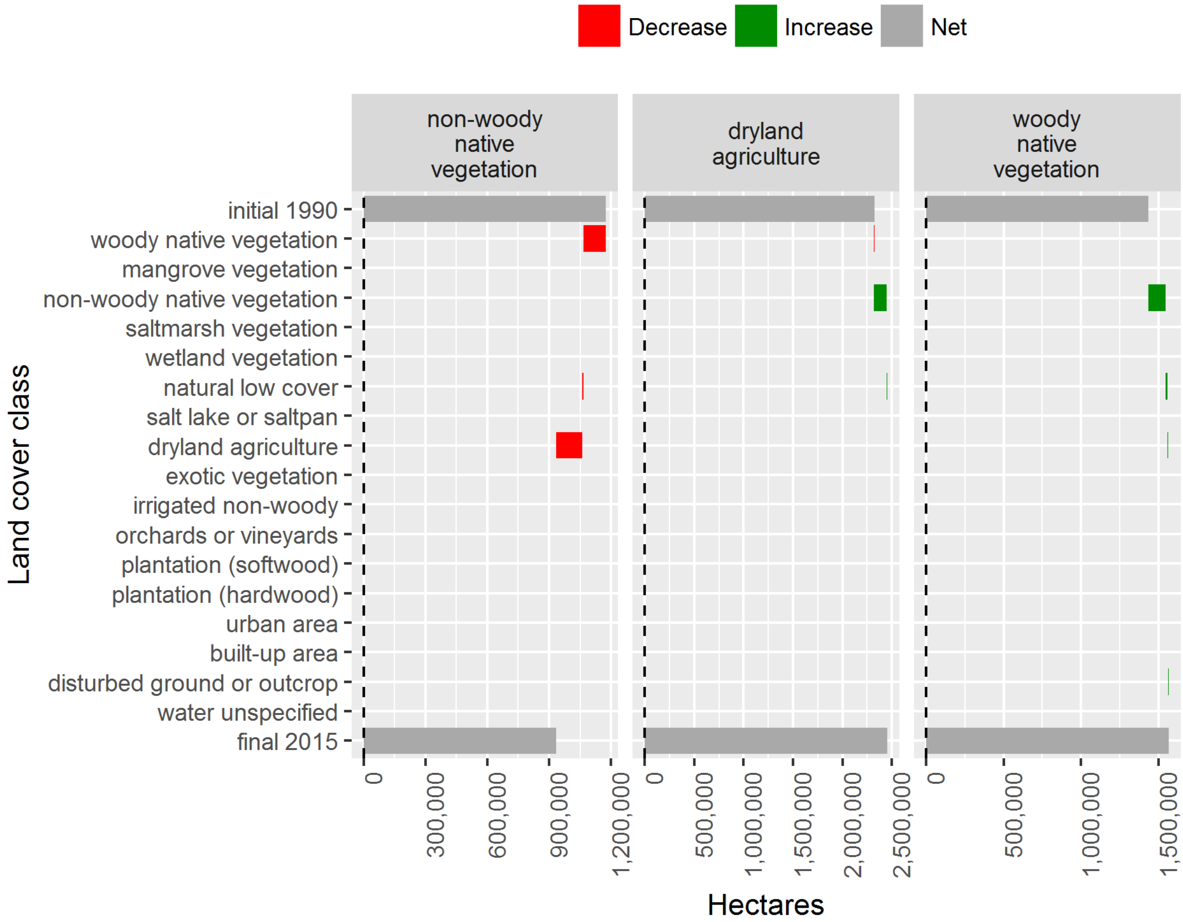

Figure 28 Large changes in land cover classes non-woody native vegetation (-4.23%), dryland agriculture (2.49%) and woody native vegetation (1.74%) in the EP NRM Region - contributions to change

4.8 Kangaroo Island Natural Resources Management Region

4.8.1 Land cover type

Figure 29 shows the results of trend analyses for land cover types in the KI NRM Region. The Appendix has more detail on results from the per cent cover trend analysis (Table 26).

In 2015:

- 59.31% of the KI NRM Region was native vegetation. Between 1990 and 2015 native vegetation per cent cover has been stable across the KI NRM Region. The estimated loss of 1,908 ha (0.43% of the area of the KI NRM Region) over that period had moderate confidence.
- the land cover type non-native vegetation covered 39.53% of the KI NRM Region. Between 1990 and 2015 non-native vegetation per cent cover has been stable across the KI NRM Region. The estimated gain of 2,123 ha (0.48% of the area of the KI NRM Region) over that period had moderate confidence.

- the land cover type 'other' covered 1.23% of the KI NRM Region. Between 1990 and 2015 other per cent cover has been stable across the KI NRM Region. The estimated gain of 178 ha (0.04% of the area of the KI NRM Region) over that period had low confidence.

Based on these data, the condition of native vegetation per cent cover in the KI NRM Region was fragmented in 2015.

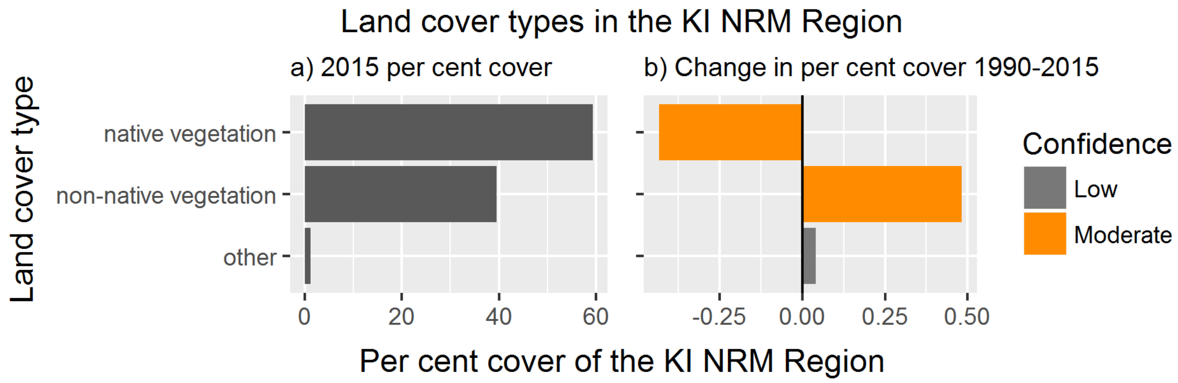

Figure 29 Per cent cover of types in the KI NRM Region

4.8.2 Land cover class

In 2015 the dominant land cover class(es) in the KI NRM Region were woody native vegetation (53.63%), dryland agriculture (35.38%), plantation (hardwood) (2.89%) and wetland vegetation (2.09%) (Figure 30a). The Appendix has more detail on results from the per cent cover trend analysis (Table 27), including a plot of the regressions for each land cover class (Figure 57).

Figure 30b shows change in each land cover class as a per cent of the KI NRM Region. Between 1990 and 2015 the most significantchanges in land cover in the KI NRM Region (with some confidence or better) occurred in the classes plantation (hardwood) (2.89%) and dryland agriculture (-2.54%). The variability in each individual land cover class was small enough that there was at least some confidence in any large overall change.

Across the KI NRM Region, plantation (hardwood) was the land cover class that changed the most between 1990 and 2015, with an increase of approximately 2.89% of the KI NRM Region or about 12,720 hectares.

As can be seen in Figure 31, parts of the KI NRM Region have seen changes in land cover, particularly plantation (hardwood) (2.89%) and dryland agriculture (-2.54%), between the first and last epoch.

The amount that each land cover class contributed to the large changes in land cover classes is shown in Figure 32. Note that Figure 32 uses only the single data points in 1990 and 2015 and thus will not necessarily indicate the same quantity of change given in Table 27.

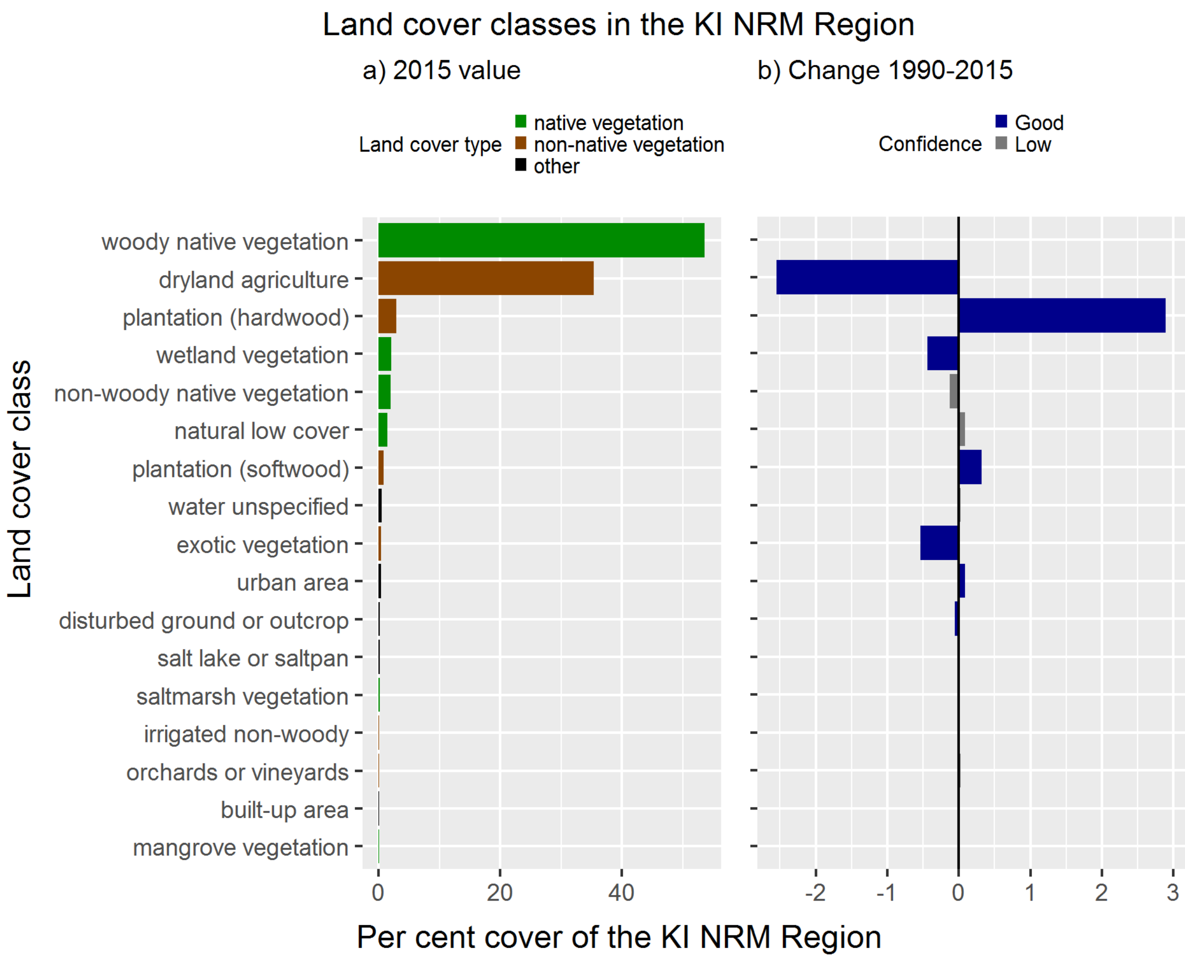

Figure 30 Per cent cover of classes in the KI NRM Region: a) as at 2015, and b) change between 1990 and 2015

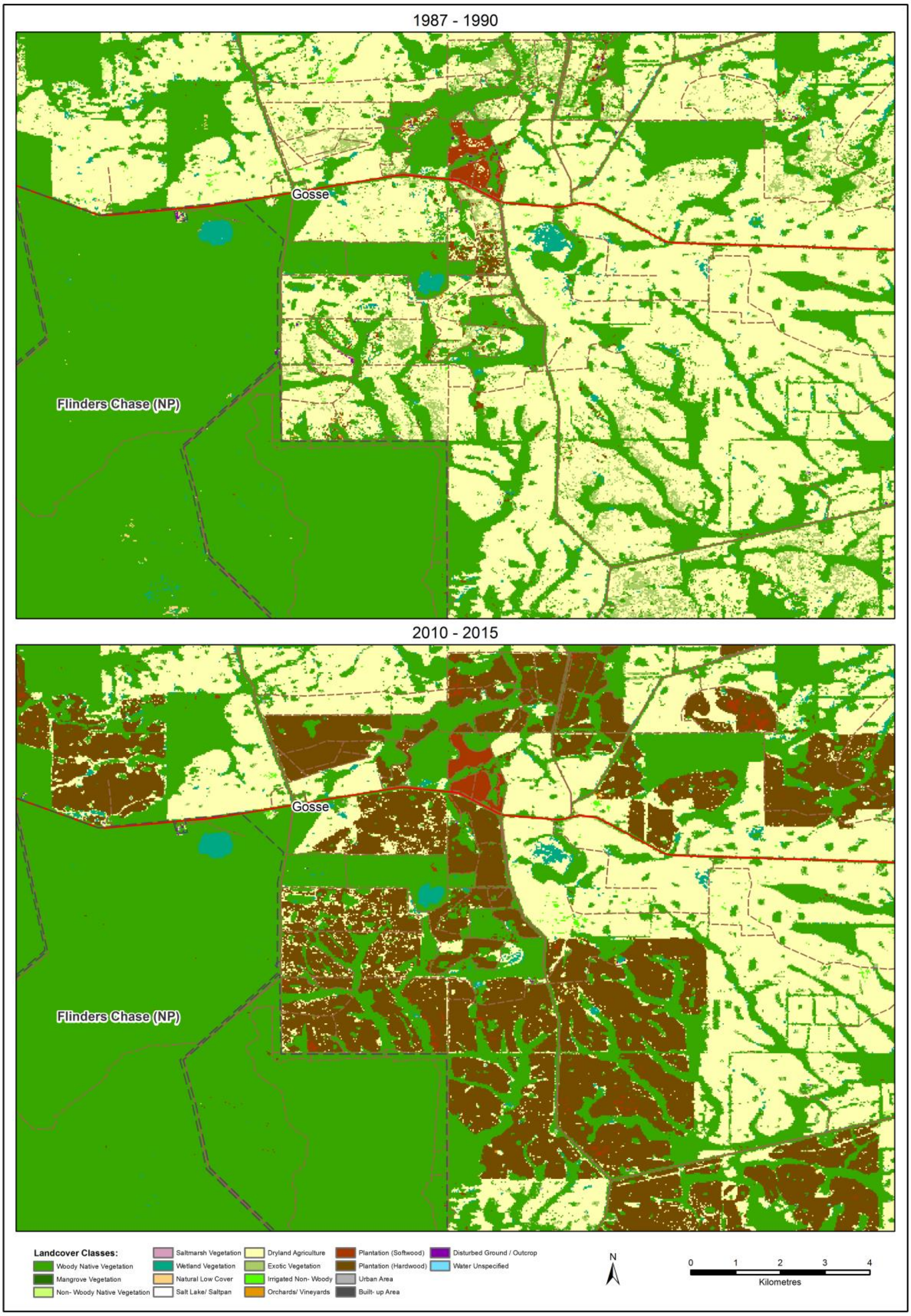

Figure 31 The most likely land cover classes for a small area of the the KI NRM Region, in the first and last epochs. The large land cover changes are visible (i.e. changes in plantation (hardwood) (2.89%) and dryland agriculture (-2.54%))

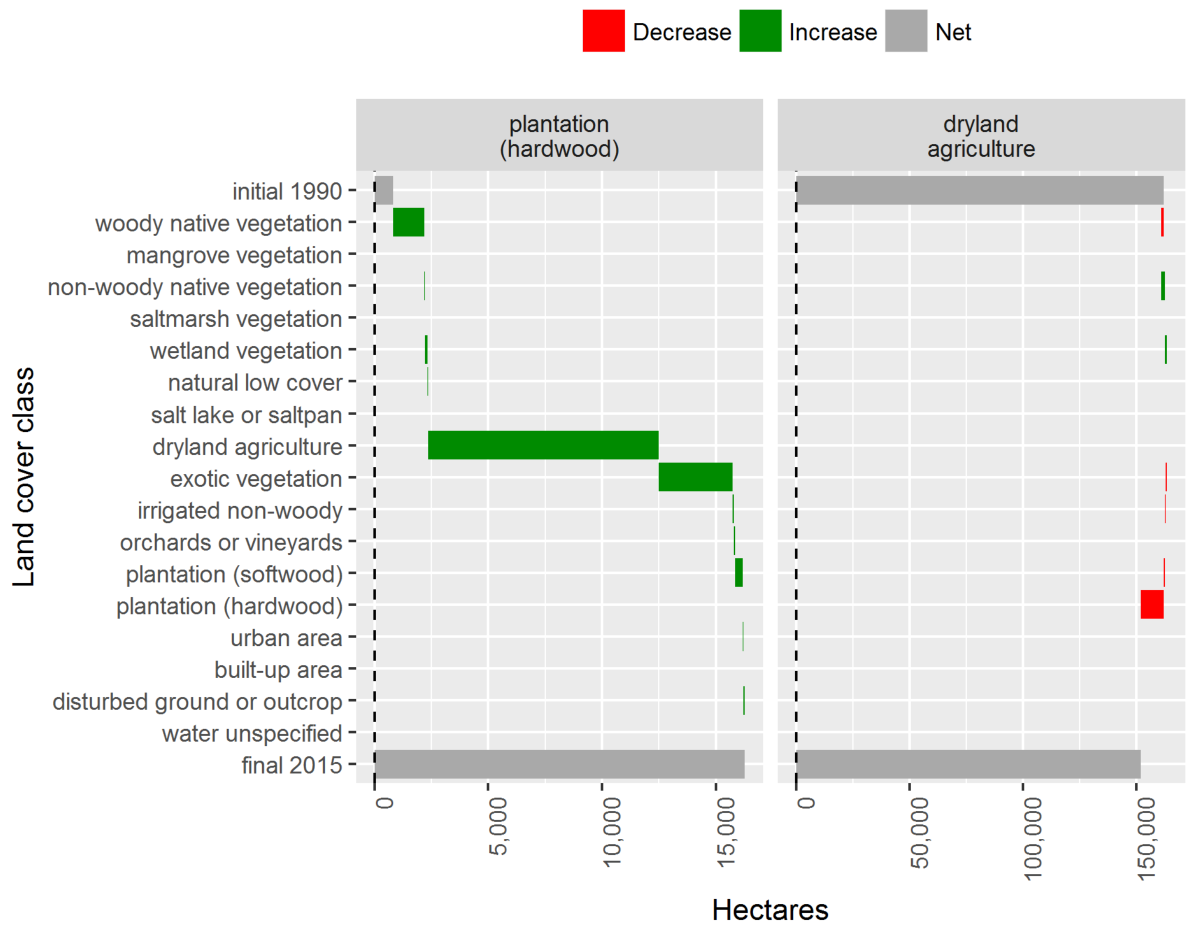

Figure 32 Large changes in land cover classes plantation (hardwood) (2.89%) and dryland agriculture (-2.54%) in the KI NRM Region - contributions to change

4.9 Northern and Yorke Natural Resources Management Region

4.9.1 Land cover type

Figure 33 shows the results of trend analyses for land cover types in the NY NRM Region. The Appendix has more detail on results from the per cent cover trend analysis (Table 28).

In 2015:

- 36.37% of the NY NRM Region was native vegetation. Between 1990 and 2015 native vegetation per cent cover has been decreasing across the NY NRM Region. The estimated loss of 132,861 ha (3.84% of the area of the NY NRM Region) over that period had good confidence.
- the land cover type non-native vegetation covered 62.76% of the NY NRM Region. Between 1990 and 2015 non-native vegetation per cent cover has been increasing across the NY NRM Region. The estimated gain of 134,397 ha (3.88% of the area of the NY NRM Region) over that period had good confidence.

- the land cover type 'other' covered 0.92% of the NY NRM Region. Between 1990 and 2015 other per cent cover has been increasing across the NY NRM Region. The estimated gain of 2,803 ha (0.08% of the area of the NY NRM Region) over that period had good confidence.

Based on these data, the condition of native vegetation per cent cover in the NY NRM Region was fragmented in 2015.

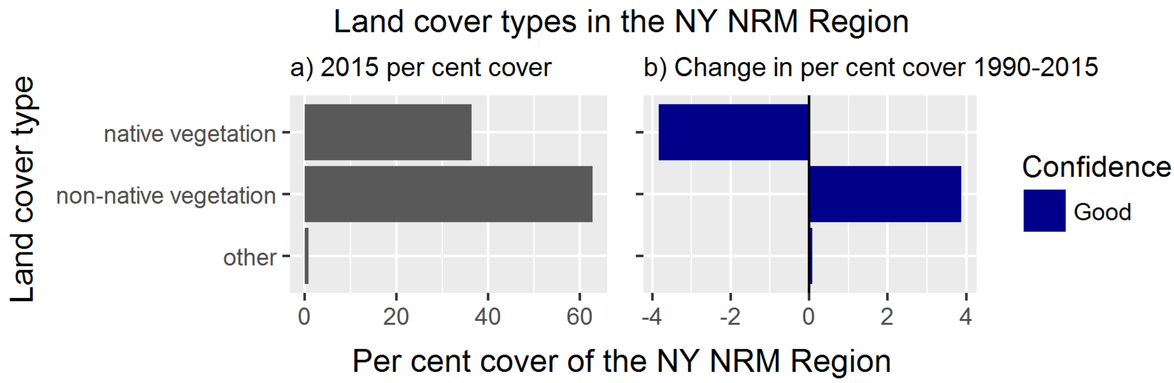

Figure 33 Per cent cover of types in the NY NRM Region

4.9.2 Land cover class

In 2015 the dominant land cover class(es) in the NY NRM Region were dryland agriculture (62.48%), non-woody native vegetation (23.61%), woody native vegetation (9.66%) and natural low cover (2.35%) (Figure 34a). The Appendix has more detail on results from the per cent cover trend analysis (Table 29), including a plot of the regressions for each land cover class (Figure 58).

Figure 34b shows change in each land cover class as a per cent of the NY NRM Region. Between 1990 and 2015 the most significantchanges in land cover in the NY NRM Region (with some confidence or better) occurred in the classes non-woody native vegetation (-4.9%), dryland agriculture (3.73%) and woody native vegetation (0.89%). The variability in each individual land cover class was small enough that there was at least some confidence in any large overall change.

Across the NY NRM Region, non-woody native vegetation was the land cover class that changed the most between 1990 and 2015, with a decrease of approximately 4.9% of the NY NRM Region or about 169,670 hectares.

As can be seen in Figure 35, parts of the NY NRM Region have seen changes in land cover, particularly non-woody native vegetation (-4.9%), dryland agriculture (3.73%) and woody native vegetation (0.89%), between the first and last epoch.

The amount that each land cover class contributed to the large changes in land cover classes is shown in Figure 36. Note that Figure 36 uses only the single data points in 1990 and 2015 and thus will not necessarily indicate the same quantity of change given in Table 29.

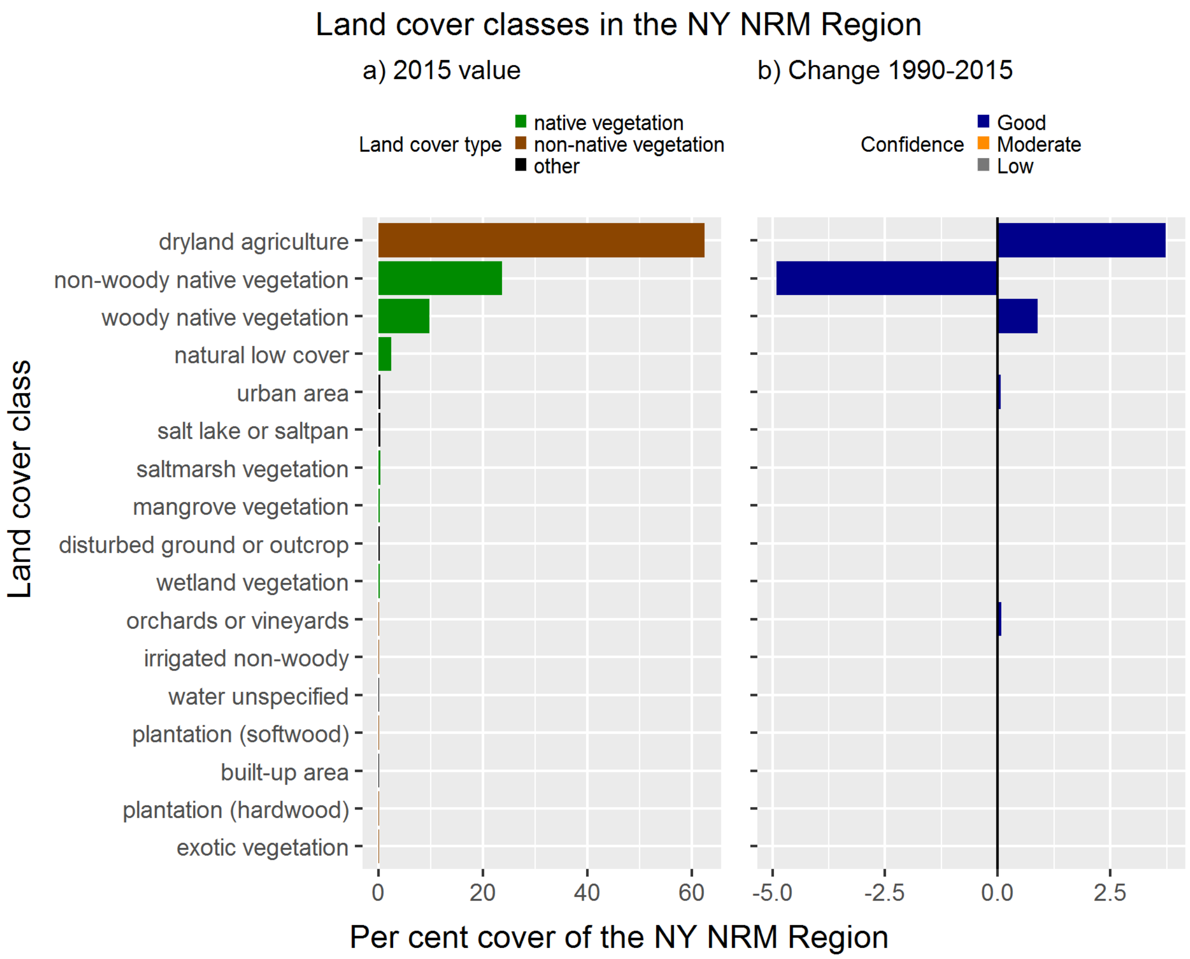

Figure 34 Per cent cover of classes in the NY NRM Region: a) as at 2015, and b) change between 1990 and 2015

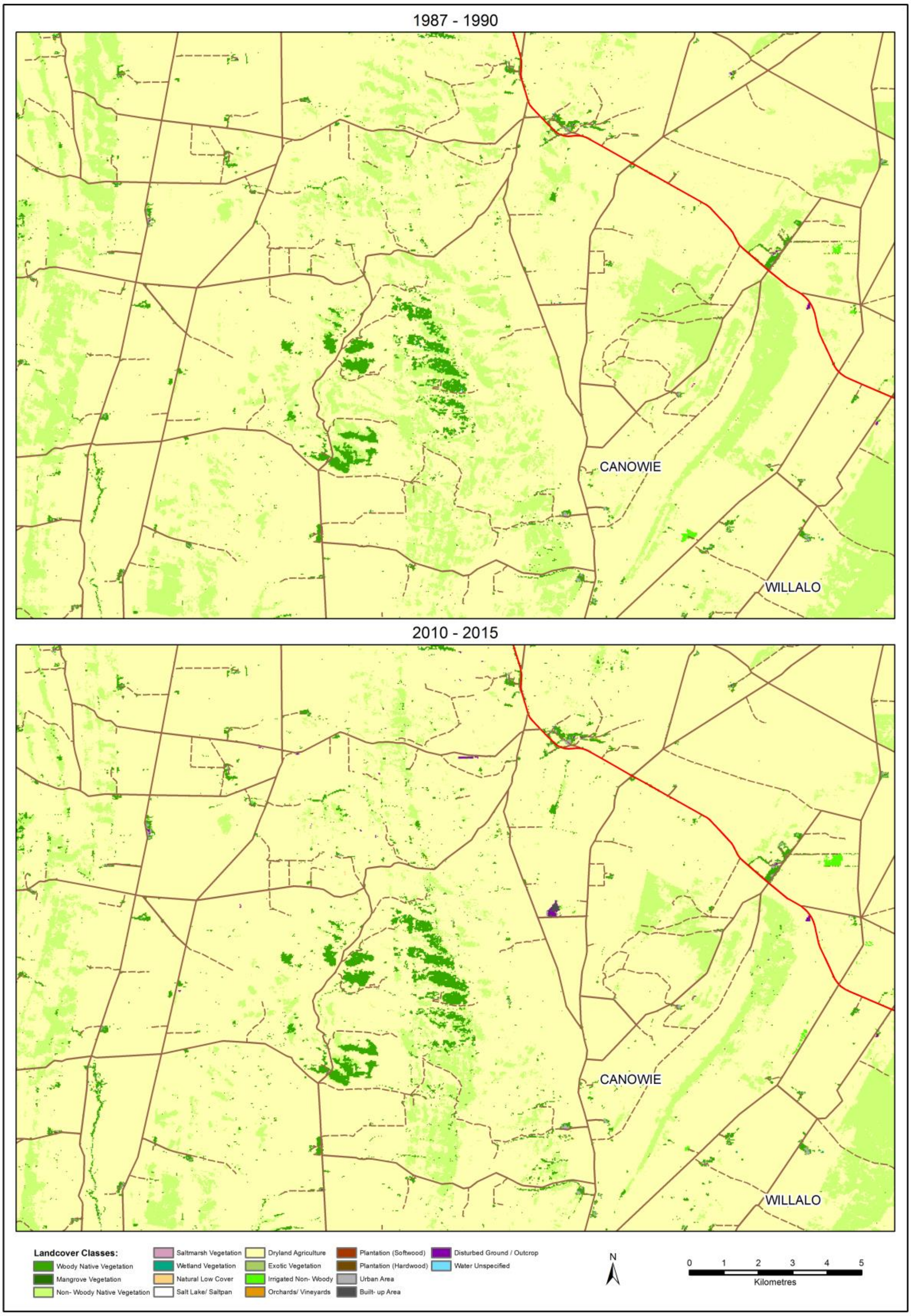

Figure 35 The most likely land cover classes for a small area of the the NY NRM Region, in the first and last epochs. The large land cover changes are visible (i.e. changes in non-woody native vegetation (-4.9%), dryland agriculture (3.73%) and woody native vegetation (0.89%))

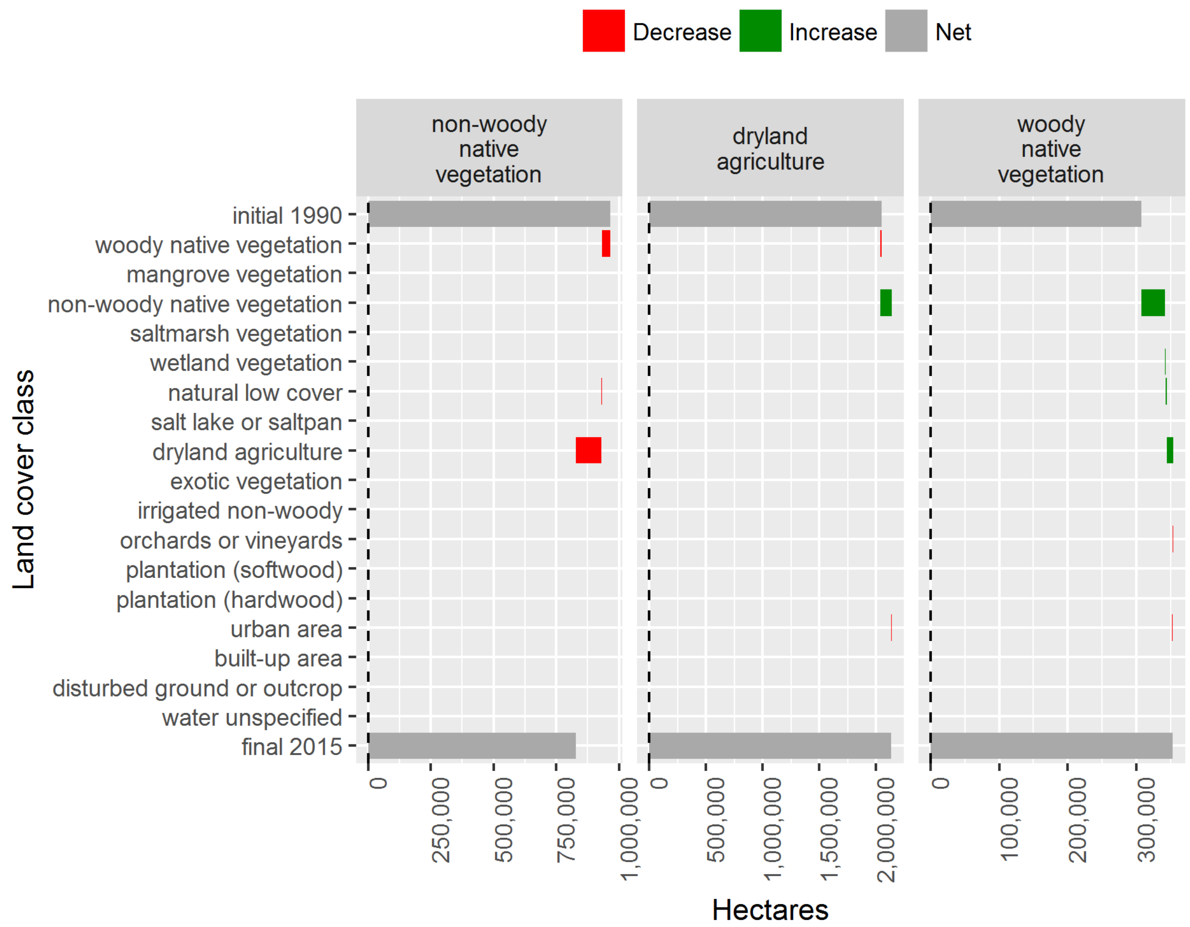

Figure 36 Large changes in land cover classes non-woody native vegetation (-4.9%), dryland agriculture (3.73%) and woody native vegetation (0.89%) in the NY NRM Region - contributions to change

4.10 South Australian Arid Lands Natural Resources Management Region

4.10.1 Land cover type

Figure 37 shows the results of trend analyses for land cover types in the SAAL NRM Region. The Appendix has more detail on results from the per cent cover trend analysis (Table 30).

In 2015:

- 96.27% of the SAAL NRM Region was native vegetation. Between 1990 and 2015 native vegetation per cent cover has been stable across the SAAL NRM Region. The estimated gain of 5,535 ha (0.01% of the area of the SAAL NRM Region) over that period had low confidence.
- the land cover type non-native vegetation covered 0.01% of the SAAL NRM Region. Between 1990 and 2015 non-native vegetation per cent cover has been stable across the SAAL NRM Region. The estimated gain of 961 ha (0% of the area of the SAAL NRM Region) over that period had low confidence.

- the land cover type 'other' covered 3.72% of the SAAL NRM Region. Between 1990 and 2015 other per cent cover has been stable across the SAAL NRM Region. The estimated loss of 3,192 ha (0.01% of the area of the SAAL NRM Region) over that period had low confidence.

Based on these data, the condition of native vegetation per cent cover in the SAAL NRM Region was intact in 2015.

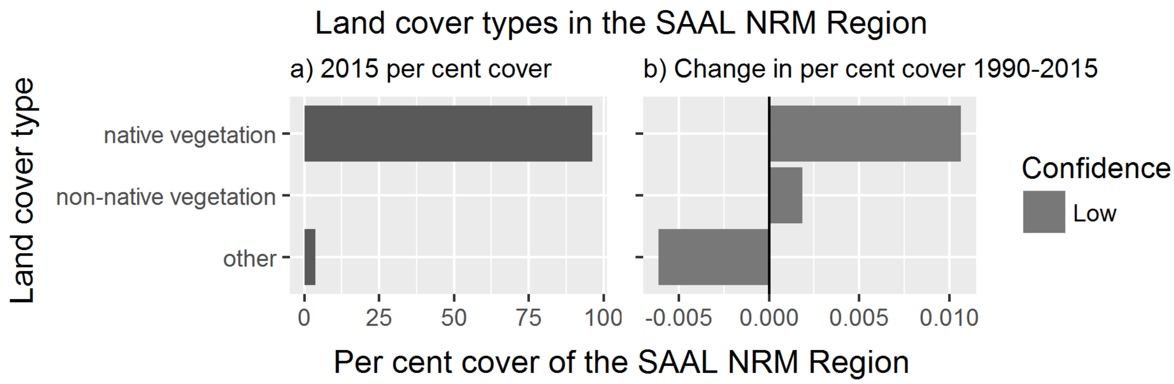

Figure 37 Per cent cover of types in the SAAL NRM Region

4.10.2 Land cover class

In 2015 the dominant land cover class(es) in the SAAL NRM Region were non-woody native vegetation (80.42%), natural low cover (10.93%) and woody native vegetation (4.66%) (Figure 38a). The Appendix has more detail on results from the per cent cover trend analysis (Table 31), including a plot of the regressions for each land cover class (Figure 59).

Figure 38b shows change in each land cover class as a per cent of the SAAL NRM Region. Between 1990 and 2015 the most significantchange in land cover in the SAAL NRM Region (with some confidence or better) occurred in the class wetland vegetation (0.14%). Large changes were observed in woody native vegetation, non-woody native vegetation and natural low cover although changes in the cover of these classes through time were too variable to have confidence in the overall pattern.

As for the arid zone as a whole, large fluctuations in land cover classes in the SAAL NRM Region led to low confidence in any overall trends.

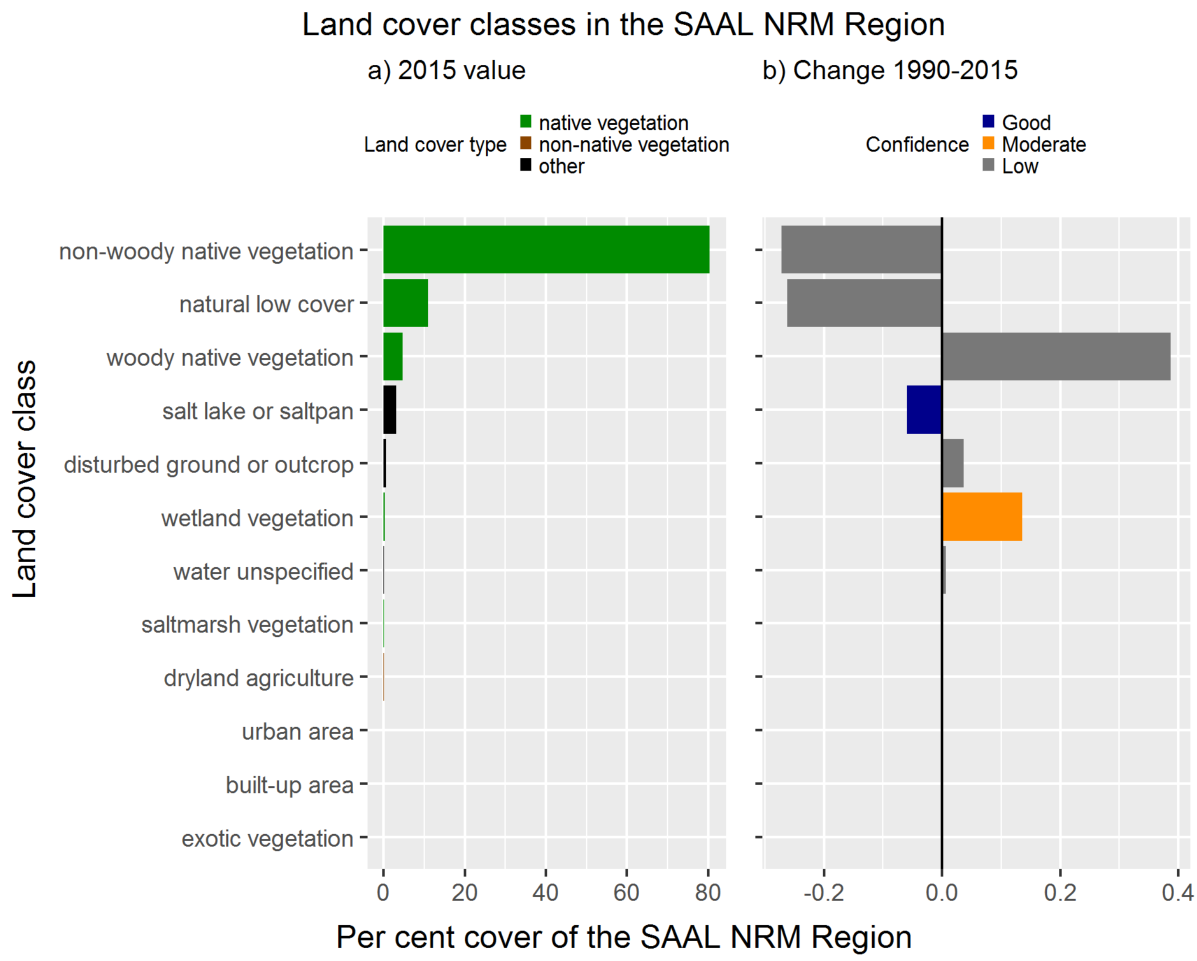

Figure 38 Per cent cover of classes in the SAAL NRM Region: a) as at 2015, and b) change between 1990 and 2015

4.11 South Australian Murray-Darling Basin Natural Resources Management Region

4.11.1 Land cover type

Figure 39 shows the results of trend analyses for land cover types in the SAMDB NRM Region. The Appendix has more detail on results from the per cent cover trend analysis (Table 32).

In 2015:

- 61.21% of the SAMDB NRM Region was native vegetation. Between 1990 and 2015 native vegetation per cent cover has been decreasing across the SAMDB NRM Region. The estimated loss of 118,535 ha (2.11% of the area of the SAMDB NRM Region) over that period had good confidence.
- the land cover type non-native vegetation covered 36.49% of the SAMDB NRM Region. Between 1990 and 2015 non-native vegetation per cent cover has been increasing across the SAMDB NRM Region. The estimated gain of 114,490 ha (2.04% of the area of the SAMDB NRM Region) over that period had good confidence.

- the land cover type 'other' covered 2.29% of the SAMDB NRM Region. Between 1990 and 2015 other per cent cover has been stable across the SAMDB NRM Region. The estimated gain of 225 ha (0% of the area of the SAMDB NRM Region) over that period had low confidence.

Based on these data, the condition of native vegetation per cent cover in the SAMDB NRM Region was variegated in 2015.

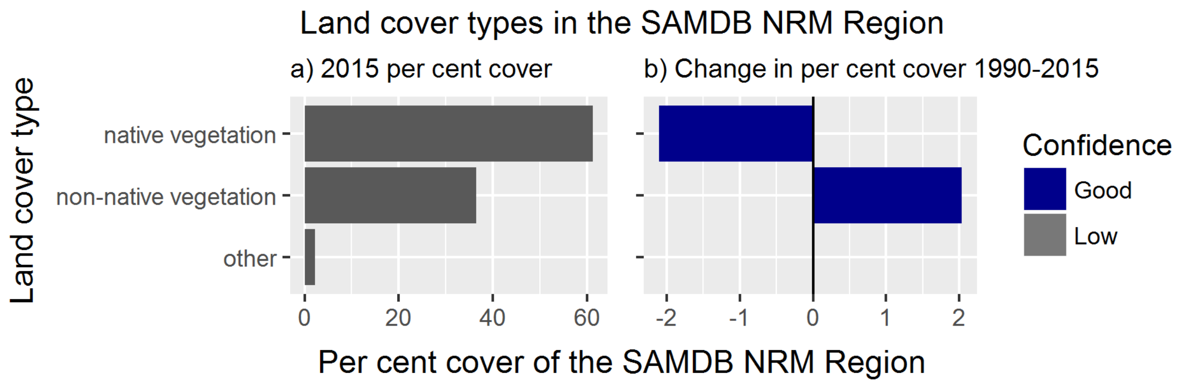

Figure 39 Per cent cover of types in the SAMDB NRM Region

4.11.2 Land cover class

In 2015 the dominant land cover class(es) in the SAMDB NRM Region were dryland agriculture (35.42%), woody native vegetation (31.93%), non-woody native vegetation (27.45%) and water unspecified (1.87%) (Figure 40a). The Appendix has more detail on results from the per cent cover trend analysis (Table 33), including a plot of the regressions for each land cover class (Figure 60).

Figure 40b shows change in each land cover class as a per cent of the SAMDB NRM Region. Between 1990 and 2015 the most significantchanges in land cover in the SAMDB NRM Region (with some confidence or better) occurred in the classes non-woody native vegetation (-4.09%), woody native vegetation (2.15%) and dryland agriculture (1.75%). The variability in each individual land cover class was small enough that there was at least some confidence in any large overall change.

Across the SAMDB NRM Region, non-woody native vegetation was the land cover class that changed the most between 1990 and 2015, with a decrease of approximately 4.09% of the SAMDB NRM Region or about 229,950 hectares.

As can be seen in Figure 41, parts of the SAMDB NRM Region have seen changes in land cover, particularly non-woody native vegetation (-4.09%), woody native vegetation (2.15%) and dryland agriculture (1.75%), between the first and last epoch.

The amount that each land cover class contributed to the large changes in land cover classes is shown in Figure 42. Note that Figure 42 uses only the single data points in 1990 and 2015 and thus will not necessarily indicate the same quantity of change given in Table 33.

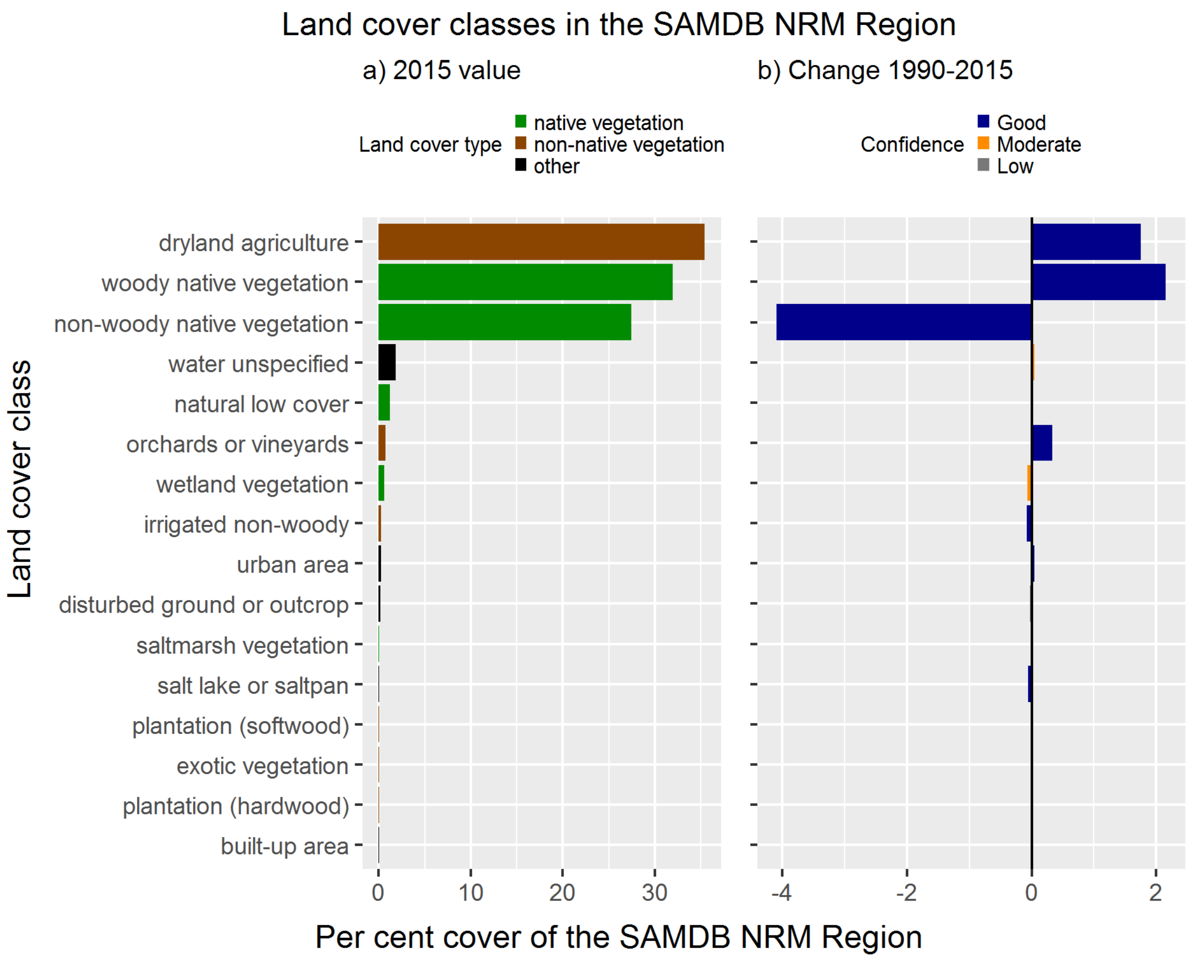

Figure 40 Per cent cover of classes in the SAMDB NRM Region: a) as at 2015, and b) change between 1990 and 2015

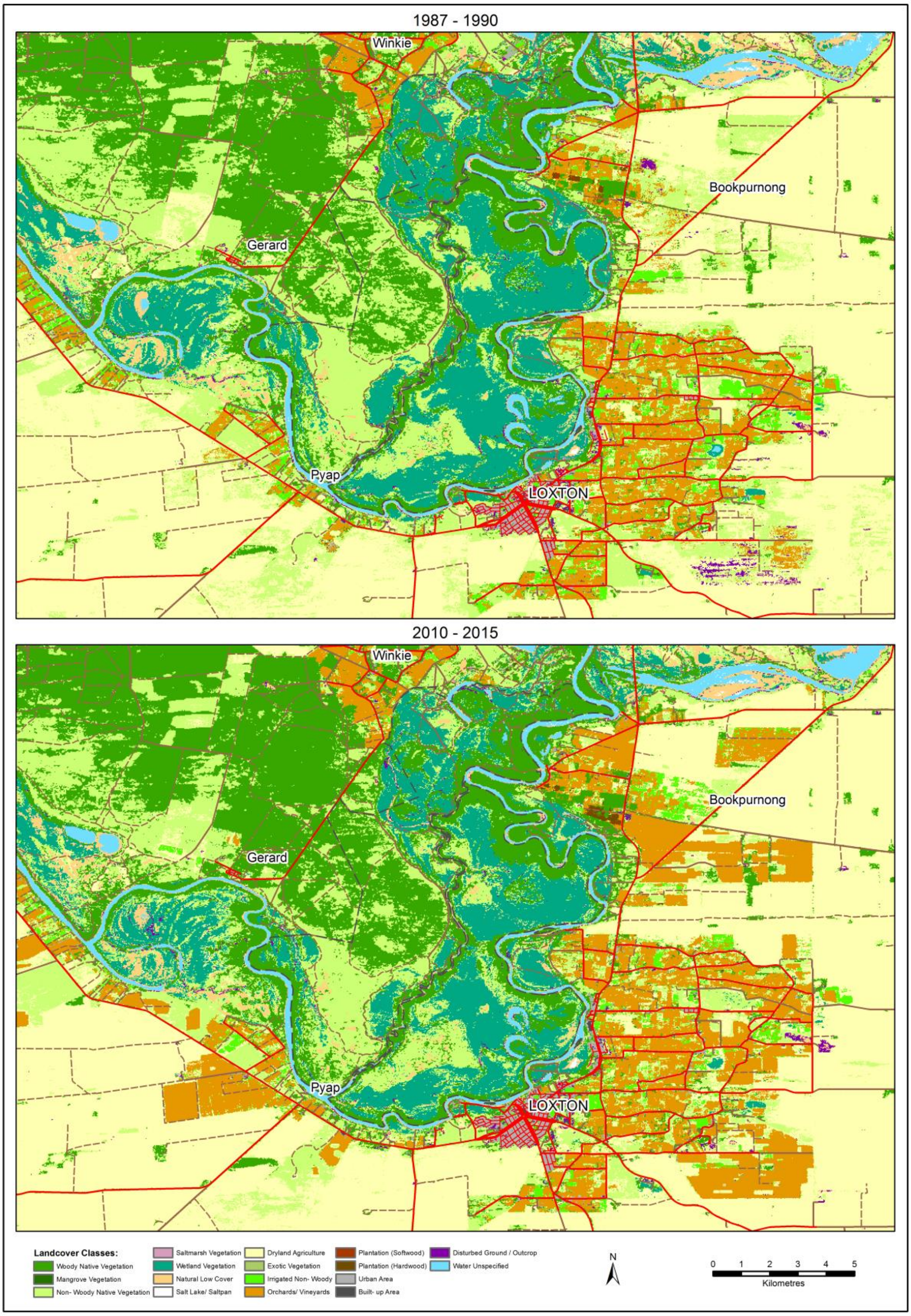

Figure 41 The most likely land cover classes for a small area of the the SAMDB NRM Region, in the first and last epochs. The large land cover changes are visible (i.e. changes in non-woody native vegetation (-4.09%), woody native vegetation (2.15%) and dryland agriculture (1.75%))

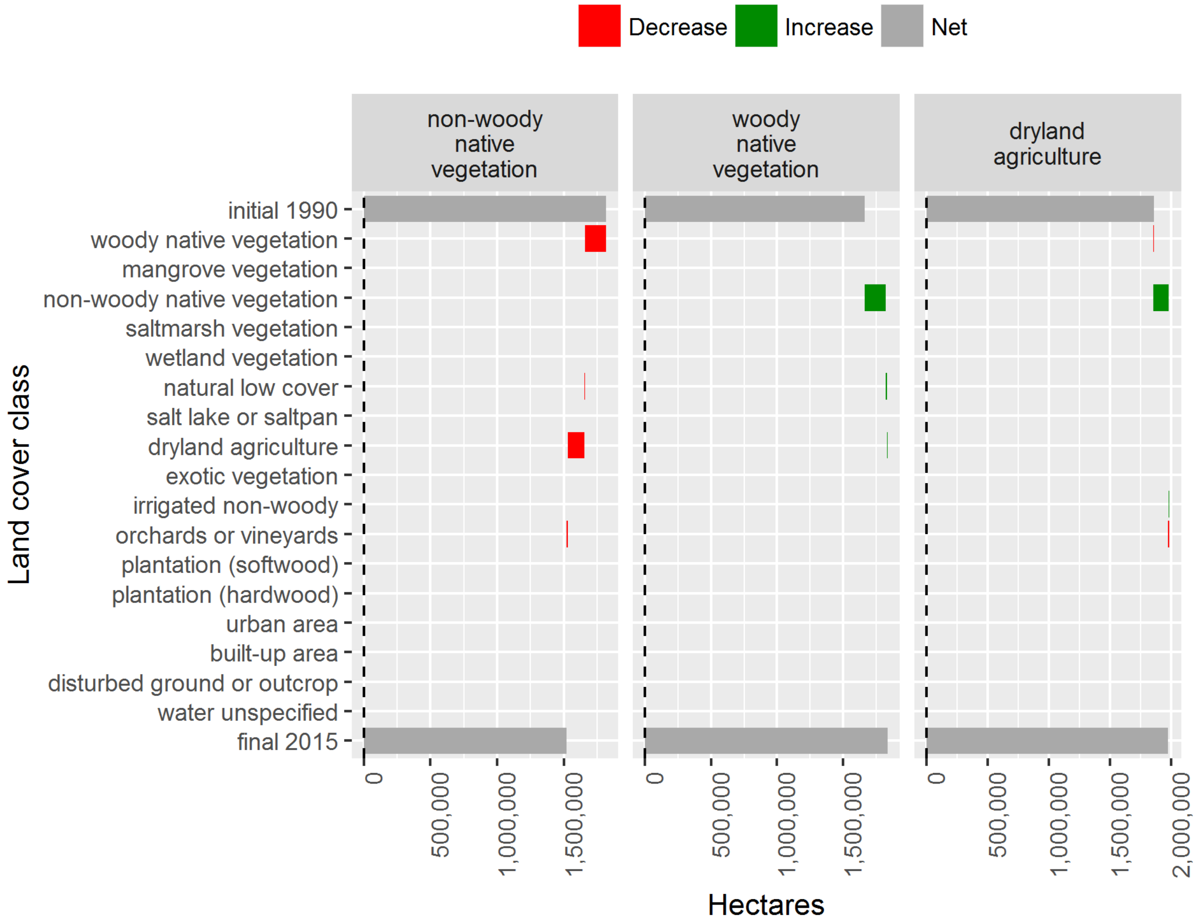

Figure 42 Large changes in land cover classes non-woody native vegetation (-4.09%), woody native vegetation (2.15%) and dryland agriculture (1.75%) in the SAMDB NRM Region - contributions to change

4.12 South East Natural Resources Management Region

4.12.1 Land cover type

Figure 43 shows the results of trend analyses for land cover types in the SE NRM Region. The Appendix has more detail on results from the per cent cover trend analysis (Table 34).

In 2015:

- 31.35% of the SE NRM Region was native vegetation. Between 1990 and 2015 native vegetation per cent cover has been stable across the SE NRM Region. The estimated loss of 82,732 ha (3.09% of the area of the SE NRM Region) over that period had moderate confidence.
- the land cover type non-native vegetation covered 66.63% of the SE NRM Region. Between 1990 and 2015 non-native vegetation per cent cover has been stable across the SE NRM Region. The estimated gain of 89,669 ha (3.35% of the area of the SE NRM Region) over that period had moderate confidence.

- the land cover type ‘other’ covered 2.04% of the SE NRM Region. Between 1990 and 2015 other per cent cover has been decreasing across the SE NRM Region. The estimated loss of 4,445 ha (0.17% of the area of the SE NRM Region) over that period had good confidence.

Based on these data, the condition of native vegetation per cent cover in the SE NRM Region was fragmented in 2015.

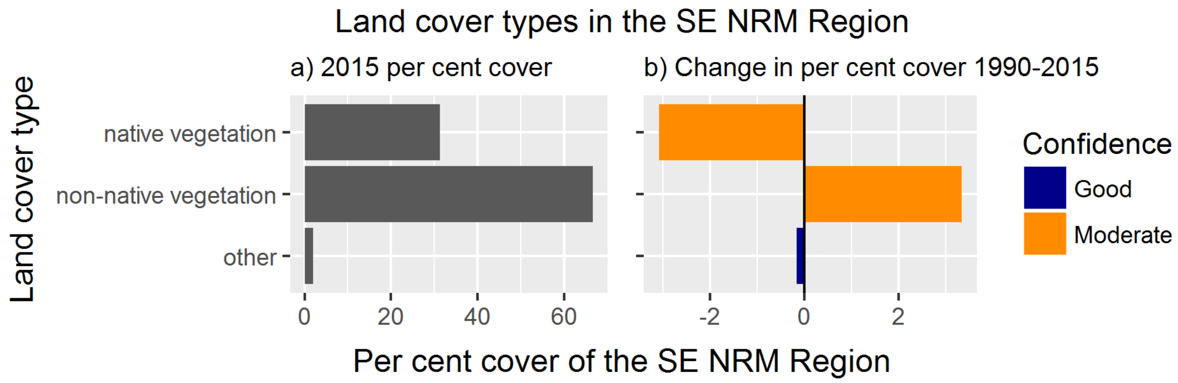

Figure 43 Per cent cover of types in the SE NRM Region

4.12.2 Land cover class

In 2015 the dominant land cover class(es) in the SE NRM Region were dryland agriculture (58.44%), woody native vegetation (17.13%), non-woody native vegetation (10.46%) and plantation (softwood) (3.6%) (Figure 44a). The Appendix has more detail on results from the per cent cover trend analysis (Table 35), including a plot of the regressions for each land cover class (Figure 61).

Figure 44b shows change in each land cover class as a per cent of the SE NRM Region. Between 1990 and 2015 the most significantchanges in land cover in the SE NRM Region (with some confidence or better) occurred in the classes plantation (hardwood) (1.75%), wetland vegetation (-1.57%) and irrigated non-woody (1.26%). The large change observed in non-woody native vegetation was too variable to have confidence in the overall pattern.

Across the SE NRM Region, plantation (hardwood) was the land cover class that changed the most between 1990 and 2015, with an increase of approximately 1.75% of the SE NRM Region or about 46,880 hectares.

As can be seen in Figure 45, parts of the SE NRM Region have seen changes in land cover, particularly plantation (hardwood) (1.75%), wetland vegetation (-1.57%) and irrigated non-woody (1.26%), between the first and last epoch.

The amount that each land cover class contributed to the large changes in land cover classes is shown in Figure 46. Note that Figure 46 uses only the single data points in 1990 and 2015 and thus will not necessarily indicate the same quantity of change given in Table 35.

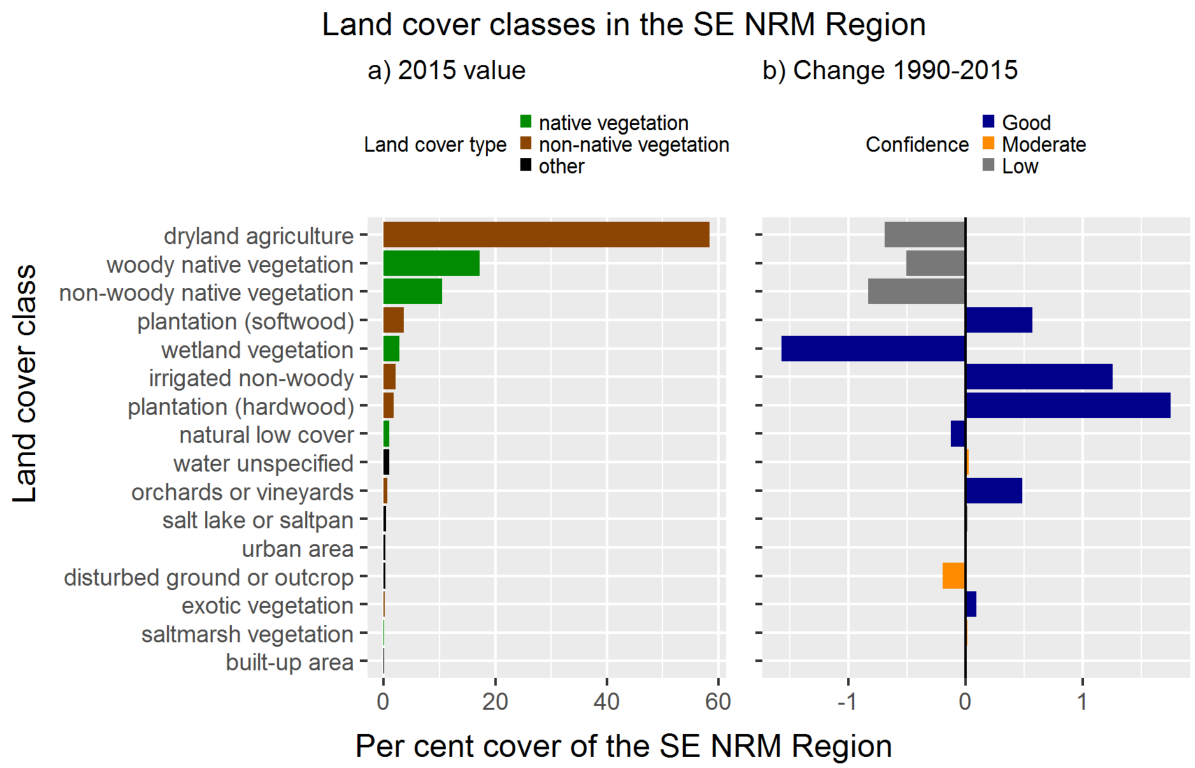

Figure 44 Per cent cover of classes in the SE NRM Region: a) as at 2015, and b change between 1990 and 2015

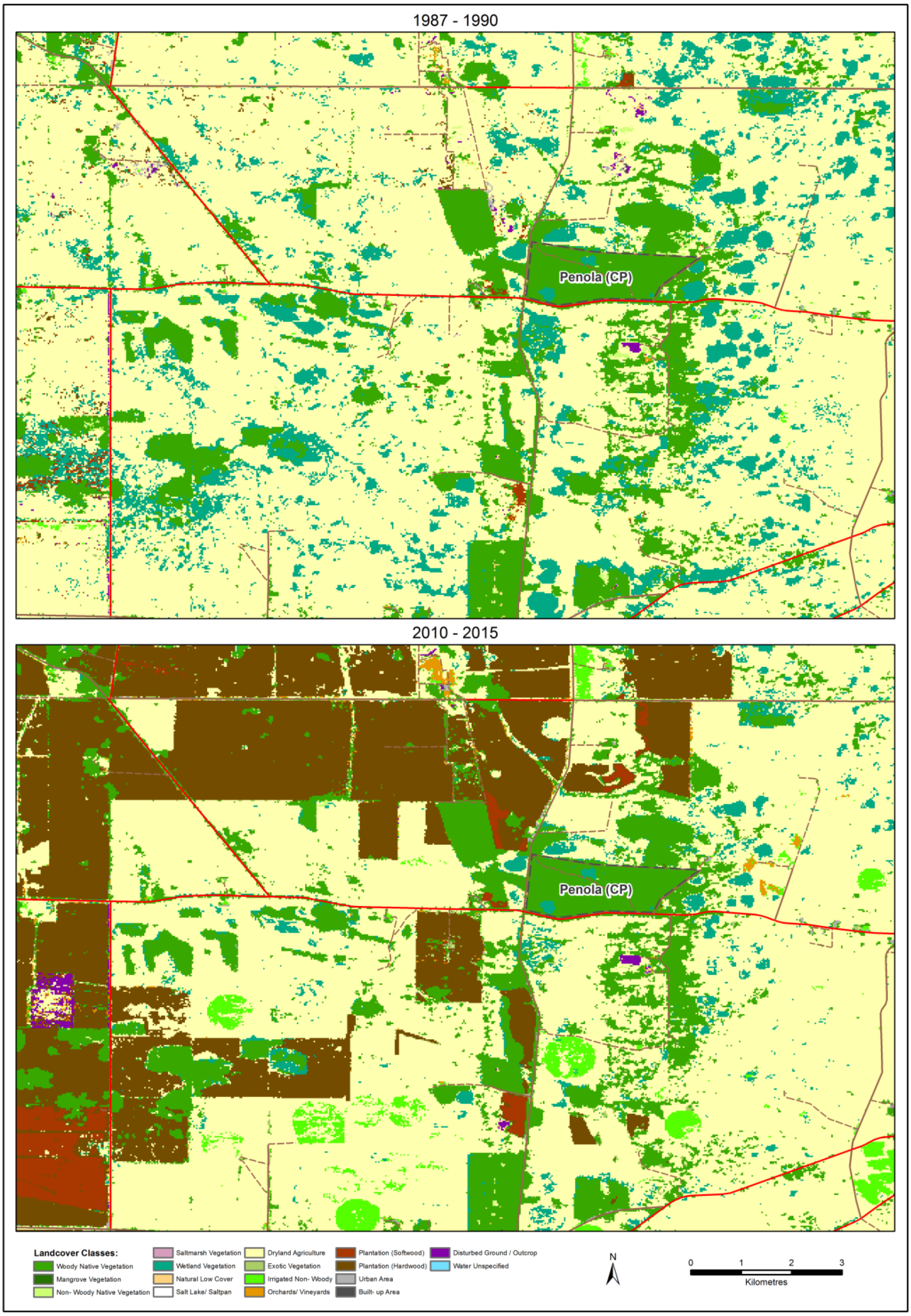

Figure 45 The most likely land cover classes for a small area of the the SE NRM Region, in the first and last epochs. The large land cover changes are visible (i.e. changes in plantation (hardwood) (1.75%), wetland vegetation (-1.57%) and irrigated non-woody (1.26%))

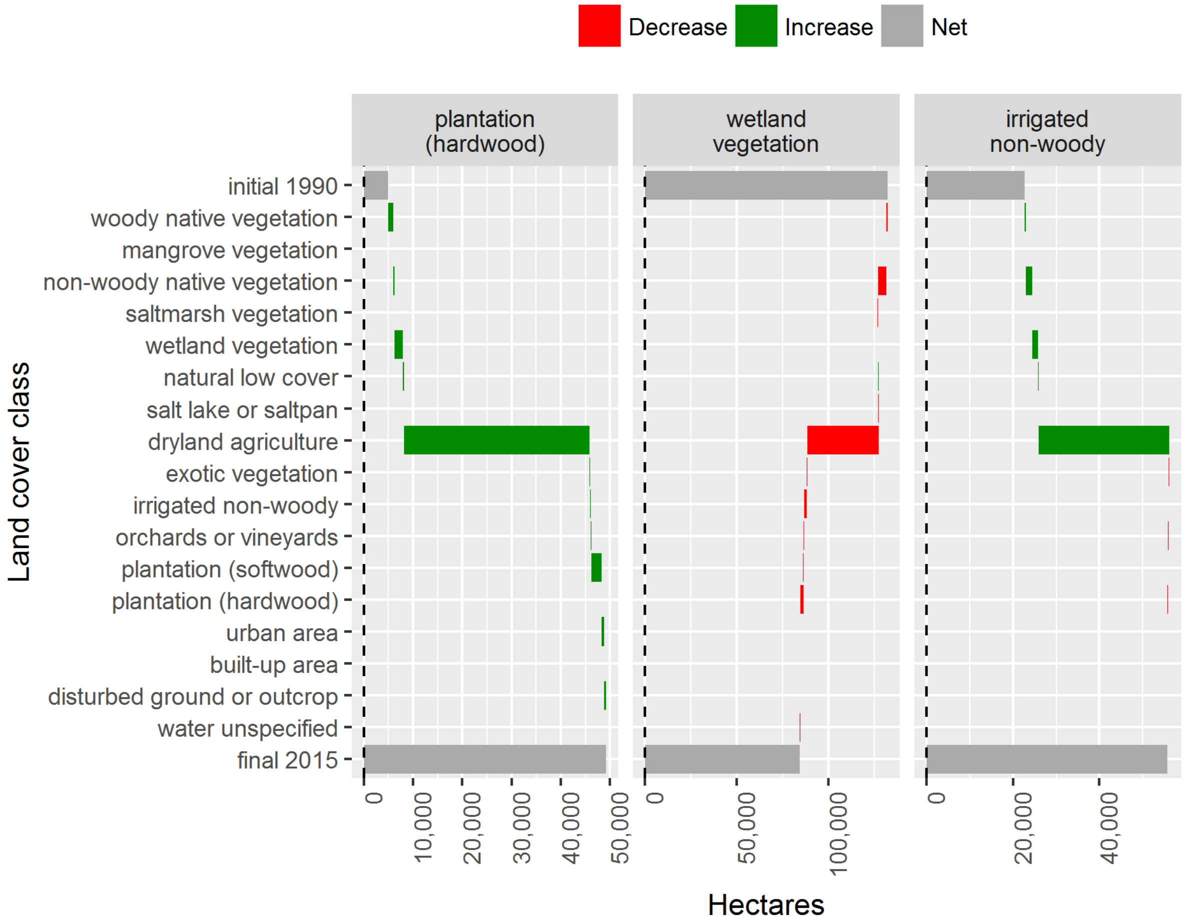

Figure 46 Large changes in land cover classes plantation (hardwood) (1.75%), wetland vegetation (-1.57%) and irrigated non-woody (1.26%) in the SE NRM Region - contributions to change

4.13 Native vegetation in protected areas

The area and per cent of native vegetation in each natural resources management region that is protected is given in Table 10.

Table 10 Native vegetation in protected areas

NRM Region	Native vegetation in protected areas (hectares)	Per cent of native vegetation in protected areas
Adelaide and Mt Lofty Ranges	25,900	12.15
Alinytjara Wilurara	14,572,300	52.17
Eyre Peninsula	1,043,100	39.36
Kangaroo Island	147,400	57.21
Northern and Yorke	79,100	6.18

NRM Region	Native vegetation in protected areas (hectares)	Per cent of native vegetation in protected areas
South Australian Arid Lands	10,555,800	21.08
South Australian Murray-Darling Basin	1,160,800	33.53
South East	283,400	35.36

5 Discussion

5.1 Land cover change in South Australia 1990-2015

This dataset and the analyses presented here suggest a number of land cover changes across South Australia. These can be summarised as:

- In the high-rainfall natural resources management regions (Kangaroo Island, Adelaide and Mount Lofty Ranges and South East):
  - increase in plantation (hardwood)
  - increase in various other high intensity land uses
    - orchards/vineyards in Adelaide and Mount Lofty Ranges and South East
    - irrigated non-woody in the South East
    - plantation (softwood) on Kangaroo Island and in the South East
    - urban area in Adelaide and Mount Lofty Ranges
  - decrease in wetland vegetation
  - decrease in dryland agriculture on Kangaroo Island
- In the low-rainfall natural resources management regions (South Australian Murray-Darling Basin, Eyre Peninsula and Northern and Yorke):
  - increase in woody native vegetation (although low confidence increase in Northern and Yorke NRM Region)
  - trends that are due, in part, to classification limitations:
    - increase in dryland agriculture
    - decrease in non-woody native vegetation
- In the arid natural resources management regions (Alinytjara Wilurara and South Australian Arid Lands) the land cover classes fluctuate between epochs and thus appear stable (low confidence in any overall trend)
- Changes, where they occur, are diffuse in nature (e.g. Figures 21 and 27), with the trends becoming most evident when analysing over relatively large areas.

A key pattern emerging from these data was a widespread change from non-woody to woody native vegetation. This change has also been observed worldwide, and is sometimes termed shrub encroachment (Suding *et al.* 2004; e.g. Briggs *et al.* 2005; Price and Morgan 2008; Rocha *et al.* 2015). Until now there was no data available to quantify any similar change in South Australia. The transition to woody vegetation is thought to be driven by a combination of factors interacting, particularly, grazing regime, climate regime and fire regime (Lunt *et al.* 2012). Once it has happened, it can be very difficult to shift back to a non-woody (i.e. grassy) system (Westoby *et al.* 1989; e.g. Suding *et al.* 2004). In Australian systems, this process has been discussed for well over a century (see Noble 1997). More recently studies have also implicated a lack of apex predators (Gordon *et al.* 2016) and missing granivore ecological function due to loss of critical weight range mammals (Mills *et al.* 2018) in the shrub encroachment process.

Another key pattern of change was the intensification of land use (e.g. increase in plantation (hardwood) and orchards/vineyards) across the higher rainfall natural resources management regions of South Australia. Intensification with respect to orchard/vineyards was also detected in the Northern & Yorke NRM Region (see Figures 34 and 35). These represent shifts in land cover from extensive agricultural systems (cropping and grazing) to intensive systems. This shift has also been noted worldwide and is strongly associated with intensification of use of water resources (Meyer and Turner 1992; Vörösmarty *et al.* 2010; Davis *et al.* 2015). Wetlands are particularly susceptible to impacts from water resource development (Brinson and Malvárez 2002), and an estimated two-thirds reduction in global wetland area occurring since 1900 has been mainly attributed to the direct actions of humans (Davidson 2014). It is therefore likely that a corresponding decline in wetland cover in higher rainfall natural resources management regions (although with low confidence in the Northern and Yorke NRM Region) is attributable, at least partially, to land use intensification and its associated impacts on water resources. Individual-wetland-scale studies in the South East provide further evidence to support the link between land and water use intensification and decline in wetland area, but also highlight the importance of declining rainfall (Harding *et al.* 2015; Harding *et al.* 2017).

5.2 Comparison of native vegetation per cent cover derived from SAVeg with that from the most likely layers

As described in the introduction the native vegetation per cent cover in South Australia was previously based on SAVeg (DEWNR 2017a). The limitations of SAVeg had been the subject of discussion for several years (O'Connor 2009; e.g. Pisanu 2010), with users keen to see improvements in mapping:

- small areas of native vegetation such as clumps of paddock trees
- open woodlands used for grazing
- linear strips such as roadsides and drainage lines
- areas of non-woody native vegetation such as grasslands
- areas of regrowth since original mapping.

It is therefore not surprising that results from the most likely layers estimate a higher native vegetation per cent cover than SAVeg for a number of natural resources management regions (Table 11). It is worth reinforcing here that this is due to the new method of mapping and delineation of native vegetation per cent cover and not because of any change in actual native vegetation cover. For example, using the new method, linear vegetation (roadside and riparian), wetland vegetation, grasslands and small patches of vegetation are now mapped. Figure 47 provides a simple, visual example of this comparison between the most likely layers and SAVeg.

Visual inspection of the new land cover layers shows there are instances in which misclassification of land cover classes by the modelling process has occurred. As these errors are investigated, it is possible these results may change, depending on the extent of misclassification error. As discussed in the limitations section, one key driver of misclassification error are distinguishing non-woody native vegetation and dryland agriculture in the low-rainfall system.

While the new land cover layers have some misclassification, they have considerable advantages in representing the distribution of native vegetation in comparison to SAVeg:

- the model predicts the distribution of a number of land cover classes including native vegetation - allowing exploration of transitions between land covers (e.g. what is driving native vegetation change in different regions)
- due to the time series, changes in the distribution of native vegetation (and other land cover classes) through time can be tracked in a repeatable way (e.g. see the section [Using these data to report on native vegetation extent]).

A quick summary of the known error types in SAVeg and the Land Cover Layers:

- SAVeg misclassification is dominated by 'false-negatives' in which the mapping suggests there is no native vegetation where native vegetation is likely
- Land cover layers misclassification is dominated by 'false-positives' in which the mapping suggests there is native vegetation where native vegetation is unlikely. These false-positives are mainly due to limitations distinguishing non-woody native vegetation and dryland agriculture

Table 11 Change in native vegetation per cent cover estimates based on the new land cover layers

NRM Region	Previous	New	Change
Adelaide and Mt Lofty Ranges	13	32	19
Alinytjara Wilurara	100	100	0
Eyre Peninsula	46	51	5
Kangaroo Island	52	59	7
Northern and Yorke	37	36	-1
South Australian Arid Lands	94	96	2
South Australian Murray-Darling Basin	53	61	8
South East	17	31	14

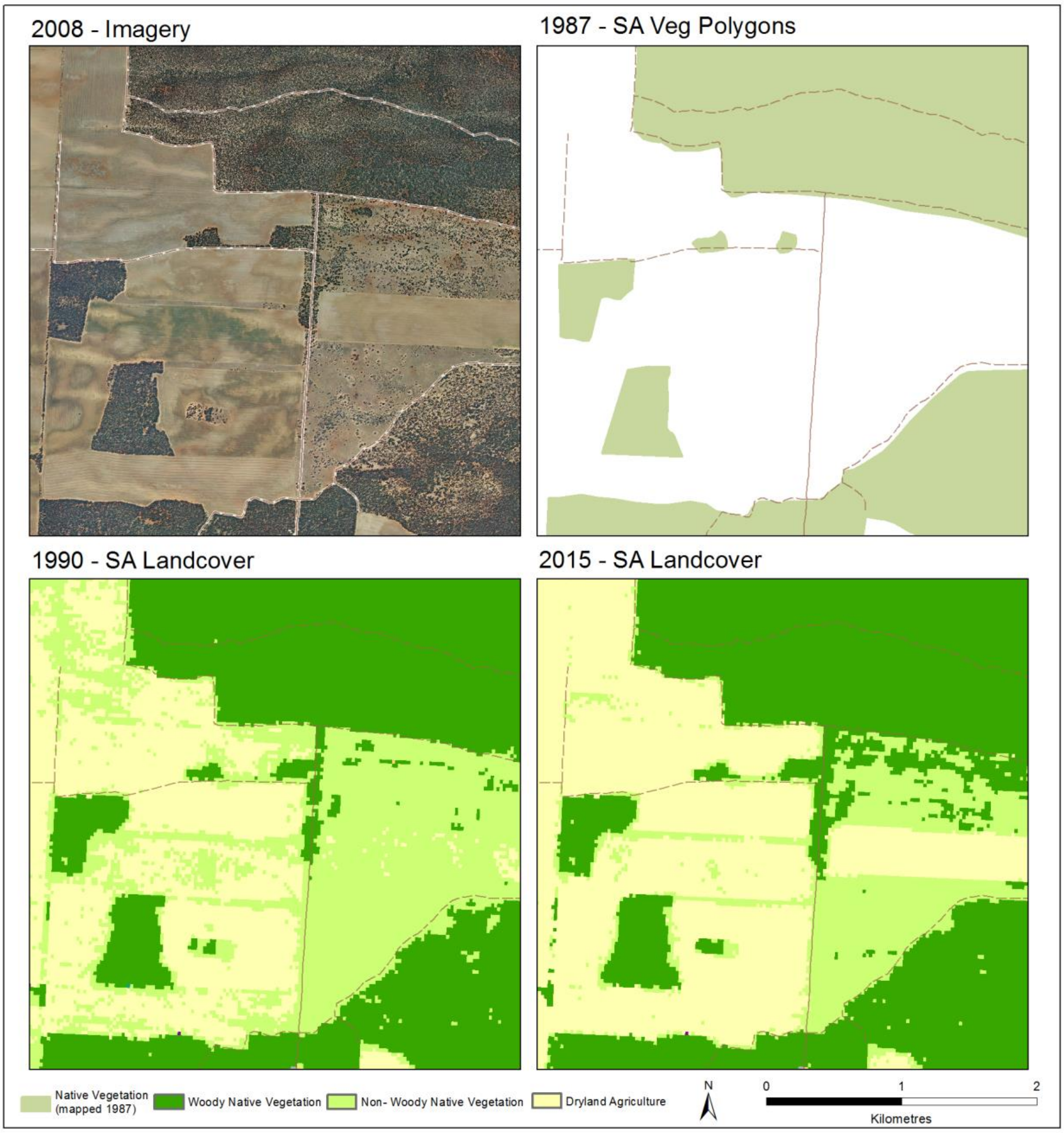

Figure 47 This example compares the most likely layers with previous mapping of native vegetation extent (SAVeg) and available aerial photography. Native vegetation areas (SAVeg polygons) were mapped in 1987, aerial photography is 2008. The most likely layers show more extensive native vegetation than polygon mapping (particularly native pastures but also native treed areas). The 2010-2015 layer shows increased native treed areas compared with 1987-1990 as well as changes in the mix between native grassland and dryland cropping.

5.3 Reporting on the trend and condition of native vegetation per cent cover

It is possible to use these results to report against a target in the state natural resources management plan (*Our Place Our Future*): Increase extent and improve condition of native vegetation (Government of South Australia 2012). However, particularly due to limitations distinguishing non-woody native vegetation and dryland agriculture in the low-rainfall system these trends and statistics should be treated as preliminary and likely to change in future versions.

At the scale of the **whole state**, native vegetation per cent cover was **decreasing** between 1990 and 2015. The 2015 condition of native vegetation per cent cover was **variegated**. This result is in contrast to previous reporting on native vegetation extent in South Australia which suggested the trend between 1999 and 2014 was stable as, 'remaining native vegetation has been protected by legislation since 1991, so both the extent and connectivity have stabilised' (Government of South Australia 2014; Government of South Australia 2016). This change is due to the availability of data that, for the first time, allows trends in land cover to be determined. It seems likely that this change, and the data it is based on, will lead to discussion regarding the definition of native vegetation and suitable methods for spatially applying that definition. For example, three key definitions of native vegetation are now discernible in South Australia:

- the subjective decisions of individuals drawing polygons in SAVeg (Pisanu 2010; DEWNR 2017a)
- the modeled results presented here based on the methods described in White and Griffioen (2016)
- 'a plant or plants of a species indigenous to South Australia including a plant or plants growing in or under waters of the sea' (*Native Vegetation Act 1991*).

In **arid** natural resources management regions, native vegetation per cent cover was **stable** between 1990 and 2015 and the 2015 condition of native vegetation per cent cover was **intact**.

In **high-rainfall** natural resources management regions, native vegetation per cent cover has been **stable** between 1990 and 2015 and the current condition of native vegetation per cent cover is **fragmented**. There was a loss of approximately 2.68 per cent cover of native vegetation over that period.

In **low-rainfall** natural resources management regions, native vegetation per cent cover has been **decreasing** between 1990 and 2015 and the current condition of native vegetation per cent cover is **fragmented**. There was a loss of approximately 2.69 per cent cover of native vegetation over that period.

Based on the land cover class results, particularly the Low-rainfall system, where native vegetation has been lost it is predominantly from the 'non-woody native vegetation' land cover class. There is good confidence that some of this loss was to 'woody native vegetation'. Confidence in the total amount lost to 'dryland agriculture' is not good due to the limitations in distinguishing non-woody native vegetation and dryland agriculture. However, there can be some confidence in the trend as there are instances where the loss is visible (e.g. Figure 15).

5.4 Limitations

Like all models, the limits of the most likely layers must be understood for its utility and value to be realised in any particular application. Some limitations suggest that the most likely layers are not necessarily the most appropriate dataset for certain land cover extent and change questions. In assessing the use of the most likely layer to any particular application, the following should be kept in mind:

- These are first release products of the modelling and validation and testing continues to improve our understanding of the applicability of the outputs to any given scenario or question. Care should be taken if relying on small-scale summary statistics and/or small or uncertain changes as later versions may result in changes to statistics

- The land cover layers provide valuable lines of evidence in addition to existing data, not necessarily instead of them. Decisions should be made on a case-by-case basis of the most appropriate data source(s) to use
- The minimum scale for effective viewing of the data is 1:50,000. This is because the minimum resolvable unit is a 25 m × 25 m pixel. (i.e. land covers smaller than that cannot be identified). The minimum resolvable unit on a physical page is 0.5mm, and when that represents 25m, the scale of such a map is 1:50,000
- The most likely layers are known to contain some classification issues. Future versions may reduce these errors and all feedback enabling this is helpful. If such errors are significant to a particular application, the 'continuous layers' can be referred to for further information
- The summary land cover statistics presented show change over time in many cases, but there were also cases where the variability of the data did not enable any statistical confidence in trends observed
- In some instances there is variability in the most likely layers that is implausible.

5.4.1 Non-woody native vegetation and dryland agriculture classes

The distinction between non-woody native vegetation and dryland agriculture was problematic. Low areas of vegetation, often dominated by grasses, can be considered to form a continuum from 'best remaining' examples of native grassland through to areas that are continuously cropped. There are three continuous layers (see Table 4) of particular importance to this continuum:

- `Grasslandpasture_native` - the 'best remaining' end of the continuum
  - non-woody native vegetation
- `grasslandpasture_Not_native` - the 'middle-of-the-continuum' thus a mix of native and non-native pasture species but probably under-estimated in the most likely layers
  - dryland agriculure
- `herb_dry_crop` - the crop end of the continuum
  - dryland agriculture

At each end of the continuum the rule set for generating the most likely layers from the continuous layers (White and Griffioen 2016) does well - i.e. the most likely layers do a good job of distinguishing land that is:

- cropped continuously - generally areas that are good for cropping (such as northern Yorke Peninsula or Pinnaroo district), have high likelihoods in the continuous `herb_dry_crop` layer, and are mapped to dryland agriculture in the most likely layers
- grazed continuously - generally areas not suitable for cropping (e.g. shallow calcrete landscapes of the Murray Mallee, hillslopes of the ranges in the Mid-North or slopes of the rolling hills in the eastern Mount Lofty Ranges). Grazing in these areas is often on native pastures and they have high likelihoods in the continuous `Grasslandpasture_native` layer and are mapped to non-woody native vegetation in the most likely layers.

The 'middle-of-the-continuum' includes cropping/grazing rotations (typical wheat-sheep belt land management), and grazing land that may be improved from time to time (through addition of non-native pastures and/or fertiliser). These areas are often a mix of native and non-native species probably best categorised as dryland agriculture and would ideally have high values in the continuous layer `grasslandpasture_Not_native`. However, the rule set apparently favours non-woody native vegetation in these areas, particularly in early epochs. This leaves the most likely layers suggesting large areas of the state are a mix of non-woody native vegetation and dryland agriculture when they should be described as dryland agriculture. Visual inspection of aerial imagery of these areas through time is possible via the Google earth engine (https://earthengine.google.com/timelapse/). Reducing misclassification within this 'middle-of-the-continuum' will be a high priority in future versions of the South Australian Land Cover Layers.

5.4.2 Classification issues

The most likely layers contain classification issues termed: 'errors of commission' where a pixel is incorrectly allocated to a class and 'errors of omission' where pixels are incorrectly not allocated to a class. Two examples of this are provided in Figure 48, which shows over estimation of woody native vegetation in an area of Brown Hill Creek near Adelaide, and Figure 49, which shows urban and built up class appearing where ground is being prepared for forestry. Such classification issues arise from a number of known sources. The following list specifies identified sources relating to the most likely layers:

- misclassification of the original training dataset - this degrades the training data used to build the continuous layers
- inherently similar spectral characteristics of different land cover classes - this leads to misclassification of pixels where the similar but incorrect land cover class win the business rules that build the most likely layers from the continuous layers (e.g. Table 6)
- the business rules by which the continuous layers are combined into the most likely layers
- mistakes introduced by the post-processing reclassification
- all users of native vegetation information have their own biases regarding what is and is not native vegetation and they expect to see this in the resulting most likely layers. i.e. Different users consider boundaries around what is native vegetation to fall at different points along a condition continuum

While post-processing of model outputs are aimed at reducing the impact of some of these issues in the first instance, others remain (e.g. Figures 48 and 49). Future iterations of the most likely layers will seek to improve them further.

5.4.3 Trend analysis

Simple linear regression has been used throughout this document. This was done to:

- provide a simple, accessible, easily understood and consistent method for all analyses
- minimise implausible variability - i.e. where the limitations described earlier cause implausible land cover class estimates

Further, the low number of data points available (6, one for each epoch) is only just adequate for such an analysis. Thus, while refinement of these models may in some instances to lead to better estimates of per cent cover of classes, particularly where the trend in per cent cover of a land cover class is clearly non-linear (e.g. plantation (hardwood) on Kangaroo Island - see Figure 6), the data are unlikely to be adequate for estimating more parameters required by more complicated models.

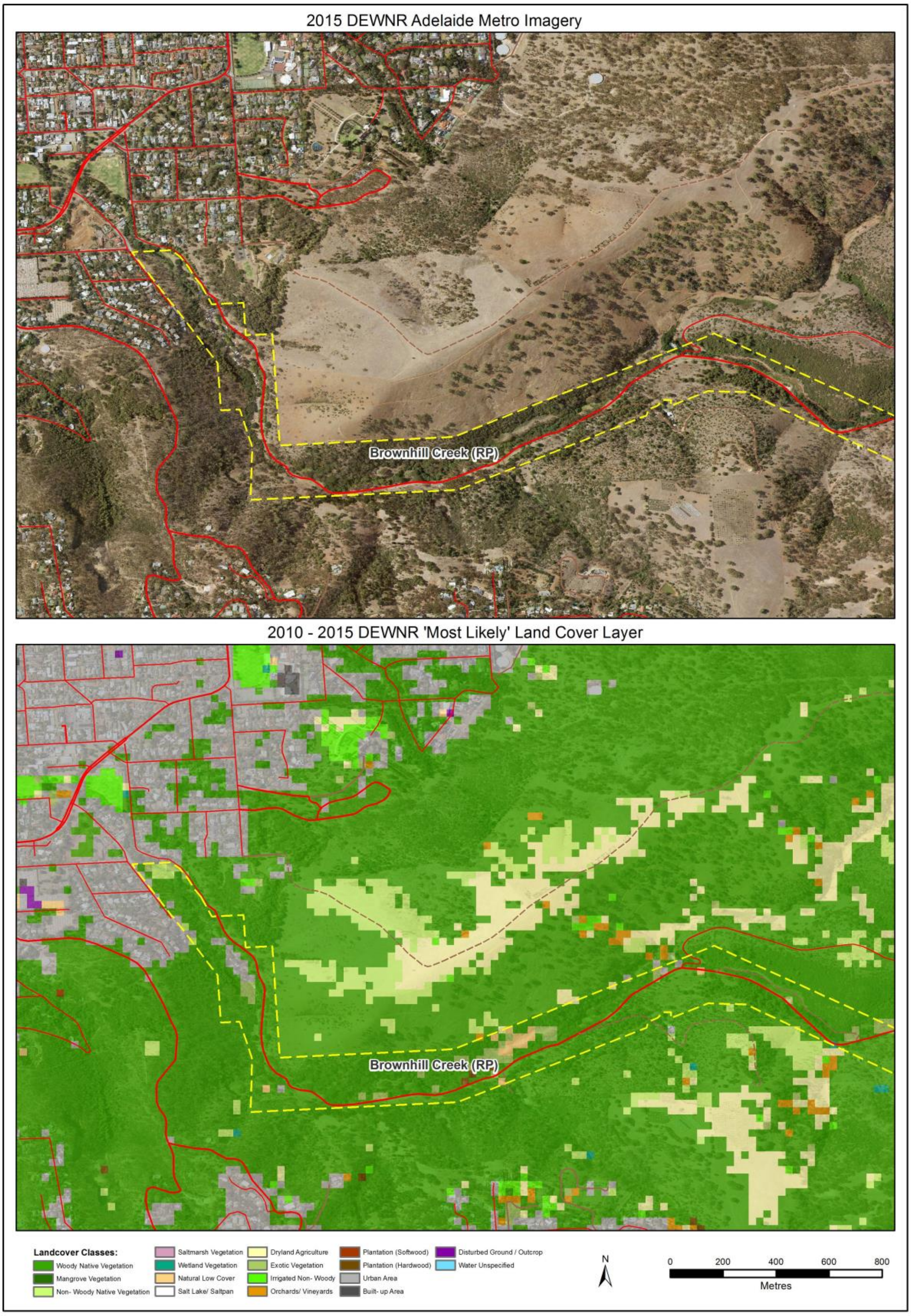

Figure 48 Example from the Brown Hill Creek area of the Mount Lofty Ranges showing over-representation of the woody native vegetation land cover class

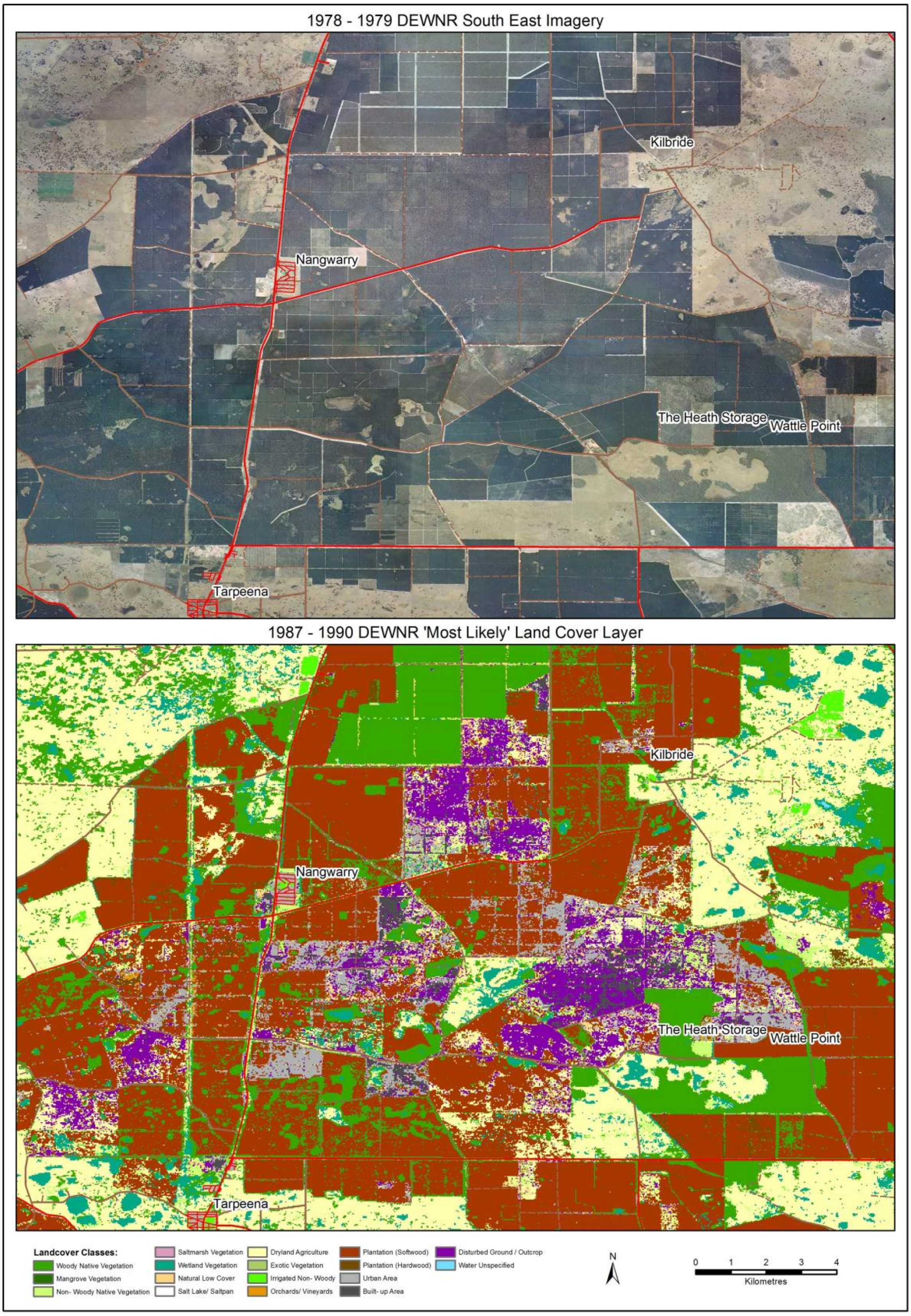

Figure 49 Example from the South East of South Australia showing an area of built-up land cover class appearing where the ground is being prepared for forestry

6 Appendix

Land cover class summary tables for each level of each scale.

6.1 Whole-of-state

Table 12 Land cover type summary for South Australia. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover type	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Native vegetation	86,662,900	88.35	-497,616	Good
Non-native vegetation	9,035,500	9.21	482,660	Good
Other	2,386,100	2.43	12,832	Low

Table 13 Land cover class summary for South Australia. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Woody native vegetation	10,670,525	10.88	492,497	Moderate
Mangrove vegetation	17,060	0.02	756	Good
Non-woody native vegetation	69,083,842	70.43	-890,011	Moderate
Saltmarsh vegetation	35,446	0.04	1,453	Low
Wetland vegetation	252,604	0.26	24,359	Low
Natural low cover	6,630,319	6.76	-89,975	Low
Dryland agriculture	8,679,611	8.85	307,519	Good
Exotic vegetation	12,531	0.01	1,961	Low
Irrigated non-woody	87,351	0.09	32,800	Good
Orchards or vineyards	79,903	0.08	48,684	Good
Plantation (softwood)	110,022	0.11	16,732	Good
Plantation (hardwood)	63,912	0.07	63,912	Good
Salt lake or saltpan	1,729,275	1.76	-20,880	Moderate

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Urban area	105,172	0.11	11,542	Good
Built-up area	9,181	0.01	1,587	Good
Disturbed ground or outcrop	391,774	0.40	18,894	Low
Water unspecified	154,162	0.16	7,458	Low

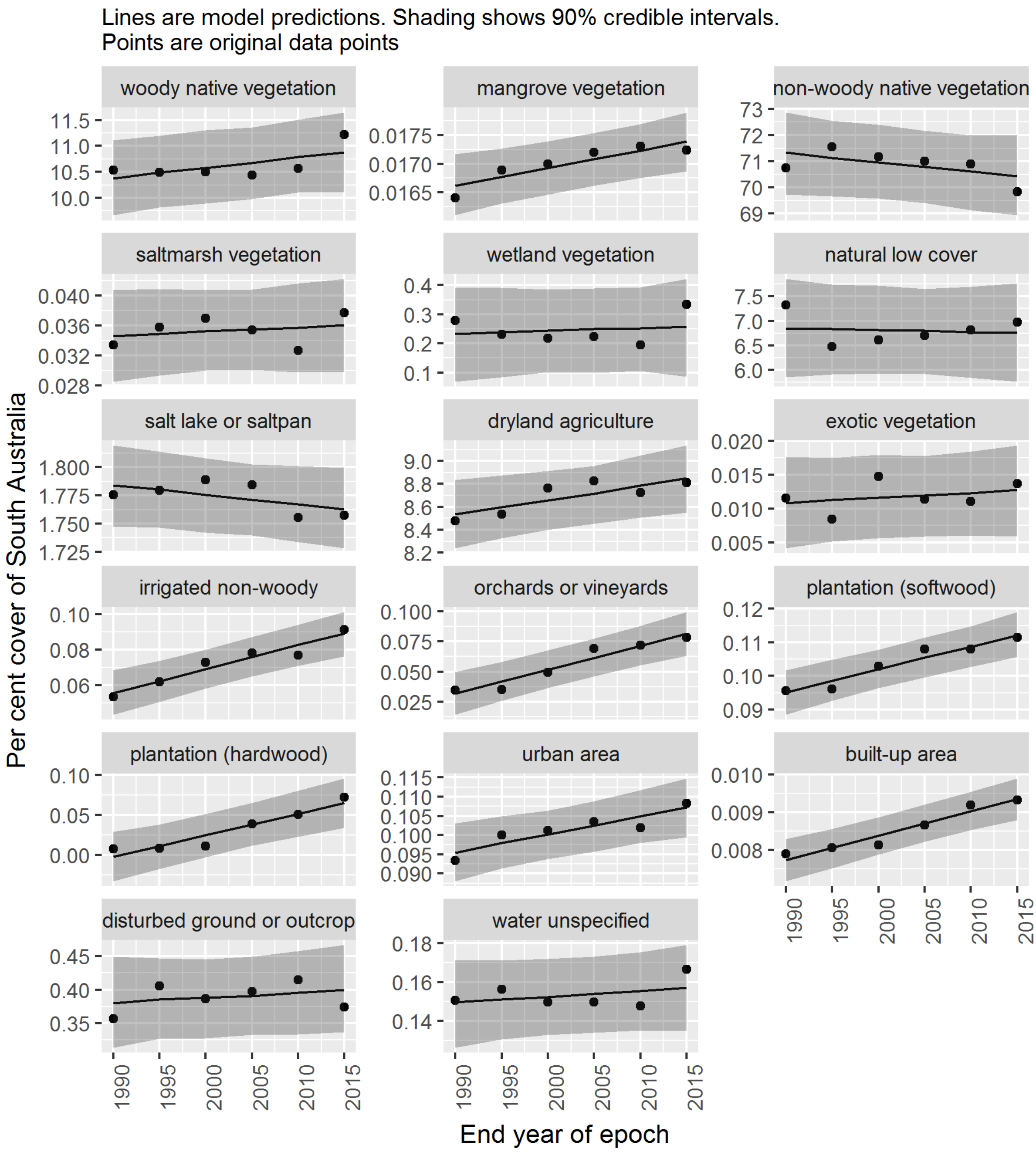

Figure 50 Per cent cover of classes in South Australia during each epoch

6.2 High-rainfall system

Table 14 Land cover type summary for the high-rainfall system. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover type	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Native vegetation	1,312,500	34.71	-101,266	Moderate
Non-native vegetation	2,328,700	61.59	94,887	Good
Other	137,900	3.65	1,075	Low

Table 15 Land cover class summary for the high-rainfall system. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Woody native vegetation	872,705	23.08	-10,850	Low
Mangrove vegetation	3,382	0.09	1	Low
Non-woody native vegetation	300,814	7.96	-41,885	Low
Saltmarsh vegetation	4,633	0.12	795	Moderate
Wetland vegetation	88,539	2.34	-46,054	Good
Natural low cover	39,402	1.04	-2,998	Moderate
Dryland agriculture	2,049,195	54.20	-42,380	Low
Exotic vegetation	9,966	0.26	857	Low
Irrigated non-woody	69,539	1.84	36,849	Good
Orchards or vineyards	35,654	0.94	25,511	Good
Plantation (softwood)	107,193	2.84	16,710	Good
Plantation (hardwood)	61,644	1.63	61,644	Good
Salt lake or saltpan	13,894	0.37	536	Low
Urban area	73,072	1.93	5,198	Good
Built-up area	6,609	0.17	943	Good
Disturbed ground or outcrop	10,874	0.29	-6,392	Good
Water unspecified	33,682	0.89	878	Low

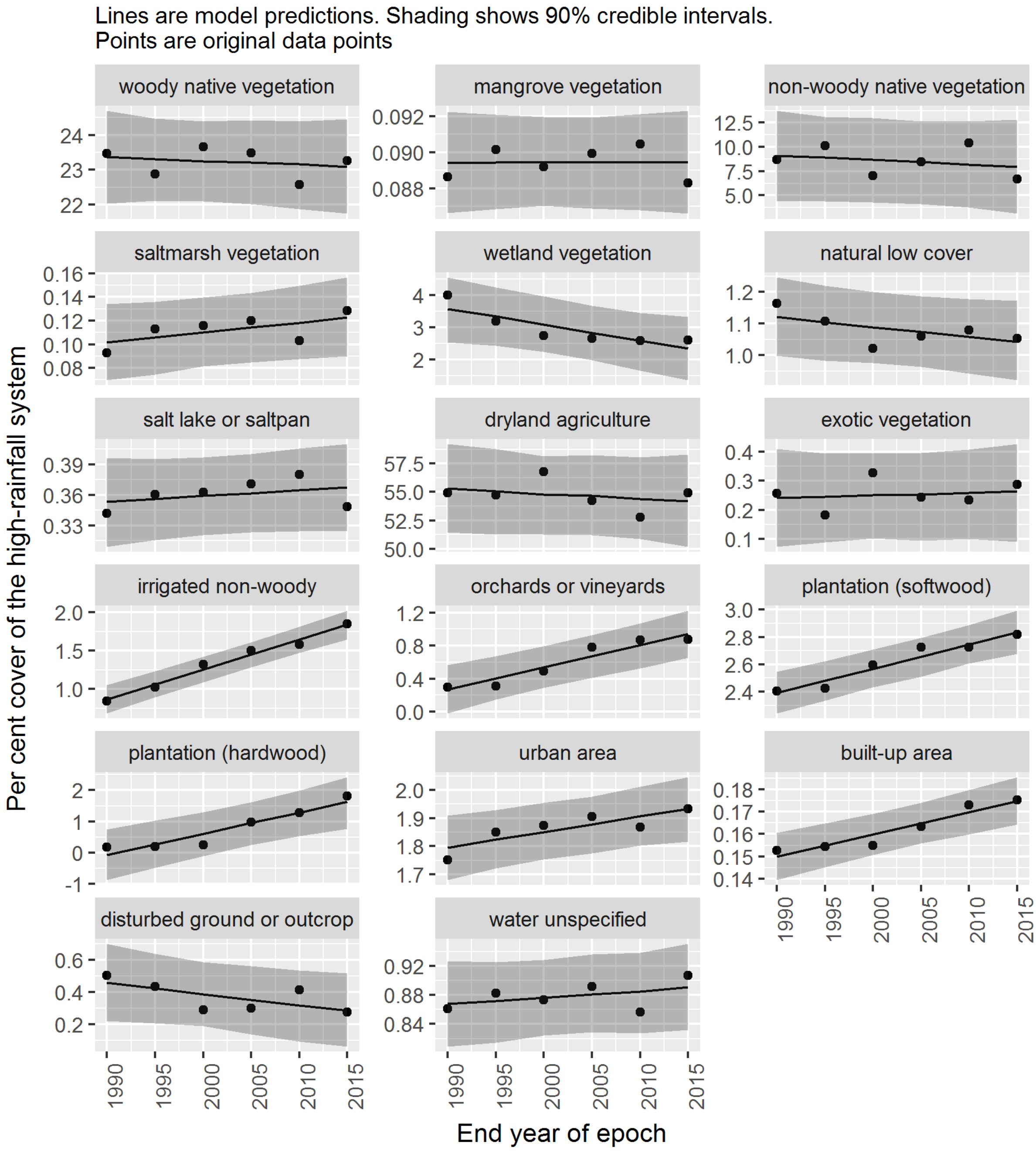

Figure 51 Per cent cover of classes in the high-rainfall system during each epoch

6.3 Low-rainfall system

Table 16 Land cover type summary for the low-rainfall system. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover type	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Native vegetation	7,348,300	51.52	-383,843	Good
Non-native vegetation	6,697,800	46.96	383,950	Good
Other	217,900	1.53	4,578	Moderate

Table 17 Land cover class summary for the low-rainfall system. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Woody native vegetation	3,665,338	25.70	242,794	Good
Mangrove vegetation	13,685	0.10	774	Good
Non-woody native vegetation	3,306,014	23.18	-625,269	Good
Saltmarsh vegetation	21,139	0.15	672	Low
Wetland vegetation	43,927	0.31	-3,668	Low
Natural low cover	288,887	2.03	-7,545	Low
Dryland agriculture	6,628,018	46.47	355,169	Good
Exotic vegetation	2,302	0.02	971	Good
Irrigated non-woody	17,976	0.13	-3,662	Moderate
Orchards or vineyards	43,680	0.31	22,351	Good
Plantation (softwood)	2,931	0.02	100	Low
Plantation (hardwood)	1,604	0.01	797	Good
Salt lake or saltpan	38,777	0.27	-2,819	Good
Urban area	31,716	0.22	6,011	Good
Built-up area	2,317	0.02	527	Good
Disturbed ground or outcrop	35,250	0.25	-1,225	Low
Water unspecified	110,093	0.77	2,625	Moderate

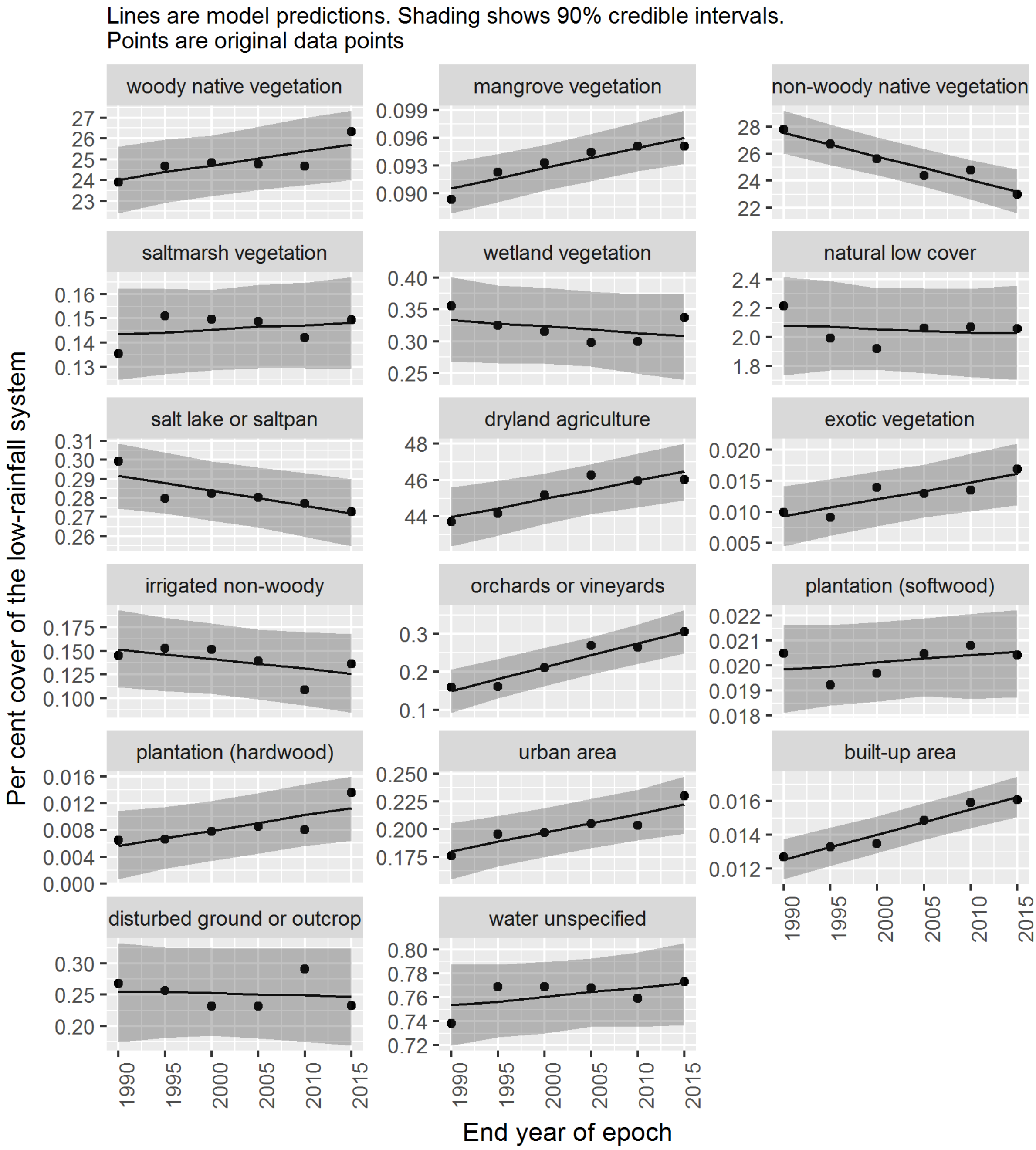

Figure 52 Per cent cover of classes in the low-rainfall system during each epoch

6.4 Arid system

Table 18 Land cover type summary for the arid system. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover type	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Native vegetation	78,010,600	97.45	-9,378	Low
Non-native vegetation	7,300	0.01	824	Low
Other	2,029,900	2.54	6,101	Low

Table 19 Land cover class summary for the arid system. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Woody native vegetation	6,112,197	7.64	262,497	Moderate
Non-woody native vegetation	65,438,992	81.75	-259,964	Low
Saltmarsh vegetation	9,534	0.01	-194	Low
Wetland vegetation	120,787	0.15	77,129	Moderate
Natural low cover	6,298,880	7.87	-84,532	Low
Dryland agriculture	7,090	0.01	791	Low
Exotic vegetation	131	0.00	24	Low
Salt lake or saltpan	1,676,656	2.09	-19,451	Moderate
Urban area	302	0.00	72	Good
Built-up area	234	0.00	70	Good
Disturbed ground or outcrop	344,169	0.43	24,896	Low
Water unspecified	10,829	0.01	3,498	Low

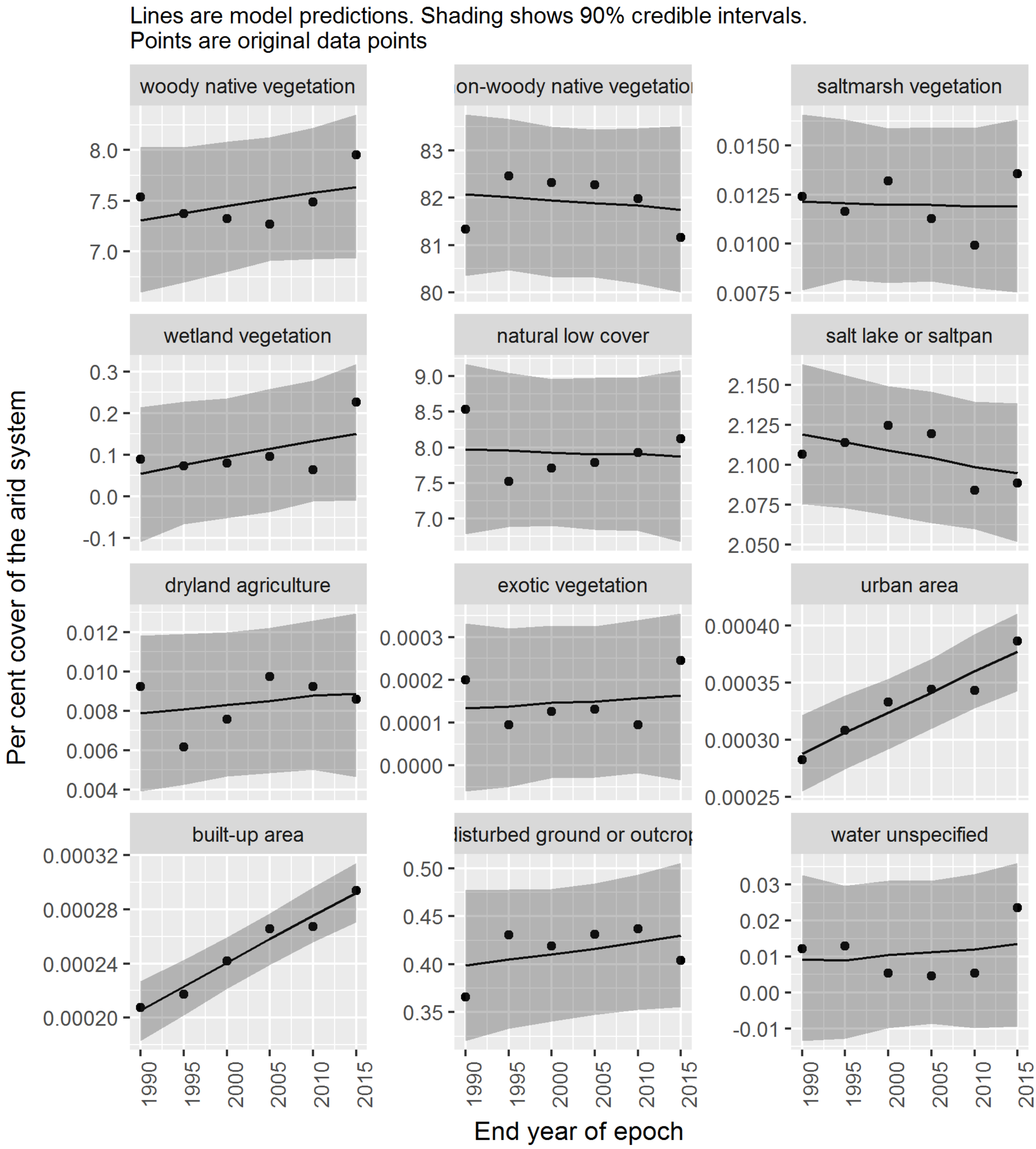

Figure 53 Per cent cover of classes in the arid system during each epoch

6.5 Adelaide and Mount Lofty Ranges Natural Resources Management Region

Table 20 Land cover type summary for the AMLR NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover type	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Native vegetation	212,300	32.00	-14,009	Good
Non-native vegetation	372,600	56.16	7,639	Moderate
Other	78,300	11.80	5,705	Good

Table 21 Land cover class summary for the AMLR NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Woody native vegetation	178,198	26.86	3,458	Low
Mangrove vegetation	3,269	0.49	-16	Low
Non-woody native vegetation	17,560	2.65	-15,369	Good
Saltmarsh vegetation	2,130	0.32	268	Good
Wetland vegetation	4,615	0.70	-2,167	Good
Natural low cover	6,414	0.97	-270	Low
Dryland agriculture	329,512	49.66	-11,703	Good
Exotic vegetation	3,422	0.52	1,216	Good
Irrigated non-woody	12,046	1.82	3,559	Good
Orchards or vineyards	18,115	2.73	12,892	Good
Plantation (softwood)	7,082	1.07	-7	Low
Plantation (hardwood)	2,763	0.42	2,188	Good
Salt lake or saltpan	1,023	0.15	191	Good
Urban area	62,605	9.44	5,042	Good
Built-up area	6,135	0.92	922	Good
Disturbed ground or outcrop	3,491	0.53	-413	Moderate
Water unspecified	5,016	0.76	-11	Low

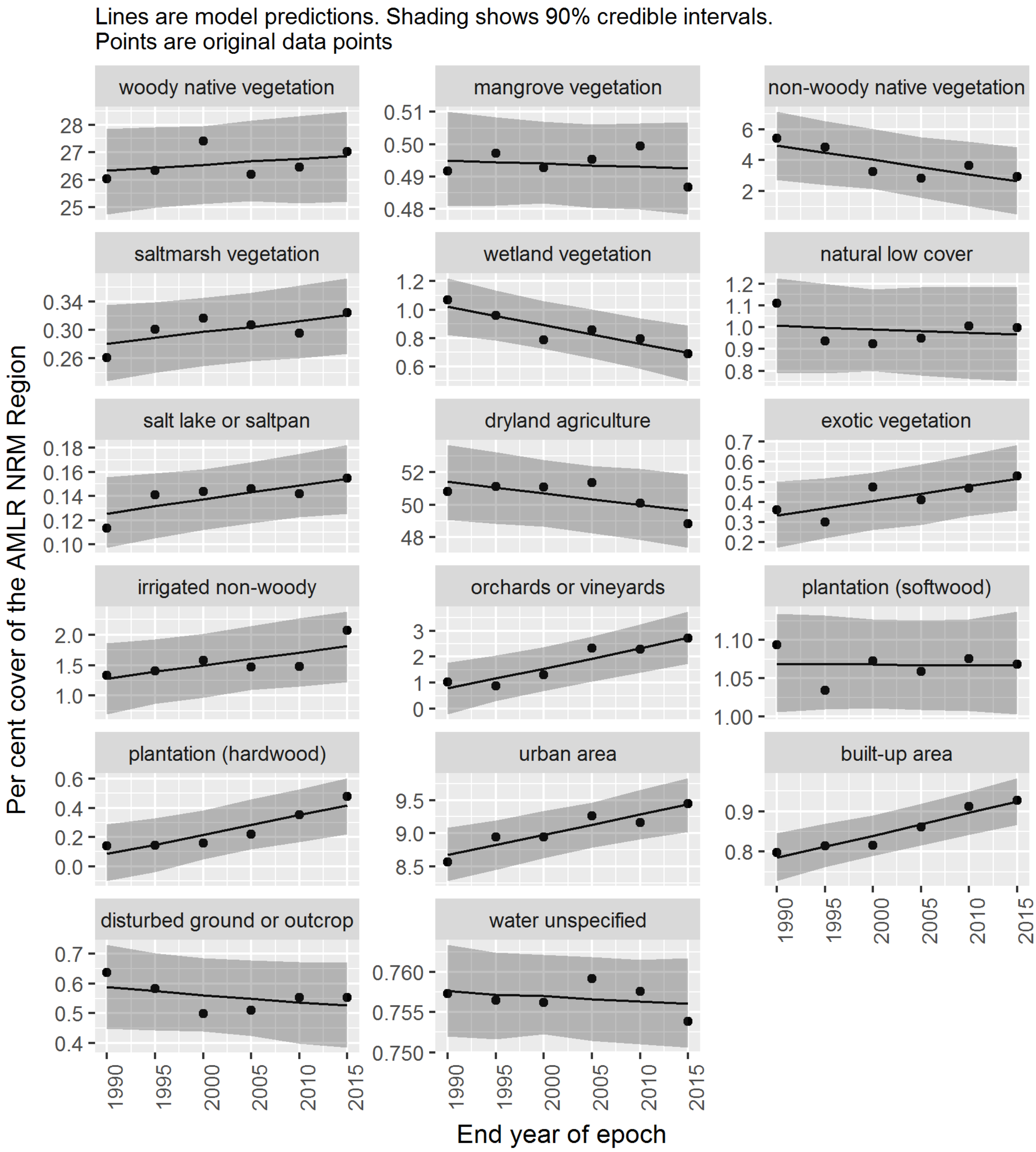

Figure 54 Per cent cover of classes in the AMLR NRM Region during each epoch

6.6 AW NRM Region

Table 22 Land cover type summary for the AW NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover type	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Native vegetation	27,954,500	99.64	-15,065	Good
Non-native vegetation	3,300	0.01	-26	Low
Other	97,900	0.35	15,480	Good

Table 23 Land cover class summary for the AW NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Woody native vegetation	3,698,370	13.18	59,416	Low
Non-woody native vegetation	23,627,073	84.22	-126,964	Moderate
Saltmarsh vegetation	193	0.00	69	Moderate
Wetland vegetation	80	0.00	-167	Good
Natural low cover	623,291	2.22	52,180	Low
Dryland agriculture	3,297	0.01	8	Low
Salt lake or saltpan	73,699	0.26	10,996	Good
Disturbed ground or outcrop	23,938	0.09	3,930	Moderate
Water unspecified	73	0.00	73	Good

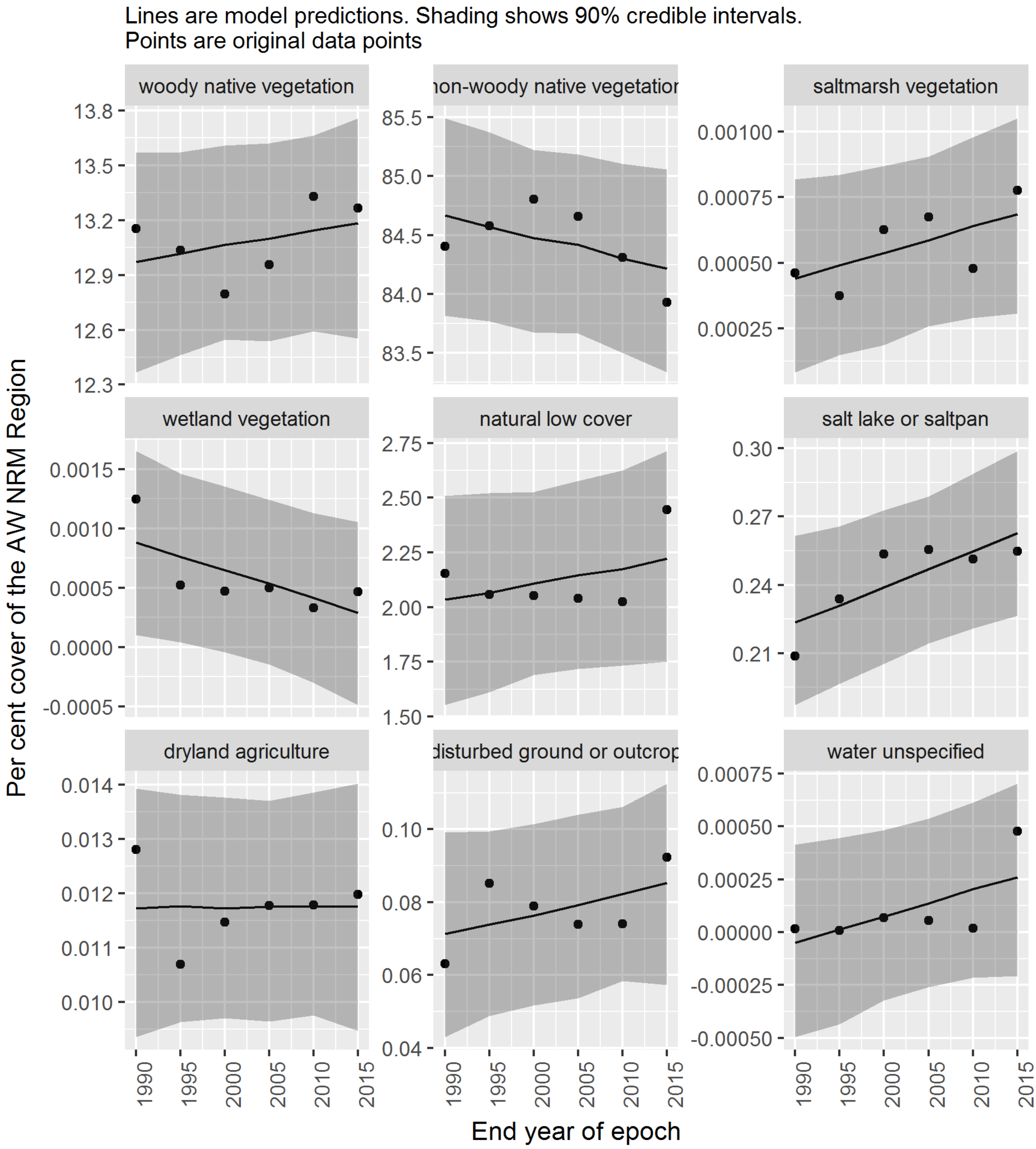

Figure 55 Per cent cover of classes in the AW NRM Region during each epoch

6.7 EP NRM Region

Table 24 Land cover type summary for the EP NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover type	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Native vegetation	2,642,000	51.05	-134,614	Good
Non-native vegetation	2,471,700	47.76	127,634	Good
Other	57,500	1.11	1,895	Low

Table 25 Land cover class summary for the EP NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Woody native vegetation	1,537,845	29.71	90,181	Good
Mangrove vegetation	5,811	0.11	283	Good
Non-woody native vegetation	946,154	18.28	-219,157	Good
Saltmarsh vegetation	6,903	0.13	739	Good
Wetland vegetation	7,230	0.14	517	Low
Natural low cover	137,392	2.65	-9,055	Low
Dryland agriculture	2,471,286	47.75	128,649	Good
Exotic vegetation	290	0.01	201	Good
Irrigated non-woody	646	0.01	278	Moderate
Orchards or vineyards	485	0.01	299	Good
Plantation (softwood)	46	0.00	4	Low
Plantation (hardwood)	132	0.00	100	Good
Salt lake or saltpan	24,514	0.47	440	Low
Urban area	7,335	0.14	1,346	Good
Built-up area	885	0.02	176	Good
Disturbed ground or outcrop	21,598	0.42	-307	Low
Water unspecified	3,201	0.06	343	Moderate

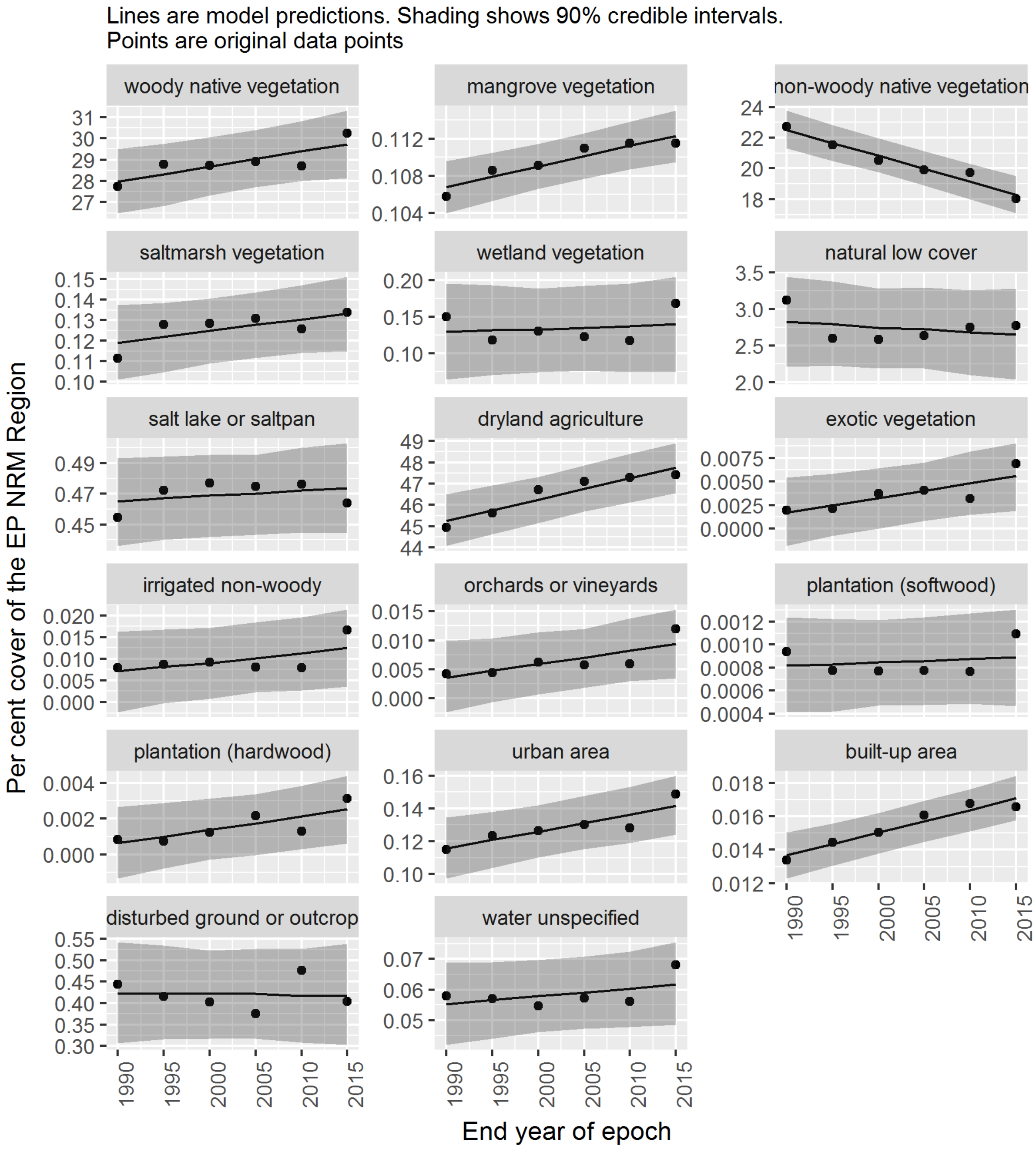

Figure 56 Per cent cover of classes in the EP NRM Region during each epoch

6.8 KI NRM Region

Table 26 Land cover type summary for the KI NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover type	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Native vegetation	260,900	59.31	-1,908	Moderate
Non-native vegetation	173,900	39.53	2,123	Moderate
Other	5,400	1.23	178	Low

Table 27 Land cover class summary for the KI NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Woody native vegetation	235,875	53.63	16	Low
Mangrove vegetation	94	0.02	6	Low
Non-woody native vegetation	8,512	1.94	-541	Low
Saltmarsh vegetation	602	0.14	12	Low
Wetland vegetation	9,209	2.09	-1,924	Good
Natural low cover	6,413	1.46	376	Low
Dryland agriculture	155,635	35.38	-11,188	Good
Exotic vegetation	1,802	0.41	-2,365	Good
Irrigated non-woody	382	0.09	-83	Low
Orchards or vineyards	361	0.08	112	Low
Plantation (softwood)	3,619	0.82	1,399	Good
Plantation (hardwood)	12,716	2.89	12,716	Good
Salt lake or saltpan	671	0.15	-78	Low
Urban area	1,532	0.35	400	Good
Built-up area	101	0.02	-16	Good
Disturbed ground or outcrop	785	0.18	-259	Good
Water unspecified	2,272	0.52	95	Low

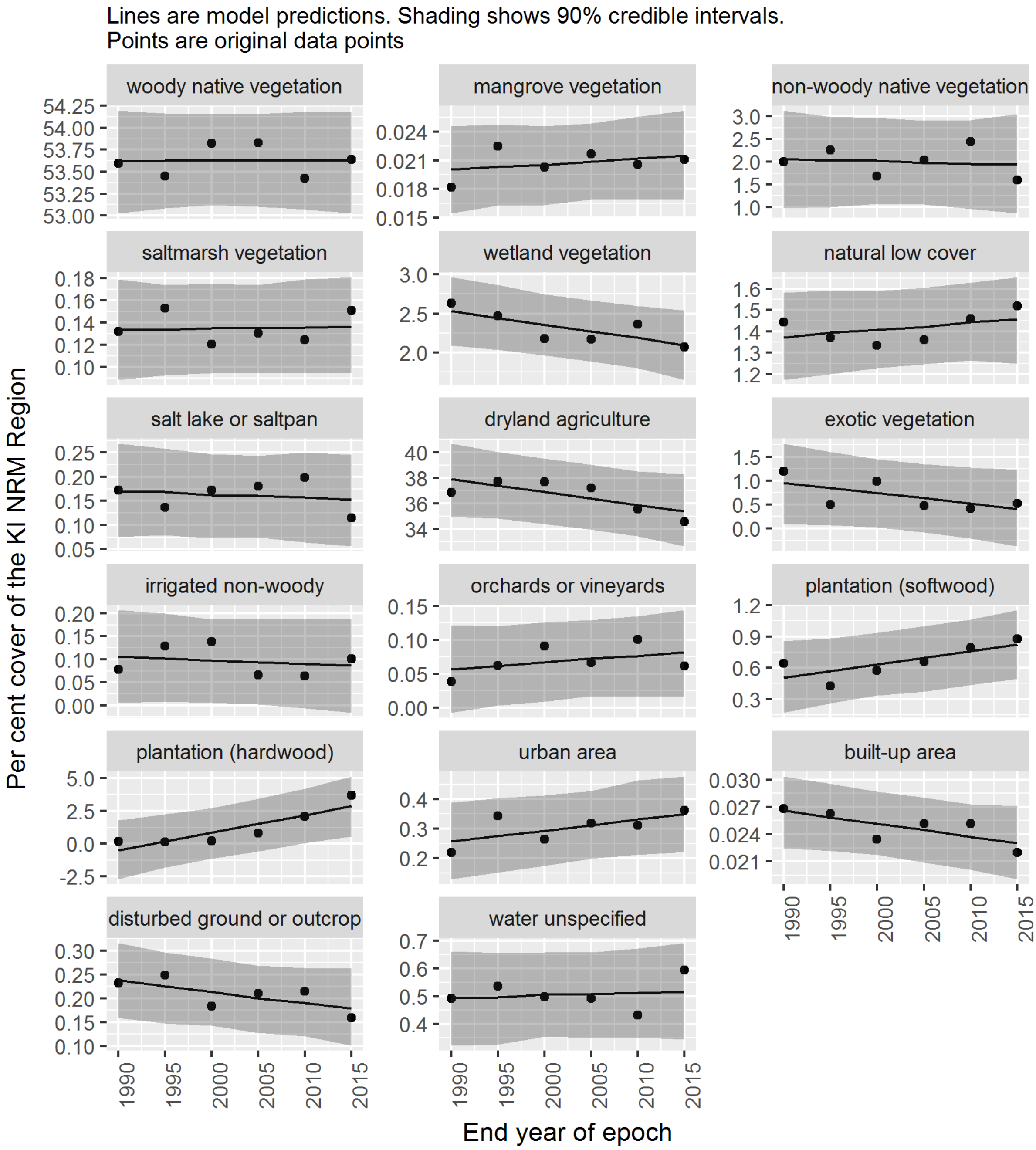

Figure 57 Per cent cover of classes in the KI NRM Region during each epoch

6.9 NY NRM Region

Table 28 Land cover type summary for the NY NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover type	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Native vegetation	1,258,600	36.37	-132,861	Good
Non-native vegetation	2,171,900	62.76	134,397	Good
Other	31,800	0.92	2,803	Good

Table 29 Land cover class summary for the NY NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Woody native vegetation	334,162	9.66	30,742	Good
Mangrove vegetation	7,869	0.23	485	Good
Non-woody native vegetation	817,216	23.61	-169,666	Good
Saltmarsh vegetation	12,103	0.35	-23	Low
Wetland vegetation	4,474	0.13	-384	Moderate
Natural low cover	81,271	2.35	670	Low
Dryland agriculture	2,162,172	62.48	129,033	Good
Exotic vegetation	321	0.01	191	Good
Irrigated non-woody	1,938	0.06	298	Low
Orchards or vineyards	3,713	0.11	2,978	Good
Plantation (softwood)	1,014	0.03	-14	Low
Plantation (hardwood)	481	0.01	-52	Low
Salt lake or saltpan	12,144	0.35	451	Moderate
Urban area	12,213	0.35	2,142	Good
Built-up area	814	0.02	168	Good
Disturbed ground or outcrop	4,883	0.14	202	Low
Water unspecified	1,859	0.05	-104	Low

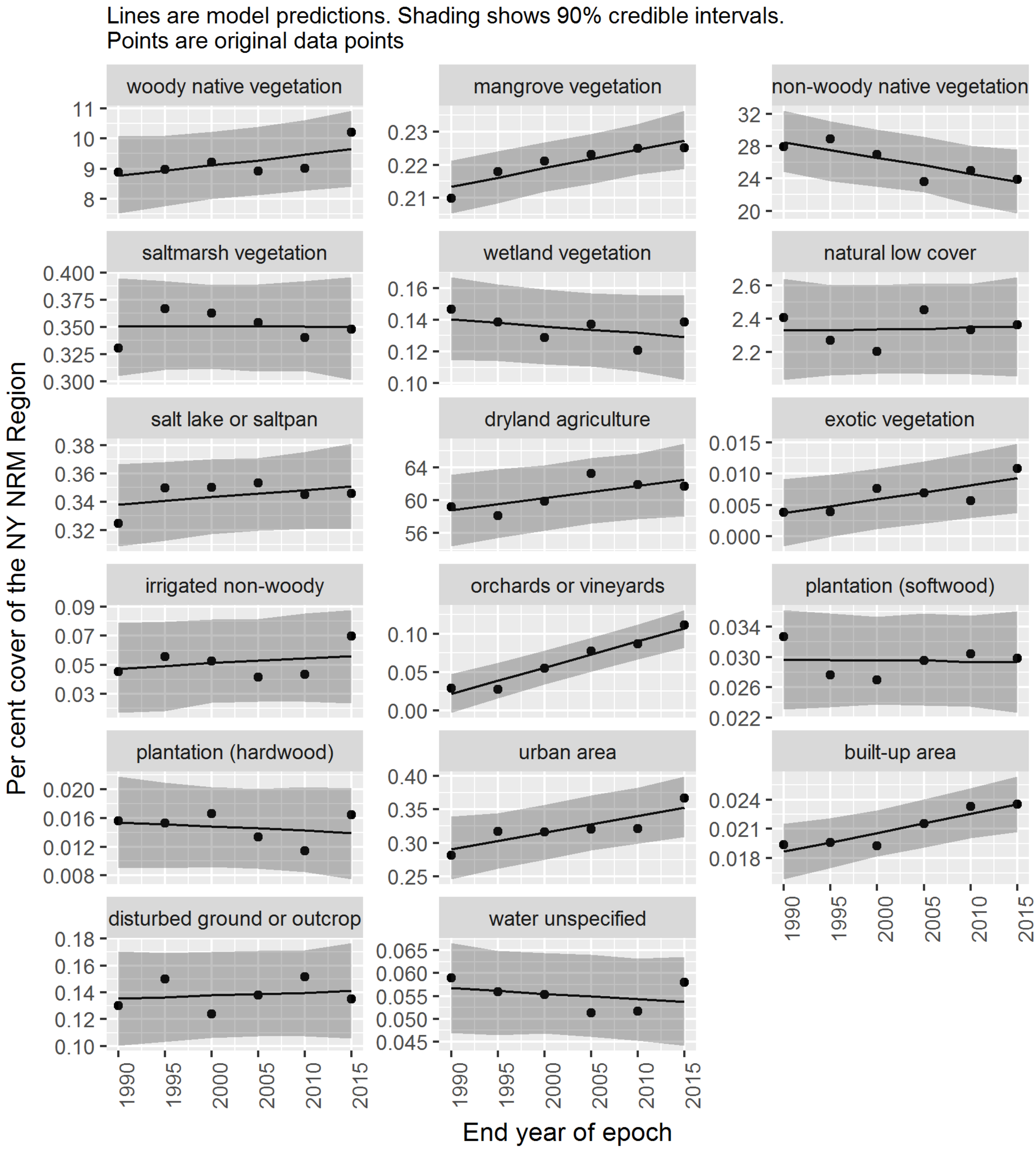

Figure 58 Per cent cover of classes in the NY NRM Region during each epoch

6.10 SAAL NRM Region

Table 30 Land cover type summary for the SAAL NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover type	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Native vegetation	50,055,900	96.27	5,535	Low
Non-native vegetation	4,100	0.01	961	Low
Other	1,935,200	3.72	-3,192	Low

Table 31 Land cover class summary for the SAAL NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Woody native vegetation	2,423,005	4.66	201,238	Low
Non-woody native vegetation	41,811,455	80.42	-141,053	Low
Saltmarsh vegetation	9,395	0.02	-114	Low
Wetland vegetation	119,025	0.23	70,608	Moderate
Natural low cover	5,681,873	10.93	-136,433	Low
Dryland agriculture	3,868	0.01	857	Low
Exotic vegetation	130	0.00	26	Low
Salt lake or saltpan	1,602,092	3.08	-30,921	Good
Urban area	300	0.00	72	Good
Built-up area	234	0.00	69	Good
Disturbed ground or outcrop	319,059	0.61	19,022	Low
Water unspecified	10,283	0.02	3,570	Low

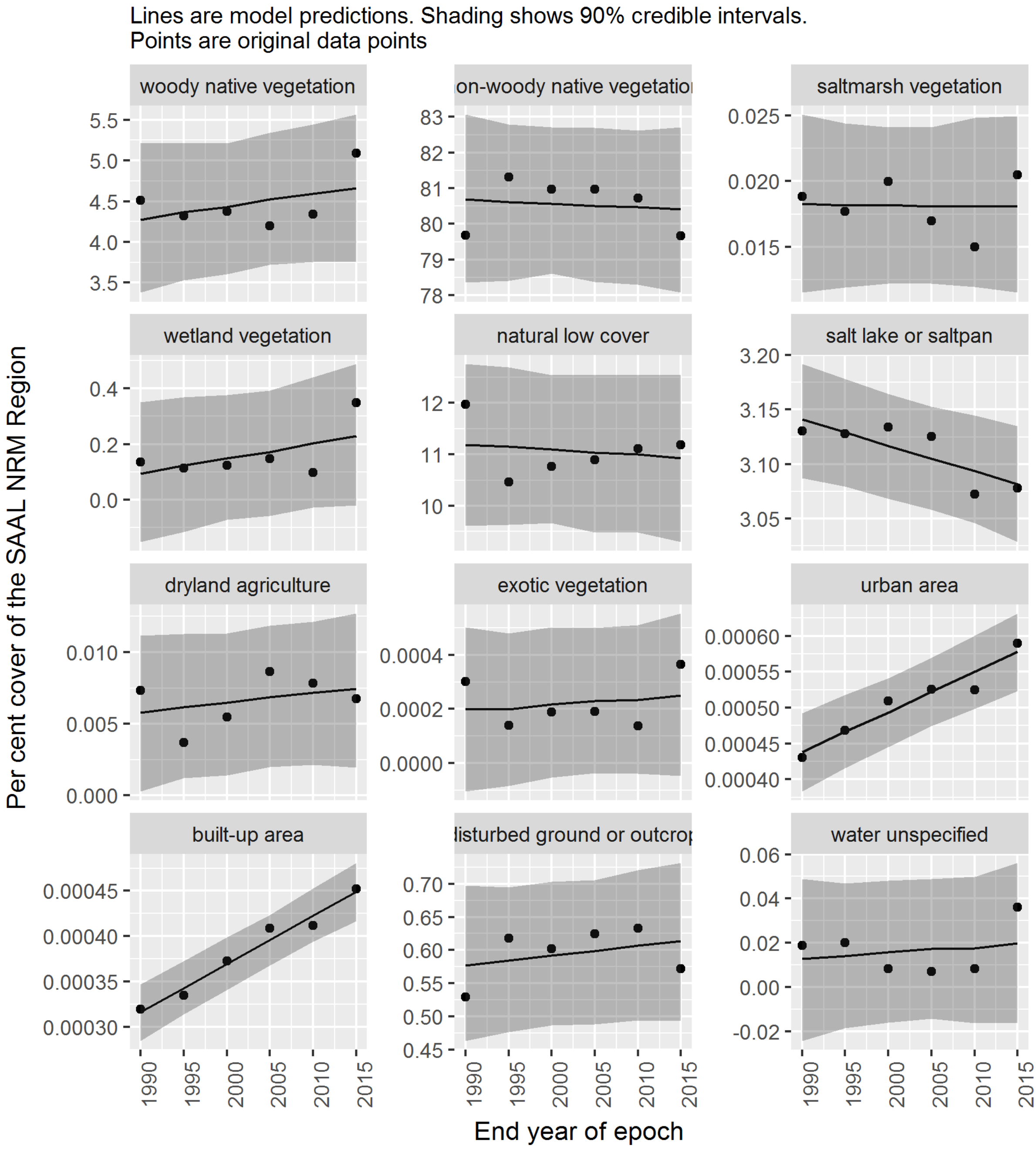

Figure 59 Per cent cover of classes in the SAAL NRM Region during each epoch

6.11 SAMDB NRM Region

Table 32 Land cover type summary for the SAMDB NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover type	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Native vegetation	3,443,400	61.21	-118,535	Good
Non-native vegetation	2,052,900	36.49	114,490	Good
Other	128,800	2.29	225	Low

Table 33 Land cover class summary for the SAMDB NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Woody native vegetation	1,796,448	31.93	121,025	Good
Non-woody native vegetation	1,544,241	27.45	-229,953	Good
Saltmarsh vegetation	2,189	0.04	37	Low
Wetland vegetation	32,412	0.58	-3,632	Moderate
Natural low cover	69,302	1.23	-1,028	Low
Dryland agriculture	1,992,631	35.42	98,361	Good
Exotic vegetation	1,667	0.03	537	Good
Irrigated non-woody	15,352	0.27	-4,276	Good
Orchards or vineyards	39,336	0.70	18,792	Good
Plantation (softwood)	1,869	0.03	109	Good
Plantation (hardwood)	1,002	0.02	776	Good
Salt lake or saltpan	2,154	0.04	-3,460	Good
Urban area	12,222	0.22	2,539	Good
Built-up area	617	0.01	183	Good
Disturbed ground or outcrop	8,689	0.15	-1,333	Low
Water unspecified	105,096	1.87	2,543	Moderate

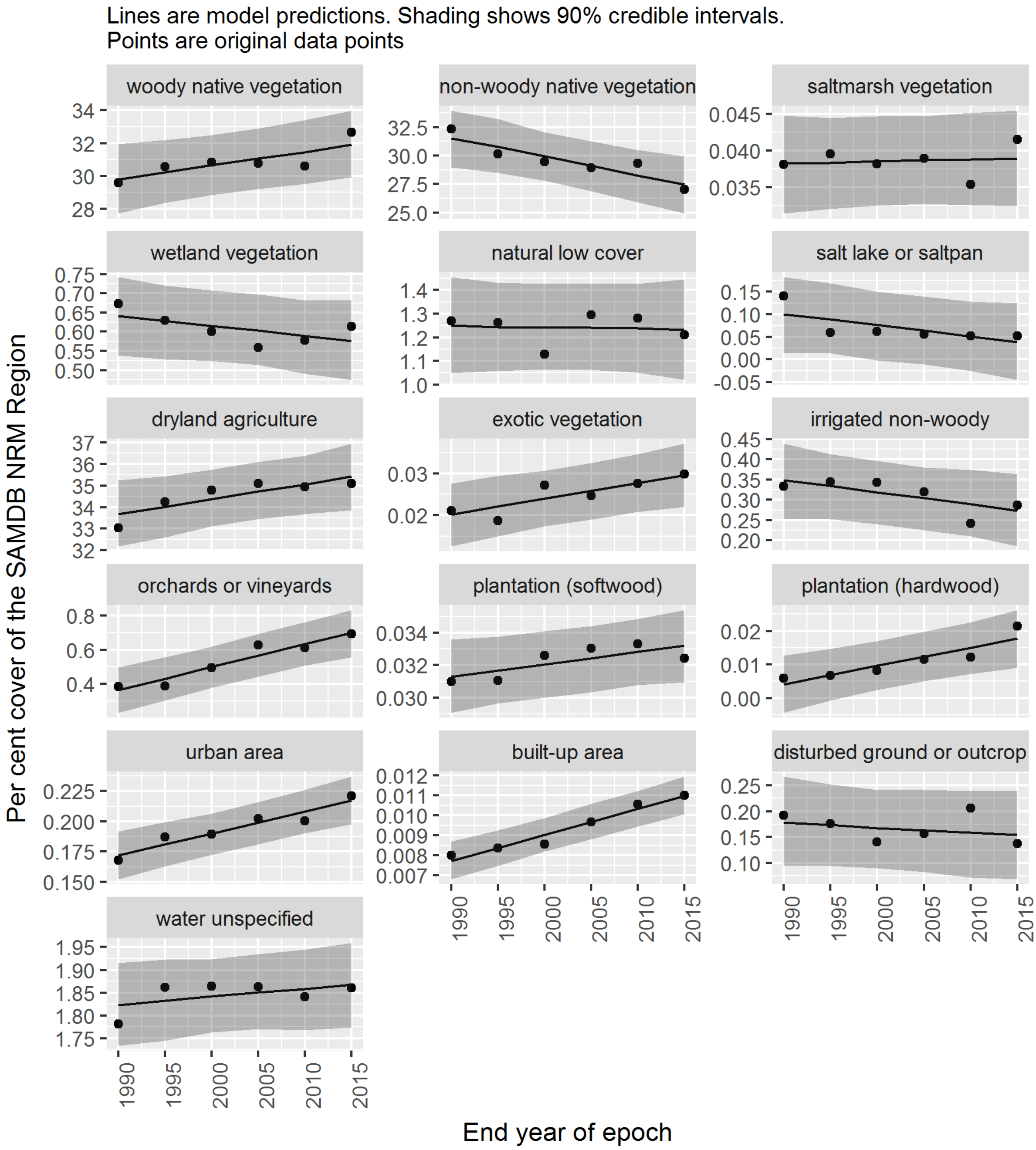

Figure 60 Per cent cover of classes in the SAMDB NRM Region during each epoch

6.12 SE NRM Region

Table 34 Land cover type summary for the SE NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover type	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Native vegetation	839,300	31.35	-82,732	Moderate
Non-native vegetation	1,784,100	66.63	89,669	Moderate
Other	54,600	2.04	-4,445	Good

Table 35 Land cover class summary for the SE NRM Region. Overall percentages are unlikely to sum to one hundred and changes are unlikely to sum to zero due to the use of the regression rather than datapoints to estimate cover in the first and last epochs.

Land cover class	Hectares in 2015	Per cent cover in 2015	Hectares change 1990 to 2015	Confidence in change
Woody native vegetation	458,682	17.13	-13,511	Low
Non-woody native vegetation	280,164	10.46	-22,310	Low
Saltmarsh vegetation	1,896	0.07	515	Moderate
Wetland vegetation	74,744	2.79	-41,955	Good
Natural low cover	26,473	0.99	-3,265	Good
Dryland agriculture	1,564,641	58.44	-18,444	Low
Exotic vegetation	5,113	0.19	2,535	Good
Irrigated non-woody	57,333	2.14	33,687	Good
Orchards or vineyards	17,317	0.65	12,904	Good
Plantation (softwood)	96,499	3.60	15,287	Good
Plantation (hardwood)	46,884	1.75	46,884	Good
Salt lake or saltpan	12,196	0.46	415	Low
Urban area	8,969	0.33	-188	Low
Built-up area	373	0.01	37	Moderate
Disturbed ground or outcrop	6,736	0.25	-5,192	Moderate
Water unspecified	26,370	0.98	783	Moderate

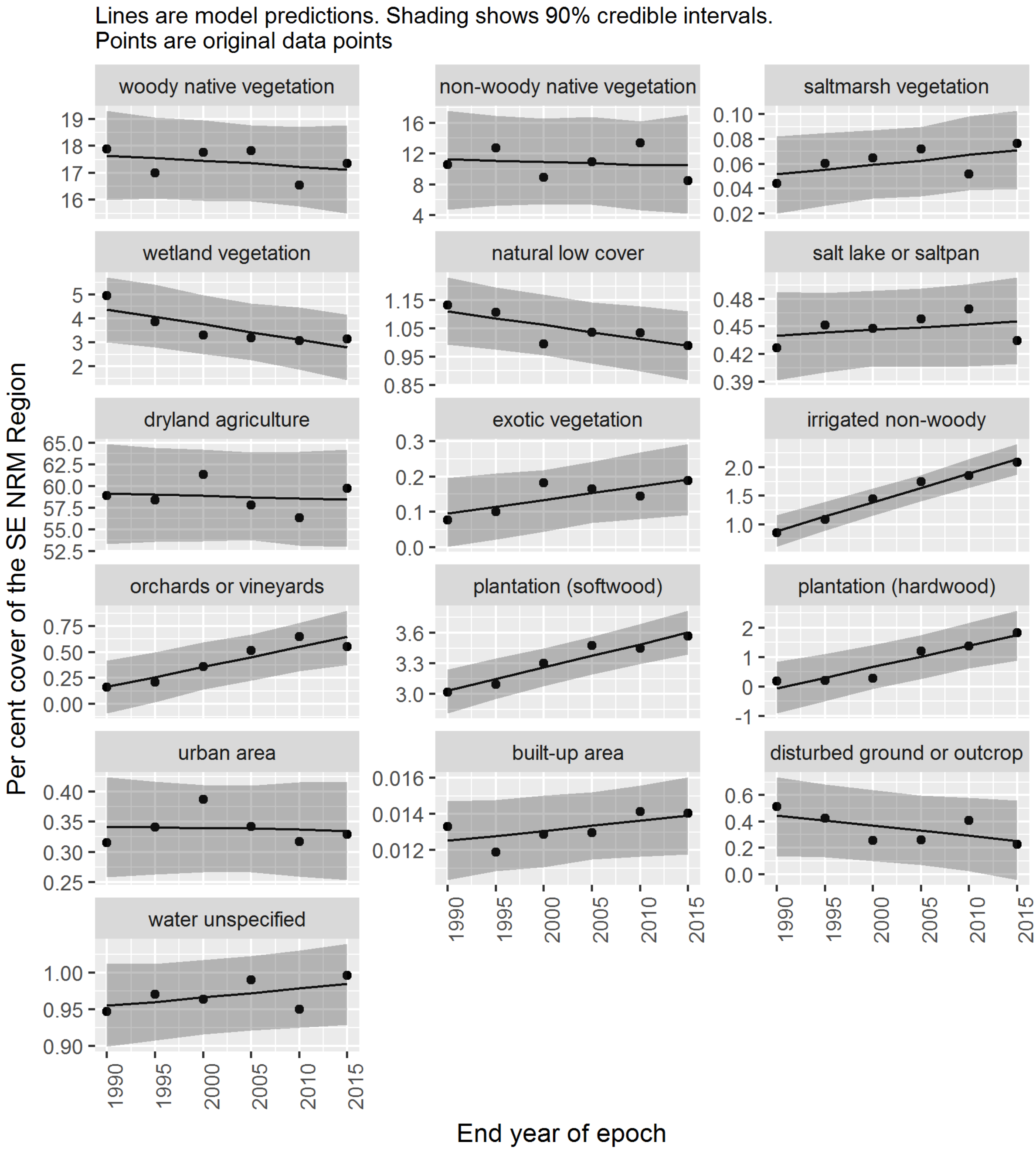

Figure 61 Per cent cover of classes in the SE NRM Region during each epoch

7 References

Allaire, J. J., Cheng, J., Xie, Y., McPherson, J., Chang, W., Allen, J., Wickham, H., Atkins, A., Hyndman, R., and Arslan, R. (2017). rmarkdown: Dynamic Documents for R. R package version 1.5. Report. Available at: https://CRAN.R-project.org/package=rmarkdown

Andrén, H. (1994). Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *Oikos* **71**, 355–366.

Auguie, B. (2016). 'GridExtra: Miscellaneous functions for "grid" graphics'. Available at: https://CRAN.R-project.org/package=gridExtra

Bivand, R., Keitt, T., and Rowlingson, B. (2017). 'Rgdal: Bindings for the geospatial data abstraction library'. Available at: https://CRAN.R-project.org/package=rgdal

Briggs, J. M., Knapp, A. K., Blair, J. M., Heisler, J. L., Hoch, G. A., Lett, M. S., and McCarron, J. K. (2005). An ecosystem in transition. Causes and consequences of the conversion of mesic grassland to shrubland. *Bioscience* **55**, 243–254. doi:10.1641/0006-3568(2005)055[0243:aeitca]2.0.co;2

Brinson, M. M., and Malvárez, A. I. (2002). Temperate freshwater wetlands: types, status, and threats. *Environmental Conservation* **29**, 115–133. doi:http://doi.org/10.1017/S0376892902000085

CSIRO (2015). Soil and Landscape Grid of Australia. Report. CSIRO & Terrestrial Ecosystem Research Network, Canberra. Available at: http://www.clw.csiro.au/aclep/soilandlandscapegrid/index.html

Davidson, N. C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research* **65**, 934–941. doi:http://doi.org/10.1071/MF14173

Davis, J., O'Grady, A. P., Dale, A., Arthington, A. H., Gell, P. A., Driver, P. D., Bond, N., Casanova, M., Finlayson, M., Watts, R. J., Capon, S. J., Nagelkerken, I., Tingley, R., Fry, B., Page, T. J., and Specht, A. (2015). When trends intersect: The challenge of protecting freshwater ecosystems under multiple land use and hydrological intensification scenarios. *Science of The Total Environment* **534**, 65–78. doi:https://doi.org/10.1016/j.scitotenv.2015.03.127

DEWNR (2017a). Native Vegetation Floristic Areas - NVIS - Statewide (Incomplete Version). Report. Department of Environment, Water and Natural Resources, Government of South Australia. Available at: http://location.sa.gov.au/lms/Reports/ReportMetadata.aspx?p_no=898&pu=y

DEWNR (2017b). SA Land Cover Layers 1987-2015: Most Likely Layers. Report. Department of Environment, Water and Natural Resources, Government of South Australia. Available at: http://sdsidata.sa.gov.au/lms/Reports/ReportMetadata.aspx?p_no=2029

DEWNR (2017c). SA Land Cover Models - Continuous Layers - DRAFT. Report. Department of Environment, Water and Natural Resources, Government of South Australia. Available at: http://sdsidata.sa.gov.au/lms/Reports/ReportMetadata.aspx?p_no=2030

DoEE (2016). Collaborative Australian Protected Area Database (CAPAD). Report. Department of Environment and Energy, Australian Government. Available at: http://www.environment.gov.au/land/nrs/science/capad/2016

Gabry, J., and Goodrich, B. (2017). 'Rstanarm: Bayesian applied regression modeling via stan'. Available at: https://CRAN.R-project.org/package=rstanarm

Geoscience Australia (2016). GEODATA TOPO 250K Series 3. Report. Geoscience Australia, Australian Government. Available at: http://pid.geoscience.gov.au/dataset/63999

Geoscience Australia (2015). Water Observations from Space. Report. Geoscience Australia, Australian Government. Available at: http://www.ga.gov.au/scientific-topics/hazards/flood/wofs

Gordon, C. E., Eldridge, D. J., Ripple, W. J., Crowther, M. S., Moore, B. D., and Letnic, M. (2016). Shrub encroachment is linked to extirpation of an apex predator. *Journal of Animal Ecology*, n/a–n/a. doi:10.1111/1365-2656.12607

Government of South Australia (2014). NRM report card: Are the extent and connectivity of our native vegetation improving? Report. Department of Environment, Water and Natural Resources. Available at: https://data.environment.sa.gov.au/NRM-Report-Cards/Documents/Are-the-extent-and-connectivity-of-our-native-vegetation-improving.pdf

Government of South Australia (2016). NRM report card: Are the extent and connectivity of our native vegetation improving? Report. Department of Environment, Water and Natural Resources. Available at: https://data.environment.sa.gov.au/NRM-Report-Cards/Documents/Are-the-extent-and-connectivity-of-our-native-vegetation-improving-2016.pdf

Government of South Australia (2012). Our Place. Our Future. State Natural Resources Management Plan South Australia 2012 – 2017. Report. Adelaide. Available at: https://www.environment.sa.gov.au/files/sharedassets/public/nrm/nrm-gen-statenrmplan.pdf

Guo, J., Gabry, J., and Goodrich, B. (2017). 'Rstan: R interface to stan'. Available at: https://CRAN.R-project.org/package=rstan

Harding, C., Deane, D., Green, D., and Kretschmer, P. (2015). Impacts of Climate Change on Water Resources in South Australia, Phase 4, Volume 2 – Predicting the impacts of climate change to groundwater dependent ecosystems: an application of a risk assessment framework to a case study site in the South East NRM region – Middlepoint Swamp. Report. Department of Environment, Water and Natural Resources, Government of South Australia. Available at: https://www.waterconnect.sa.gov.au/Content/Publications/DEWNR/DEWNR-TR-2015-01.pdf

Harding, C., Herpich, D., and Cranswick, R. H. (2017). Examining temporal and spatial changes in surface water hydrology of groundwater dependent ecosystems using remotely sensed data: southern border groundwater agreement area, South East South Australia, DEWNR technical report 2017/XX. Report. Department of Environment, Water and Natural Resources, Government of South Australia.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., and Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* **25**, 1695–1978. Available at: http://worldclim.org/bioclim

Hobbs, T. J., Armstrong, D., Wenham, D., Howell, S., Spencer, J., Maconochie, J., Facelli, F., Brandle, R., Bowen, Z., and Fitzgerald, L. (2017). Flora and fauna communities of the Cooper-Eromanga Basin, DEWNR Technical report 2017/23. Report. Department of Environment, Water and Natural Resources and Department of the Premier and Cabinet, Government of South Australia.

Lunt, I. D., Prober, S. M., and Morgan, J. W. (2012). How do fire regimes affect ecosystem structure, function and diversity in grasslands and grassy woodlands of southern Australia. In 'Flammable australia: Fire regimes, biodiversity and ecosystems in a changing world'. (Eds R. A. Bradstock, A. M. Gill, and R. J. Williams.) pp. 253–270. (CSIRO Publishing: Melbourne.)

McIntyre, S., and Hobbs, R. J. (1999). A framework for conceptualising human effects on landscapes and its relevance to management and research models. *Conservation Biology* **13**, 1282–1292.

McIntyre, S., and Hobbs, R. J. (2000). Human impacts on landscapes: matrix condition and management priorities. In 'Nature conservation 5: Nature conservation in production environments: Managing the matrix'. (Eds J. L. Craig, N. Mitchell, and D. A. Saunders.) pp. 301–307. (Surrey Beatty & Sons: Chipping Norton, NSW.)

Meyer, W. B., and Turner, B. L. (1992). Human population growth and global land-use/cover change. *Annual Review of Ecology and Systematics* **23**, 39–61.

Mills, C. H., Gordon, C. E., and Letnic, M. (2018). Rewilded mammal assemblages reveal the missing ecological functions of granivores. *Functional Ecology* **32**, 475–485. doi:10.1111/1365-2435.12950

Noble, J. C. (1997). 'The Delicate and Noxious Scrub: CSIRO Studies on Native Tree and Shrub Proliferation in the Semi-arid Woodlands of Eastern Australia'. (CSIRO Wildlife; Ecology: Lyneham, A.C.T.)

O'Connor, P. (2009). Vegetation Information Framework for South Australia. Report. A report prepared by O'Connor NRM Pty Ltd for the Department for Environment and Heritage, Government of South Australia.

Phillips, S. J., Dudík, M., and Schapire, R. E. (2006). Maximum entropy modeling of species graphic distributions. *Ecological Modelling* **190**, 231–259.

Pisanu, P. (2010). Discussion Paper – Priority Setting for the SRC Vegetation Information Improvement Project. Report. Department of Environment and Natural Resources, Government of South Australia.

Price, J. N., and Morgan, J. W. (2008). Woody plant encroachment reduces species richness of herb-rich woodlands in southern Australia. *Austral Ecology* **33**, 278–289. doi:doi:10.1111/j.1442-9993.2007.01815.x

R Core Team (2017). R: A Language and Environment for Statistical Computing. Report. R Foundation for Statistical Computing, Vienna, Austria. Available at: https://www.R-project.org/

Radford, J. Q., and Bennett, A. F. (2004). Thresholds in landscape parameters: occurrence of the white-browed treecreeper *Climacteris affinis* in Victoria, Australia. *Biological Conservation* **117**, 375–391.

Radford, J. Q., Bennett, A. F., and Cheers, G. J. (2005). Landscape-level thresholds of habitat cover for woodland-dependent birds. *Biological Conservation* **124**, 317–337.

Robinson, D. (2017). 'Broom: Convert statistical analysis objects into tidy data frames'. Available at: https://CRAN.R-project.org/package=broom

Rocha, J. C., Peterson, G. D., and Biggs, R. (2015). Regime shifts in the anthropocene: drivers, risks, and resilience. *PLoS ONE* **10**, e0134639. doi:10.1371/journal.pone.0134639

RStudio Team (2016). RStudio: Integrated Development Environment for R. Report. RStudio, Inc, Boston, MA. Available at: http://www.rstudio.com/

Stan Development Team (2016). rstanarm: Bayesian applied regression modeling via Stan. R package version 2.13.1. Report. Available at: http://mc-stan.org/

Suding, K. N., Gross, K. L., and Houseman, G. R. (2004). Alternative states and positive feedbacks in restoration ecology. *Trends in Ecology and Evolution* **19**, 46–53.

Thompson, D., and Royal, M. (2017). South Australian Land Cover Layers - Post-processing of Model Outputs. Report. Department of Environment, Water and Natural Resources, Government of South Australia.

Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Liermann, C. R., and Davies, P. M. (2010). Global threats to human water security and river biodiversity. *Nature* **467**, 555–561. doi:http://www.nature.com/nature/journal/v467/n7315/abs/nature09440.html

Westoby, M., Walker, B., and Noy-Meir, I. (1989). Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* **42**, 266–274.

White, M., and Griffioen, P. (2016). Native Vegetation Extent and Landcover. South Australia. Report. Arthur Rylah Institute, Government of Victoria.

Wickham, H. (2017a). 'Forcats: Tools for working with categorical variables (factors)'. Available at: https://CRAN.R-project.org/package=forcats

Wickham, H. (2017b). 'Modelr: Modelling functions that work with the pipe'. Available at: https://CRAN.R-project.org/package=modelr

Wickham, H. (2016). 'Scales: Scale functions for visualization'. Available at: https://CRAN.R-project.org/package=scales

Wickham, H. (2017c). 'Tidyverse: Easily install and load the 'tidyverse''. Available at: https://CRAN.R-project.org/package=tidyverse

Wickham, H., and Bryan, J. (2017). 'Readxl: Read excel files'. Available at: https://CRAN.R-project.org/package=readxl

Xie, Y. (2016). 'Bookdown: Authoring books and technical documents with r markdown'. Available at: https://CRAN.R-project.org/package=bookdown

Xie, Y. (2017). 'Knitr: A general-purpose package for dynamic report generation in r'. Available at: https://CRAN.R-project.org/package=knitr