Technical information supporting the 2023 environmental trend and condition report cards based on SA land cover layers: wetlands, native vegetation, mangrove vegetation and coastal saltmarsh

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Acknowledgement of Country

We acknowledge and respect the Traditional Custodians whose ancestral lands we live and work upon and we pay our respects to their Elders past and present. We acknowledge and respect their deep spiritual connection and the relationship that Aboriginal and Torres Strait Islanders people have to Country. We also pay our respects to the cultural authority of Aboriginal and Torres Strait Islander people and their nations in South Australia, as well as those across Australia.

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Summary

The 2023 release of South Australia's environmental trend and condition report cards summarises our understanding of the current condition of the South Australian environment, and how it is changing over time.

This document describes the indicators, information sources, analysis methods and results used to develop this report and the associated 2023 report cards:

- Wetlands: percentage cover
- Native vegetation: percentage cover
- Mangroves: percentage cover
- Coastal saltmarsh: percentage cover.

The reliability of information sources used in the report card is also described.

The report cards sit within the report card Biodiversity theme and Inland waters, Terrestrial and Coastal and marine sub-themes. Report cards are published by the Department for Environment and Water and can be accessed at www.environment.sa.gov.au.

1 Introduction

1.1 Environmental trend and condition reporting in SA

The Minister for Climate, Environment and Water under the *Landscape South Australia Act 2019* is required to 'monitor, evaluate and audit the state and condition of the State's natural resources, coasts and seas; and to report on the state and condition of the State's natural resources, coasts and seas' (9(1(a-b)). Environmental trend and condition report cards are produced as the primary means for the Minister to undertake this reporting. Trend and condition report cards are also a key input into the State of the Environment Report for South Australia, which must be prepared under the *Environment Protection Act 1993*. This Act states that the State of the Environment Report must:

- include an assessment of the condition of the major environmental resources of South Australia (112(3(a))), and
- include a specific assessment of the state of the River Murray, especially taking into account the Objectives for a Healthy River Murray under the *River Murray Act 2003* (112(3(ab))), and
- identify significant trends in environmental quality based on an analysis of indicators of environmental quality (112(3(b))).

1.2 Purpose and benefits of SA's environmental trend and condition report cards

South Australia's environmental trend and condition report cards focus on the state's priority environmental assets and the pressures that impact on these assets. The report cards present information on trend, condition, and information reliability in a succinct visual summary.

The full suite of report cards captures patterns in trend and condition, generally at a state scale, and gives insight to changes in a particular asset over time. They also highlight gaps in our knowledge on priority assets that prevent us from assessing trend and condition and might impede our ability to make evidence-based decisions.

Although both trend and condition are considered important, the report cards give particular emphasis to trend. Trend shows how the environment has responded to past drivers, decisions, and actions, and is what we seek to influence through future decisions and actions.

The benefits of trend and condition report cards include to:

- provide insight into our environment by tracking its change over time
- interpret complex information in a simple and accessible format
- provide a transparent and open evidence base for decision-making
- provide consistent messages on the trend and condition of the environment in South Australia
- highlight critical knowledge gaps in our understanding of South Australia's environment
- support alignment of environmental reporting, ensuring we 'do once, use many times'.

Environmental trend and condition report cards are designed to align with and inform state of the environment reporting at both the South Australian and national level. The format, design and accessibly of the report cards has been reviewed and improved with each release.

1.3 Land cover based reporting

Land cover is the observed biophysical cover of the earth's surface (Di Gregorio 2005). 'Grassland', 'forest' or 'urban area' are examples of land cover. Earth observation data from satellites, combined with machine learning, is now being used to produce land cover maps for regions and larger areas across the globe (Phiri and Morgenroth 2017; Potapov et al. 2020; Witjes et al. 2022). It is only with the temporal and spatial scales now available from satellite data that trends in land cover can be investigated. The Landsat series of satellites in particular provide the only data source for generating land cover maps and associated land use change analysis over multi-decadal time frames at pixel scales of around 30 m (Potapov et al. 2020). From the late 2010s the Sentinel series of satellites provide another data source at similar temporal and spatial scales.

Since 2017 South Australia has had land cover available for six time periods (epochs) from 1990 to 2015, enabling the change in various land cover classes to be estimated over that time (see SA Land Cover). A seventh epoch (2015-2020) became available in 2022. Several of these land cover classes are suitable for environmental trend and condition reporting: wetlands, native vegetation, mangrove vegetation and coastal saltmarsh (Table 1.1).

Table 1.1: Land cover based environmental trend and condition report cards 2023

Theme	Subtheme	Title	Indicator
Biodiversity	Inland waters	Wetlands	percentage cover
Biodiversity	Terrestrial	Native vegetation	percentage cover
Biodiversity	Coastal and Marine	Mangrove vegetation	percentage cover
Biodiversity	Coastal and Marine	Coastal saltmarsh	percentage cover

1.3.1 Wetlands

Wetlands cover at least six per cent of the earth's surface (Junk et al. 2013). They play important roles in a range of environmental, social, cultural and economic services such as protecting shorelines from wave action, reducing the impacts of floods, absorbing pollutants, improving water quality and providing habitat for animals and plants. Wetlands have been shown to contain a wide diversity of life, supporting plants and animals that are found nowhere else - and they are amongst the most productive and biodiverse ecosystems (Davidson 2014; Hu et al. 2017). Wetlands also provide important benefits for industry. For example, they form nurseries for fish and other freshwater and marine life and are critical to Australia's commercial and recreational fishing industries.

Pressures on wetlands of all continents include land reclamation, intense resource exploitation, changes in hydrology, and pollution (Junk et al. 2013; Davidson 2014). Depending on the region, 30-90 % of the world's wetlands have already been lost or considerably altered (Junk et al. 2013). In many cases climate change predictions are likely to add stresses to wetlands, mainly because of changes in hydrology, temperature increases, and a rise in sea level (Junk et al. 2013).

1.3.1.1 Long term trends

Over longer time frames than available from remote sensing data, the loss of wetlands has been very extensive. For example, in the South East, Williams (1974) documented the loss of the 'watery waste' - an area originally covering over 1.6 million hectares - through the introduction of various drainage schemes. Another example of large scale historic loss of wetlands in South Australia was the Reedbeds (Witongga), an ephemeral wetland system that stretched from Glenelg to the Port River, fed by the Torrens River. Witongga was eventually drained by the cutting at Breakout Creek.

1.3.2 Native vegetation

Information on native vegetation percentage cover - and the distribution of that cover - is used for a range of important natural resources management activities including regional and statewide environmental reporting, evaluation of investment activities, and supporting landscape management.

Native vegetation provides a range of ecosystem services to the landscapes in which it occurs (UN 2014). Loss of native vegetation is therefore a key driver of land degradation, especially in areas susceptible to salinity and/or water quality issues. Loss of native vegetation cover also:

- causes habitat loss, which is known to have large and consistently negative effects on biodiversity (Haila 2002; Fahrig 2003)
- causes habitat fragmentation, which changes the way species disperse and use native vegetation through:
  - increased distance between patches (of habitat)
  - decrease in size of patches (Fahrig 2003)
- contributes to the degradation of any remaining native vegetation as it is often accompanied by a suite of other pressures such as changed grazing regime, insect attack, disease, weeds, rising water tables, salinity, changed fire regime and/or unsustainable firewood collection (e.g. Saunders et al. 1991)

When clearance controls were first introduced in 1983 there was a period of unrest focused largely on a lack of compensation rather than the controls themselves (Department for Environment and Heritage 2002; Harris 2017). The issue of compensation was addressed by the *Native Vegetation Management Act 1985* but wound down by the *Native Vegetation Act 1991* that now provides for the management, enhancement and protection of native vegetation in South Australia (Harris 2017; The Native Vegetation Council and Department of Environment and Water 2021).

1.3.2.1 Long term trends

Figure 1.1 shows estimated cover of native vegetation, across several regions in the agricultural zone of South Australia, since the mid-1800s. Figure 1.2 shows where those regions are. Figure 1.1 was generated using several different data sources:

- historic sources:
  - the 1976 Clearance Report
  - Atlas of South Australia
- aerial image interpretation
- remote sensing vegetation cover
  - South Australian Land Cover Layers
  - Ecosystems of South Australia

The 1976 Report of the Interdepartmental Committee on Vegetation Clearance (Department for the Environment 1976) includes useful information on the level of clearance within each region of the state (as they were recognised at that time), generated from aerial interpretation. It also contains clearance assessments for some regions at earlier points in time, generated from historic air-photo interpretation. However, the resolution of assessment (just focusing on larger blocks of vegetation >100 hectares) and nature of aerial interpretation means that the assessment is likely to have under-represented the total amount of vegetation in the landscape by missing smaller patches and non-woody native vegetation.

The 1986 Atlas of South Australia (Griffin and McCaskill 1986) presents maps and tallied summaries approximately every 25 years on the amount of sold and cultivated land across the different parts of the state, along with information on the growing population. While not directly presenting historic figures on clearance, the figures on development will be strongly correlated with clearance.

Aerial photo interpretation was undertaken at a higher resolution than the historic assessments (mapping areas > 2 hectares), but is still likely to under represent non-woody native vegetation.

The remote sensing products available include the South Australian Land Cover Layers and the Ecosystems of South Australia project (currently only in draft). These projects both use remote sensing data, environmental data and ground survey data to describe and map the different landcover and ecosystems of South Australia. A by-product of this work is a depiction of native vegetation cover, currently captured at a resolution of approximately 30 x 30 metres.

The historic sources, aerial imagery interpretation and remote sensing products are available for different time periods and area of the state. Figure 1.1 was developed by choosing the best available product(s) for a given area and time frame. The regions used in Figure 1.1 follow the boundaries used in the 1976 Clearance Report (Department for the Environment 1976), with subsequent products being summarised to those same regions.

As highlighted in the 1976 Report (Department for the Environment 1976), vegetation clearance of the South Australian agricultural zone is extensive. Some regions were largely cleared by the late 1800s. However, some of the less productive parts of the agricultural zone were still being cleared into the 1970s. The trajectories of clearance in these regions appear to have been curtailed by the introduction of clearance controls in South Australia in 1983, initially as regulations under the *Planning Act 1982*, and later replaced by the *Native Vegetation Management Act 1985* and *Native Vegetation Act 1991*.

While there appears to be some fluctuation in the amount of native vegetation since 1983, this change appears to be a result of cyclical processes (such as bushfires) rather than directional change. When accounting for these events and the estimation errors inherent with each method, there appears to be little detectable change in native vegetation cover in the agricultural zone since 1983.

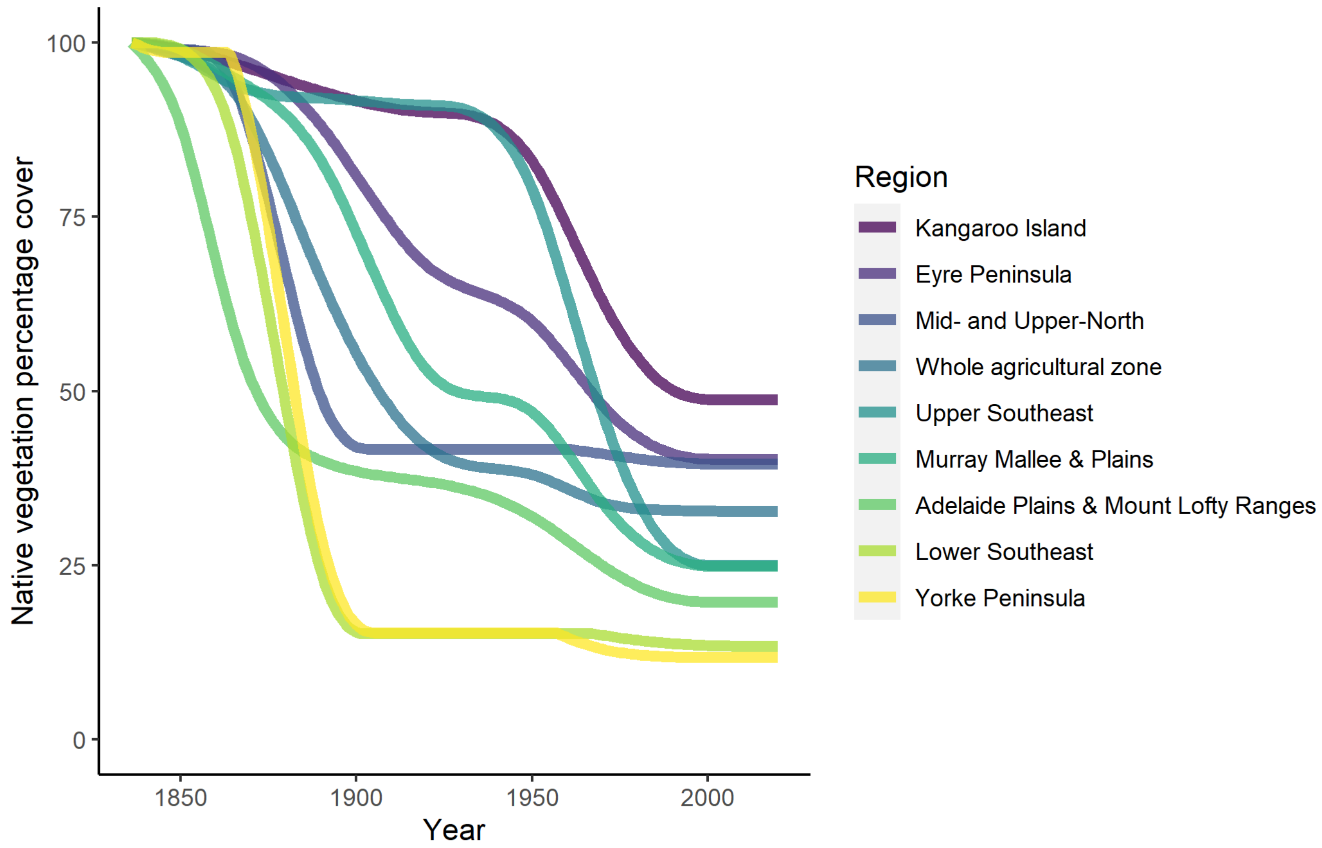

Figure 1.1: South Australian native vegetation cover - long term trends

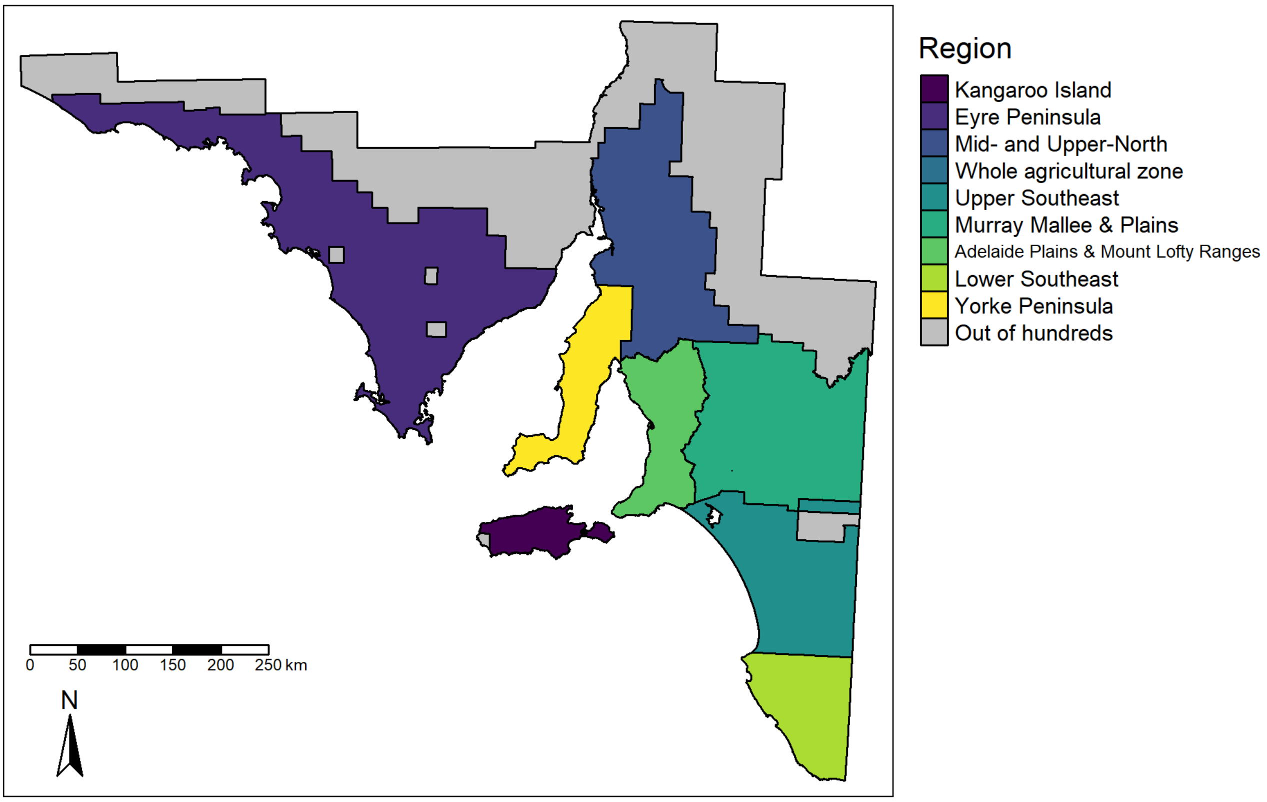

Figure 1.2: Regions used to generate the long term trends in native vegetation. These regions were originally used by the 1986 Atlas of South Australia and are based on Counties and Hundreds

1.3.3 Mangrove vegetation and coastal saltmarsh

Mangrove vegetation and coastal saltmarsh are located in tidal estuaries and on muddy coasts, and form a transition zone between land and marine ecosystems (Edyvane and Francis 1995). Mangrove vegetation is where mangrove trees grow in dense thickets. Coastal saltmarsh are areas covered by small, hardy bushes (samphire). The lower limit of mangroves is determined by the average sea level and the upper limit is set by the average high water mark. Coastal saltmarsh is found just above the upper limit set by the average high water mark. Coastal saltmarsh varies from areas regularly inundated by tides to areas only occasionally flooded by high tides. Thus, changes in sea level through land sinking (subsidence) or increases in sea level from climate change can alter the distribution of mangroves and coastal saltmarsh. Also, the accumulation of sediment on the seaward edge of mangroves can encourage colonisation.

Mangrove vegetation and coastal saltmarsh trap sediment and prevent coastal erosion. They also maintain coastal water quality, cycle nutrients, store carbon and provide food and shelter for marine animals, including commercial fish in their juvenile stages. Mangrove vegetation and coastal saltmarsh are threatened by clearance, coastal development, construction of tidal barriers and drains, and changes in freshwater inputs that decrease salinity and increase nutrients, pollutants and sediments.

The health of mangrove vegetation and coastal saltmarsh relies on the management of coastal development and water quality within catchments. The marine environment provides valuable resources for regional economies, supporting tourism, commercial and recreational fishing, aquaculture, shipping and mining. Most South Australians live near the coast, and many coastal and marine systems are under pressure from human impacts.

Mangroves are present in the Eyre Peninsula, Northern and Yorke, South Australian Arid Lands and Green Adelaide South Australian landscape regions and predominantly occur in the upper parts of Gulf St Vincent and Spencer Gulf. Small areas of mangroves are also found around Eyre Peninsula.

Coastal saltmarsh is present in the Hills and Fleurieu, Eyre Peninsula, Kangaroo Island, Northern and Yorke, South Australian Arid Lands, Murraylands and Riverland, Limestone Coast and Green Adelaide South Australian landscape regions. The core habitat for several threatened species includes coastal saltmarsh, such as the critically endangered orange-bellied parrot (Orange-bellied Parrot Recovery Team 2006) and the vulnerable Gulf St Vincent slender-billed thornbill (Matthew 1994; Coleman et al. 2017).

1.3.3.1 Long term trends

Previously it had been estimated that in the Green Adelaide Landscape SA (LSA) Region, mangroves cover now only 80 per cent of their former extent. Changes from the original extent of mangroves in the Eyre Peninsula, South Australian Arid Lands and Northern and Yorke LSA regions are unknown. This previous loss of mangrove vegetation was due to the clearing and filling of mangrove sites for use as industrial areas, harbour facilities, waterfront housing, dumps and sports fields (Scientific Working Group 2011). Additional mangrove loss can be attributed to elevated nutrient levels from sewage and storm water runoff as a result of land modification. For example it is estimated approximately 250 hectares have been lost since 1956 in the Green Adelaide LSA Region immediately adjacent to the Bolivar sewage outfall (Bayard 1992). Improvements in the treatment of waste water has resulted in a discharge reduction from 1265 tonnes of nitrogen to 477 tonnes and 320 tonnes of phosphorous to 232 tonnes, but nutrient inputs may still support growth of algae such as *Ulva* spp. which are detrimental to mangrove health and growth (Pfennig 2008).

In 2020, approximately 9 hectares of mangroves and 10 hectares of saltmarsh were lost due to seepage of hypersaline water from salt ponds into ground water near St Kilda in the Green Adelaide LSA Region (Leyden et al. 2022).

Coastal Saltmarsh and Mangrove Mapping for South Australia, largely completed in 1997 with updates for the Upper Spencer Gulf in 2004, suggests there were about 15,600 hectares of mangroves and 60,600 hectares of coastal saltmarsh in South Australia (DEW 2023a).

1.3.3.2 Patch-scale condition

Some areas of the Green Adelaide LSA Region (e.g. Barker Inlet) have been assessed as having a lack of mangrove seedlings, and reduced numbers of pneumatophores (aerial roots to allow mangroves to breath while their roots are submerged), suggesting sub-optimal conditions for mangrove vegetation (McDowell and Pfennig 2013).

The patch-scale condition of mangrove vegetation has also been assessed on the Eyre Peninsula. A 2012 analysis found mangrove vegetation as being in good condition, with a score of 71 out of 100, where 100 represents undisturbed condition (Wiebkin 2013). More recent assessments of patch-scale condition of mangroves on the Eyre Peninsula or elsewhere are not available.

Statewide mapping of coastal ecosystems between 1997 and 2007 classed most (over 90%) of the extant coastal saltmarsh in good condition (DEW 2023a).

2 Methods

2.1 Data sources

2.1.1 SA Land Cover Layers

The SA Land Cover Layers use Landsat satellite imagery and training data to map land cover across South Australia in five-year epochs from 1990 to 2020). Table 2.1 defines the epochs including information on the Landsat satellites collecting the data for that epoch. From Table 2.1 it is clear that change in satellites (and therefore satellite sensors) is an integral part of the Landsat data series. However, Landsat 8 now collects more precise data, including more accurately mapping each pixel to a specific point on the ground, resulting in images that are crisper than previous Landsat missions. These accuracy improvements, combined with a range of other improvements in the Landsat sensors, have created challenges for generating comparable data between current and previous Landsat missions (e.g. Roy et al. 2016; Zhu et al. 2016; Sulla-Menashe et al. 2016). For the SA Land Cover Layers, the issues with improving sensors is compounded by the underlying model (White and Griffioen 2016) not including any training data based on Landsat 8.

Each layer from the satellite data consists of approximately 1,403,522,543 pixels across South Australia, with each pixel being about 0.00025 decimal degrees or roughly 28 metres north/south by 25 metres east/west. The SA Land Cover Layers is comprised of:

- 55 statewide 'continuous' raster layers - one for each land cover class. These contain likelihood measures (between 0 and 100) that a pixel is that land cover class (DEW 2023d)
- 55 'confidence' layers. For each of the continuous layers there is a confidence measure (DEW 2023d)
- **most likely layers**. Summary layers displaying the most likely land cover class for each pixel in each epoch. Information on accesing these layers is here including an introduction with summary statistics (Willoughby et al. 2017).

The most likely layers (DEW 2023c) are the data sources used in this report for the following report cards:

- Biodiversity: **wetlands** percentage cover
- Biodiversity: **native vegetation** percentage cover
- Biodiversity: **mangrove vegetation** percentage cover
- Biodiversity: **coastal saltmarsh** percentage cover

The most likely layers (DEW 2023c) contain 18 land cover classes (as defined in Table 2.2). There is not usually a one to one relationship between a report card and the land cover classes (with the exception of mangrove vegetation). Table 2.3 shows which classes are included in each report card. Note that coastal saltmarsh was not part of the original land cover classes (e.g. DEW 2023c) but was derived for the report card as a subset of the saltmarsh vegetation land cover class. To extract just coastal saltmarsh the following process was used:

- Using 'coastal saltmarsh and mangrove mapping' (DEW 2023b) that pre-dates the SA Land Cover Layers, polygons defined as 'saltmarsh' were analysed against a digital elevation model to determine the highest height above sea level that those polygons existed in South Australia
- A buffer of 10 km was created inland from the South Australian coastline
- The intersection of these two layers defined a 'coastal saltmarsh environmental setting'
- Areas were tabulated for pixels defined as the saltmarsh vegetation land cover class within the coastal saltmarsh environmental setting.

The 10 km buffer around the coastline was used after visual inspection of aerial imagery and represents the furthest inland that coastal saltmarsh (as defined by DEW 2023b) was detected (near Port Pirie).

The use of the 10 km buffer around the coastline, even in conjunction with the digital elevation model used, may have included areas of saltmarsh that are not tidally influenced. Saltmarsh may be establishing in some of these non-tidally influenced areas due to a range of land management issues. The extent to which any non-coastal saltmarsh was included in the coastal saltmarsh figure is not known.

Table 2.1: Definition of epochs, including Landsat satellite missions used

Epoch	Years	Satellite(s)
1	1987 - 1990	Landsat 5
2	1990 - 1995	Landsat 5
3	1995 - 2000	Landsat 5 / Landsat 7
4	2000 - 2005	Landsat 7 / Landsat 5
5	2005 - 2010	Landsat 5
6	2010 - 2015	Landsat 5 / Landsat 8
7	2015 - 2020	Landsat 8

Table 2.2: Land cover classes in the most likely layers, their approximate area in South Australia and a brief description. Coastal saltmarsh has been added specifically for the report cards

Land cover class	Hectares	Description
woody native vegetation	21,262,000	Woody native vegetation generally > 1 m tall (e.g. eucalypt forests and woodlands, wattle shrublands, hop-bush shrublands)
mangrove vegetation	33,000	Mangrove dominated forest
non-woody native vegetation	138,302,000	Non-woody native vegetation generally < 1 m tall (e.g. grasslands including herbs and low shrubs such as chenopods)
saltmarsh vegetation	26,000	Low native vegetation in areas with saline soils dominated by samphire species
coastal saltmarsh	40,000	Coastal saltmarsh vegetation
wetland vegetation	480,000	Non-woody native vegetation occurring in association with wetlands (e.g. emergent vegetation, lignum)
natural low cover	13,461,000	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	3,415,000	Salt lakes and salt pans
dryland agriculture	17,113,000	Non-native vegetation that is used for dryland cropping and/or grazing
exotic vegetation	26,000	Any form of (generally woody) vegetation dominated by non-native species and not classified to the other non-native vegetation classes
irrigated non-woody	163,000	Irrigated pasture or crops (e.g. irrigated cropping/ pasture, grassed reserves, golf courses)
orchards or vineyards	115,000	Irrigated woody crops (e.g. grapes, citrus, stone fruit)
plantation (softwood)	211,000	Pine plantations
plantation (hardwood)	72,000	Plantations other than pine (often Tasmanian blue gum)

Land cover class	Hectares	Description
urban area	202,000	A mix of vegetation and built surfaces (e.g. roads, gardens, houses, street trees)
built-up area	18,000	Dominated by built surfaces (e.g. roads, buildings)
disturbed ground or outcrop	958,000	Disturbed ground or outcrop (e.g. open-cut mines)
water unspecified	298,000	Open water bodies

Table 2.3: The land cover classes used for each report card

Land cover type	Land cover class	Coastal saltmarsh	Mangrove vegetation	Native vegetation	Wetlands
native vegetation	woody native vegetation	FALSE	FALSE	TRUE	FALSE
native vegetation	mangrove vegetation	FALSE	TRUE	TRUE	FALSE
native vegetation	non-woody native vegetation	FALSE	FALSE	TRUE	FALSE
native vegetation	saltmarsh vegetation	FALSE	FALSE	TRUE	TRUE
native vegetation	coastal saltmarsh	TRUE	FALSE	TRUE	TRUE
native vegetation	wetland vegetation	FALSE	FALSE	TRUE	TRUE
native vegetation	natural low cover	FALSE	FALSE	TRUE	FALSE
other	salt lake or saltpan	FALSE	FALSE	FALSE	TRUE
other	urban area	FALSE	FALSE	FALSE	FALSE
other	built-up area	FALSE	FALSE	FALSE	FALSE
other	disturbed ground or outcrop	FALSE	FALSE	FALSE	FALSE
other	water unspecified	FALSE	FALSE	FALSE	TRUE
non-native vegetation	dryland agriculture	FALSE	FALSE	FALSE	FALSE
non-native vegetation	exotic vegetation	FALSE	FALSE	FALSE	FALSE
non-native vegetation	irrigated non-woody	FALSE	FALSE	FALSE	FALSE
non-native vegetation	orchards or vineyards	FALSE	FALSE	FALSE	FALSE
non-native vegetation	plantation (softwood)	FALSE	FALSE	FALSE	FALSE
non-native vegetation	plantation (hardwood)	FALSE	FALSE	FALSE	FALSE
no data/ unclassified	no data or unclassified	FALSE	FALSE	FALSE	FALSE

2.1.1.1 Accuracy

Kappa statistic (Cohen 1960) can be used as an indicator of the overall accuracy of the most likely layers. Using approximately 10% of the original training points that were retained as 'test-points' to assess model performance (see 'test points' in Table 2.1), the most likely layers have kappa values between 0.75 and 0.92 (Thompson and Royal 2017). Kappa values above 0.9 are sometimes considered to be essentially a perfect fit (Cohen 1960). Table 2.4 gives the kappa statistic for the most likely layer in each epoch.

As a measure of the accuracy of the most likely layers with respect to each class, Table 2.5 shows how training points originally classified as wetlands, native vegetation, mangrove vegetation and coastal saltmarsh were predicted in the most likely layers across all epochs (true positive rate) while Table 2.6 shows how predicted points that were not originally classified as that class should have been classified (true negative rate).

Full confusion matrix, accuracy and kappa statistics for the first six epochs were generated by Thompson and Royal (2017).

Table 2.4: Number of training and test points and an estimate of their accuracy (kappa statistic). There was no training data specific to epoch 7. Test data for epoch 7 were from an unpublished point-based land cover data set being generated by DEW to improve future land cover mapping for South Australia

Epoch	Training points	Test points	Kappa statistic	Satellite(s)
1	43893	4879	0.8984	Landsat 5
2	56570	6285	0.9181	Landsat 5
3	52027	5785	0.8848	Landsat 5 / Landsat 7
4	43588	4838	0.9120	Landsat 7 / Landsat 5
5	44190	4910	0.9211	Landsat 5
6	49825	5538	0.9053	Landsat 5 / Landsat 8
7	0	89753	0.7456	Landsat 8

Table 2.5: True positive rate across all epochs: number of test points and percentage of land cover class predictions. The cells where predict = truth give the percentage of correctly identified pixels. For example 93.7% of wetland test points were correctly predicted to be wetlands whereas 2.9% of woody native vegetation test points were incorrectly predicted to be wetlands

Truth	Predict: mangrove vegetation	Predict: native vegetation	Predict: saltmarsh vegetation	Predict: wetlands
wetlands	-	-	-	13769 (93.7%)
native vegetation	-	46624 (83.9%)	-	-
woody native vegetation	32 (1.2%)	-	42 (23.3%)	423 (2.9%)
mangrove vegetation	2685 (98.3%)	-	23 (12.8%)	32 (0.2%)
non-woody native vegetation	4 (0.1%)	-	24 (13.3%)	338 (2.3%)
saltmarsh vegetation	6 (0.2%)	-	80 (44.4%)	-
wetland vegetation	4 (0.1%)	-	8 (4.4%)	-
natural low cover	0 (0%)	-	0 (0%)	8 (0.1%)
salt lake or saltpan	0 (0%)	4471 (8%)	3 (1.7%)	-
dryland agriculture	0 (0%)	1311 (2.4%)	0 (0%)	80 (0.5%)

Truth	Predict: mangrove vegetation	Predict: native vegetation	Predict: saltmarsh vegetation	Predict: wetlands
exotic vegetation	0 (0%)	37 (0.1%)	0 (0%)	0 (0%)
irrigated non-woody	0 (0%)	93 (0.2%)	0 (0%)	20 (0.1%)
orchards or vineyards	0 (0%)	108 (0.2%)	0 (0%)	8 (0.1%)
plantation (softwood)	0 (0%)	75 (0.1%)	0 (0%)	0 (0%)
plantation (hardwood)	0 (0%)	42 (0.1%)	0 (0%)	1 (0%)
urban area	1 (0%)	1321 (2.4%)	0 (0%)	9 (0.1%)
built-up area	0 (0%)	280 (0.5%)	0 (0%)	2 (0%)
disturbed ground or outcrop	0 (0%)	1103 (2%)	0 (0%)	4 (0%)
water unspecified	0 (0%)	93 (0.2%)	0 (0%)	-

Table 2.6: True negative rate across all epochs: number of test points and percentage of land cover class test points. For example 86 mangrove vegetation test points were predicted to be woody native vegetation

Predict	Truth: mangrove vegetation	Truth: native vegetation	Truth: saltmarsh vegetation	Truth: wetlands
woody native vegetation	86 (58.9%)	-	76 (60.3%)	312 (5.8%)
mangrove vegetation	-	-	6 (4.8%)	10 (0.2%)
non-woody native vegetation	0 (0%)	-	24 (19%)	715 (13.3%)
saltmarsh vegetation	23 (15.8%)	-	-	-
wetland vegetation	5 (3.4%)	-	4 (3.2%)	-
natural low cover	3 (2.1%)	-	11 (8.7%)	4253 (78.8%)
salt lake or saltpan	0 (0%)	16 (0.7%)	0 (0%)	-
dryland agriculture	25 (17.1%)	1796 (83.1%)	5 (4%)	72 (1.3%)
exotic vegetation	0 (0%)	33 (1.5%)	0 (0%)	1 (0%)
irrigated non-woody	0 (0%)	15 (0.7%)	0 (0%)	5 (0.1%)
orchards or vineyards	0 (0%)	12 (0.6%)	0 (0%)	3 (0.1%)
plantation (softwood)	0 (0%)	81 (3.7%)	0 (0%)	2 (0%)
plantation (hardwood)	0 (0%)	6 (0.3%)	0 (0%)	0 (0%)
urban area	0 (0%)	58 (2.7%)	0 (0%)	6 (0.1%)
built-up area	0 (0%)	0 (0%)	0 (0%)	0 (0%)
disturbed ground or outcrop	0 (0%)	93 (4.3%)	0 (0%)	15 (0.3%)
water unspecified	4 (2.7%)	51 (2.4%)	0 (0%)	-

2.1.2 National Land Cover Account

As a result of the challenges in generating trends from the SA Land Cover Layers (stemming from changing satellite sensors), other potential sources of cover change data were explored. Other datasets that encompass South Australia have the same inherent challenges with changing satellite sensors. However, the Australian Bureau of Statistics 'National Land Cover Account' methodology attempts to reduce the impact of these issues through spatial resampling and the consistent application of the international land cover classification standard through time (Australian Bureau of Statistics 2020). As a result, this dataset was used to assess land cover changes through time.

The National Land Cover Account provides estimates of land cover changes through time, from 1988 to 2020, as the State scale. Terrestrial native vegetation is a specific cover category within this dataset, enabling its assessment. However, the mangrove, saltmarsh and wetland land cover classes are not specifically captured in the National Land Cover Accounts, so cannot be assessed using this dataset.

2.2 Sub-state scale

The overall trend and condition given on a report card are for all of South Australia. For context, most report cards also provide results for sub-state regions.

2.2.1 Landscape regions

For most report cards the landscape regions defined by the *Landscapes South Australia Act 2019* are used. Figure 2.1 shows the location of LSA regions. There are nine landscape regions (Hills and Fleurieu, Alinytjara Wilurara, Eyre Peninsula, Kangaroo Island, Northern and Yorke, South Australian Arid Lands, Murraylands and Riverland, Limestone Coast and Green Adelaide).

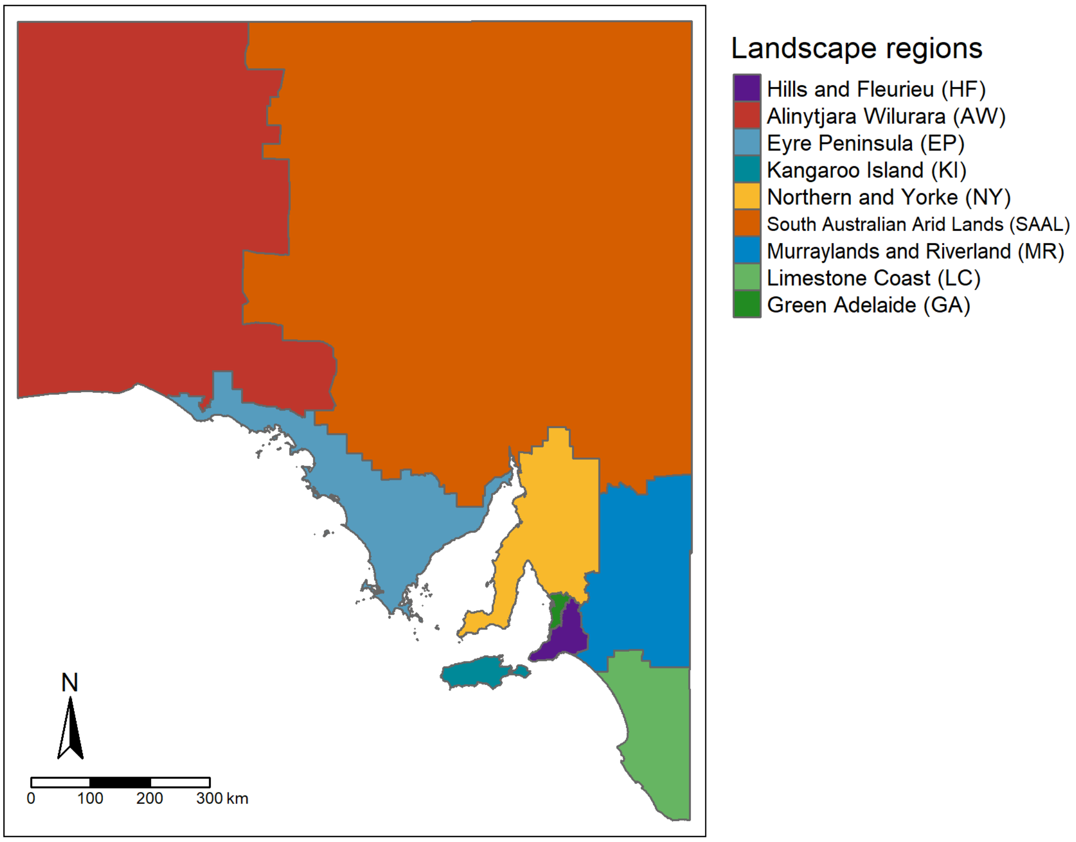

Figure 2.1: Landscape regions

2.3 Analysis

2.3.1 Percentage Cover

Percentage cover statistics were calculated from the current (most accurate) epoch of the SA Land Cover Layers (based on Landsat 8 data) as the hectares of a class in an area × 100 / Total hectares of that area. Areas were either all of South Australia or sub-state scale. Percentage cover always refers to the percentage of a class within a spatial area.

Due to the current challenges for creating time series from different Landsat sensors, the 2023 Trend and Condition report cards based on land cover layers only provide current estimates rather than trend. In the future it is likely that improved methods will again enable trends to be generated from historic datasets.

2.3.2 Trend in Terrestrial Native Vegetation

As trends could not be derived from the SA Land Cover Layers, the National Land Cover Accounts were used to provide a trend for terrestrial native vegetation cover (Australian Bureau of Statistics 2020). However, this dataset captures significant temporal transitions between vegetation cover and other cover classes (such as bare natural surfaces) that result from climatic conditions (Australian Bureau of Statistics 2020). These transitions are particularly pronounced in the arid parts of South Australia, that account for the majority of the State's terrestrial native vegetation. During wetter periods, native vegetation cover increases substantially across these landscapes. In drier periods, a lot of this vegetation senesces, with extensive areas transitioning to bare soil or rock.

To determine any underlying trend in terrestrial vegetation cover, additional analyses are necessary to remove the fluctuating effect of wet and dry cycles. This was achieved by modelling native vegetation cover as a function of both time and rainfall and then predicting cover under median rainfall conditions. A range of potentially suitable modelling methods were identified and applied (including regression, tree ensemble, support vector machine and neural network approaches), with standard performance metrics (root mean squared error and mean absolute percentage error; Hodson 2022) used to determine the best performing method. In this instance, gaussian process regression was the best performing method (using a polynomial kernel; Mackay, 1998). To be consistent with past land cover based report cards, the latest five year epoch was chosen as the period for trend assessment (2015-2020).

2.4 Reliability

Information is scored for reliability based on subjective scores (1 [worst] to 5 [best]) given for information currency, applicability and level of spatial representation. Where there is information available regarding accuracy, this is included as well. Definitions guiding the application of these scores are provided in Table 2.7 for currency, Table 2.8 for applicability, Table 2.9 for spatial representation and Table 2.10 for accuracy.

The reliability score given on a report card is the minimum of any of those scores. Minimum is used, as the average can mask a very low reliability for one of the scores (say, currency if the information is quite old) if other scores are not as low.

Table 2.7: Guides for applying information currency

Currency score	Criteria
1	Most recent information >10 years old
2	Most recent information up to 10 years old
3	Most recent information up to 7 years old
4	Most recent information up to 5 years old
5	Most recent information up to 3 years old

Table 2.8: Guides for applying information applicability

Applicability score	Criteria
1	Data are based on expert opinion of the measure
2	All data based on indirect indicators of the measure
3	Most data based on indirect indicators of the measure
4	Most data based on direct indicators of the measure
5	All data based on direct indicators of the measure

Table 2.9: Guides for applying spatial representation of information (sampling design)

Spatial score	Criteria
1	From an area that represents less than 5% the spatial distribution of the asset within the region/state or spatial representation unknown
2	From an area that represents less than 25% the spatial distribution of the asset within the region/state
3	From an area that represents less than half the spatial distribution of the asset within the region/state
4	From across the whole region/state (or whole distribution of asset within the region/state) using a sampling design that is not stratified
5	From across the whole region/state (or whole distribution of asset within the region/state) using a stratified sampling design

Table 2.10: Guides for applying accuracy information

Accuracy score	Criteria
1	Slightly better than chance (say, Kappa > 0)
2	Fair accuracy (say, Kappa > 0.2)
3	Moderate accuracy (say, Kappa > 0.4)
4	Substantial accuracy (say, Kappa > 0.75)
5	Almost perfect accuracy (say, Kappa > 0.9)

2.5 Workflow

The data import, cleaning, analysis and report writing associated with the SA Land Cover Layers were delivered as a scripted workflow using the programs `R` and 'R-studio Desktop'. R (R Core Team 2020) is an open source software environment for statistical computing and graphics. Base R can be extended via a range of open source packages to enable specific tasks or analyses. The packages used to produce this report are listed in Table 2.11.

R-studio Desktop is a set of open source tools built to facilitate interaction with `R`.

A workflow diagram (managing environmental knowledge chart) is provided in Figure 2.2.

Table 2.11: R (R Core Team 2020) packages used in the production of this report

package	citation	loadedversion	date	source
base	R Core Team (2020)	4.0.2	2020-06-22	local
bookdown	Xie (2021a)	0.24	2021-09-02	CRAN (R 4.0.5)
dplyr	Wickham et al. (2022)	1.0.8	2022-02-08	CRAN (R 4.0.5)
envFunc	Willoughby (2023a)	0.0.0.9000	2023-05-31	Github (acanthiza/envFunc@bbeb4c1)
envReport	Willoughby (2023b)	0.0.0.9000	2023-05-31	Github (acanthiza/envReport@bd9b258)
forcats	Wickham (2021)	0.5.1	2021-01-27	CRAN (R 4.0.5)
fs	Hester et al. (2021)	1.5.2	2021-12-08	CRAN (R 4.0.5)
GGally	Schloerke et al. (2021)	2.1.2	2021-06-21	CRAN (R 4.0.5)
knitr	Xie (2021b)	1.33	2021-04-24	CRAN (R 4.0.5)
lubridate	Spinu et al. (2021)	1.7.10	2021-02-26	CRAN (R 4.0.5)
purrr	Henry and Wickham (2020)	0.3.4	2020-04-17	CRAN (R 4.0.5)
readr	Wickham and Hester (2021)	2.0.1	2021-08-10	CRAN (R 4.0.5)
readxl	Wickham and Bryan (2019)	1.3.1	2019-03-13	CRAN (R 4.0.5)
rio	Chan and Leeper (2021)	0.5.27	2021-06-21	CRAN (R 4.0.5)
sf	Pebesma (2021)	1.0-4	2021-11-14	CRAN (R 4.0.5)
stringr	Wickham (2019)	1.4.0	2019-02-10	CRAN (R 4.0.5)
tibble	Müller and Wickham (2021)	3.1.6	2021-11-07	CRAN (R 4.0.5)
tidyr	Wickham and Girlich (2022)	1.2.0	2022-02-01	CRAN (R 4.0.5)
tidytext	Robinson and Silge (2021)	0.3.1	2021-04-10	CRAN (R 4.0.5)
tmap	Tennekes (2021)	3.3-2	2021-06-16	CRAN (R 4.0.5)

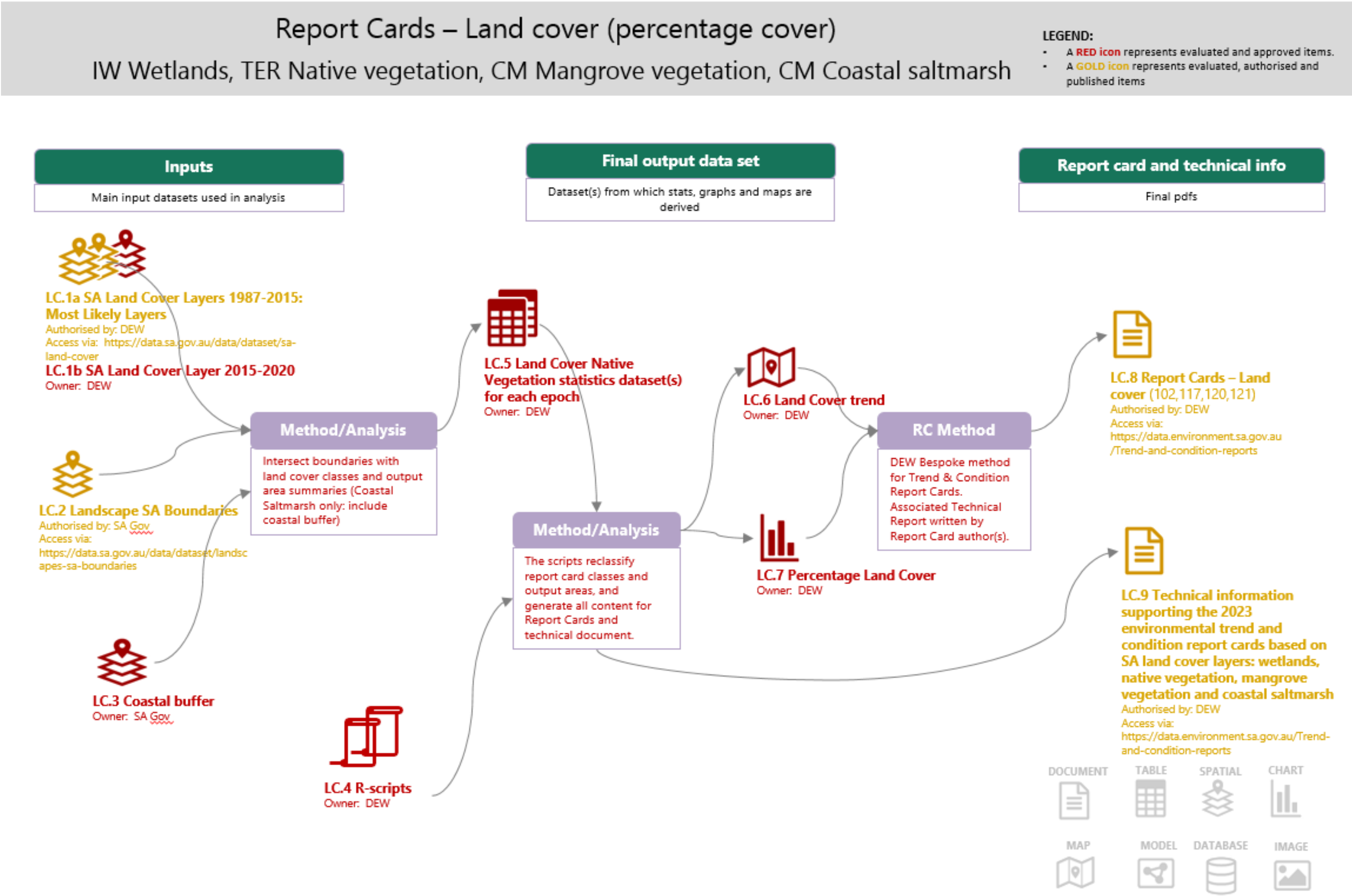

Figure 2.2: Workflow diagram (managing environmental knowledge chart) for landcover based report cards

The data import, cleaning and analysis associated with the Australian Bureau of Statistics National Land Cover Account was undertaken as a workflow within the KNIME Analytics Platform (version 5.1). KNIME is an open source software environment for creating data analysis and machine learning workflows (KNIME 2023).

3 Wetlands

3.1 Trend in wetlands percentage cover

Trend was assigned as unknown at all scales for percentage cover of wetlands (Figure 3.1) due to the challenges resulting from improved sensors in Landsat 8 see data sources. Methods to deal with changing satellite technology are evolving and it is likely that future reporting will be able to retrospectively apply trends to percentage cover of wetlands for the current reporting period see discussion.

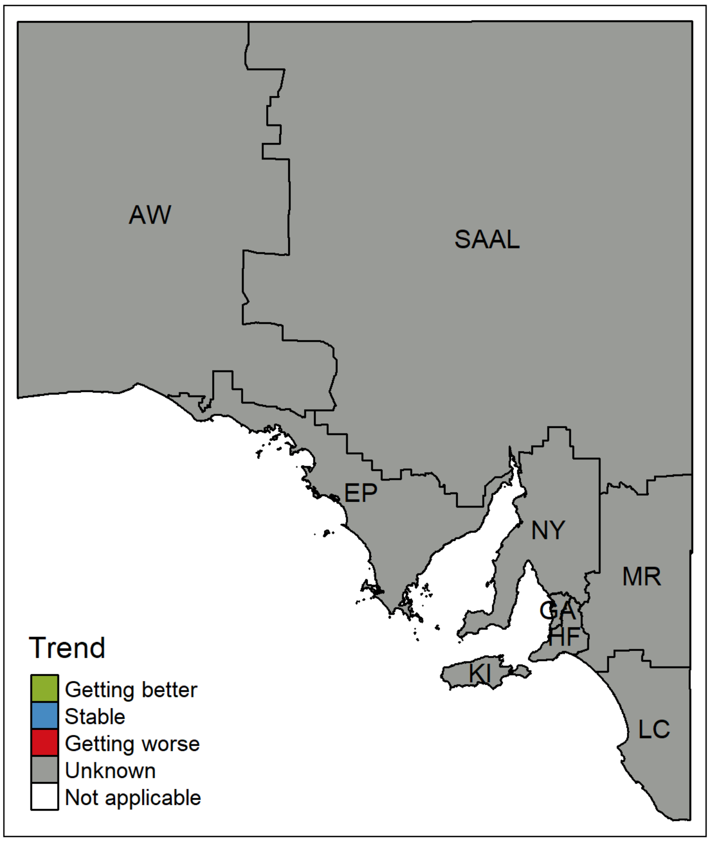

Figure 3.1: Trend for percentage cover of wetlands in each landscape region

3.2 Condition of wetlands percentage cover

Percentage cover estimates for 2020 are provided in Table 3.1. Statewide there was an estimated 1,903,100 hectares of wetlands (or 1.9% of South Australia). Regional results were 31,000 hectares in Hills and Fleurieu (HF) (6.7% of the region), 71,600 hectares in Alinytjara Wilurara (AW) (0.3% of the region), 49,500 hectares in Eyre Peninsula (EP) (1.0% of the region), 12,800 hectares in Kangaroo Island (KI) (2.9% of the region), 33,000 hectares in Northern and Yorke (NY) (0.9% of the region), 1,453,400 hectares in South Australian Arid Lands (SAAL) (2.8% of the region), 114,600 hectares in Murraylands and Riverland (MR) (2.4% of the region), 132,300 hectares in Limestone Coast (LC) (4.9% of the region) and 4,900 hectares in Green Adelaide (GA) (3.8% of the region).

As there are no agreed benchmarks or thresholds relating to condition classes for percentage cover of wetlands it is not possible to assign condition to the 2020 estimates for wetlands.

Table 3.1: Estimates of 2020 value for percentage cover of wetlands at regional and state level

LSA	2020 estimate (hectares)	2020 percentage cover
HF	31,000	6.7
AW	71,600	0.3
EP	49,500	1.0
KI	12,800	2.9
NY	33,000	0.9
SAAL	1,453,400	2.8
MR	114,600	2.4
LC	132,300	4.9
GA	4,900	3.8
State	1,903,100	1.9

3.3 Information reliability for wetlands percentage cover

The overall reliability score for wetlands percentage cover was 3 out of 5, based on Table 3.2. This was classed as good.

The overall reliability score was the minimum of (each out of 5): currency, which was 5 (most recent information up to 3 years old); applicability, which was 3 (most data based on indirect indicators of the measure); spatial, which was 5 (from across the whole region/state (or whole distribution of asset within the region/state) using a stratified sampling design); and accuracy, which was 4 (substantial accuracy (say, kappa > 0.75). Here Kappa was 0.78.

Table 3.2: Information reliability scores for wetlands percentage cover

Title	Indicator	Currency	Applicability	Spatial	Accuracy	Reliability
Wetlands	percentage cover	5	3	5	4	3

4 Native vegetation

4.1 Trend in native vegetation percentage cover

Due to the challenges resulting from improved sensors in Landsat 8 (see data sources), trend was unable to be assigned from the SA Land Cover Layers at either State or regional scales (Figure 4.1). Methods to deal with changing satellite technology are evolving and it is likely that future reporting will be able to retrospectively apply trends to percentage cover of native vegetation for the current reporting period see discussion.

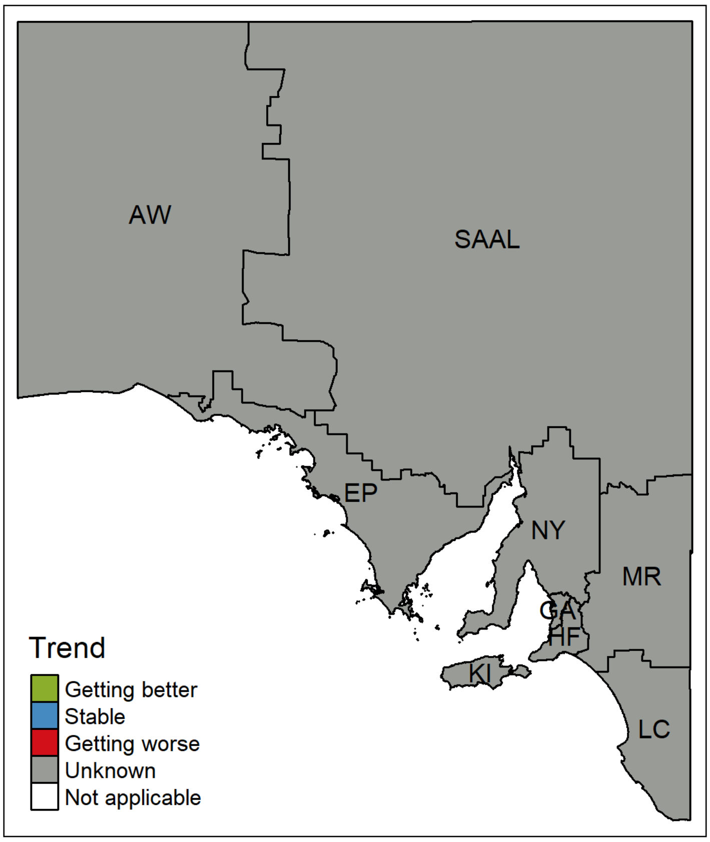

Figure 4.1: Trend for percentage cover of native vegetation in each landscape region

Instead, a Statewide trend in terrestrial native vegetation cover was derived from the Australian Bureau of Statistics National Land Cover Account (Australian Bureau of Statistics 2020). Between 2015 and 2020, there was a reduction in terrestrial native vegetation cover of 29,418 hectares (based on estimates after the rainfall-induced fluctuations had been removed through modelling). This equates to 0.03% reduction in percentage cover of native vegetation.

4.2 Condition of native vegetation percentage cover

Percentage cover estimates for 2020 are provided in Table 4.1. Statewide there was an estimated 86,085,000 hectares of native vegetation (or 87.8% of South Australia). Regional results were 134,000 hectares in Hills and Fleurieu (HF) (29.0% of the region), 28,009,000 hectares in Alinytjara Wilurara (AW) (99.3% of the region), 2,475,900 hectares in Eyre Peninsula (EP) (49.3% of the region), 248,200 hectares in Kangaroo Island (KI) (56.4% of the region), 1,313,000 hectares in Northern and Yorke (NY) (34.6% of the region), 50,236,300 hectares in South Australian Arid Lands (SAAL) (95.7% of the region), 2,955,100 hectares in Murraylands and Riverland (MR) (61.1% of the region), 678,900 hectares in Limestone Coast (LC) (25.4% of the region) and 34,500 hectares in Green Adelaide (GA) (26.8% of the region).

As there are no agreed benchmarks or thresholds relating to condition classes for percentage cover of native vegetation it is not possible to assign condition to the 2020 estimates for native vegetation.

Table 4.1: Estimates of 2020 value for percentage cover of native vegetation at regional and state level

LSA	2020 estimate (hectares)	2020 percentage cover
HF	134,000	29.0
AW	28,009,000	99.3
EP	2,475,900	49.3
KI	248,200	56.4
NY	1,313,000	34.6
SAAL	50,236,300	95.7
MR	2,955,100	61.1
LC	678,900	25.4
GA	34,500	26.8
State	86,085,000	87.8

4.3 Information reliability for native vegetation percentage cover

The overall reliability score for native vegetation percentage cover was 3 out of 5, based on Table 4.2. This was classed as good.

The overall reliability score was the minimum of (each out of 5): currency, which was 5 (most recent information up to 3 years old); applicability, which was 3 (most data based on indirect indicators of the measure); spatial, which was 5 (from across the whole region/state (or whole distribution of asset within the region/state) using a stratified sampling design); and accuracy, which was 4 (substantial accuracy (say, kappa > 0.75). Here Kappa was 0.81.

Table 4.2: Information reliability scores for native vegetation percentage cover

Title	Indicator	Currency	Applicability	Spatial	Accuracy	Reliability
Native vegetation	percentage cover	5	3	5	4	3

5 Mangrove vegetation

5.1 Trend in mangrove vegetation percentage cover

Trend was assigned as unknown at all scales for percentage cover of mangrove vegetation (Figure 5.1) due to the challenges resulting from improved sensors in Landsat 8 see data sources. Methods to deal with changing satellite technology are evolving and it is likely that future reporting will be able to retrospectively apply trends to percentage cover of mangrove vegetation for the current reporting period see discussion.

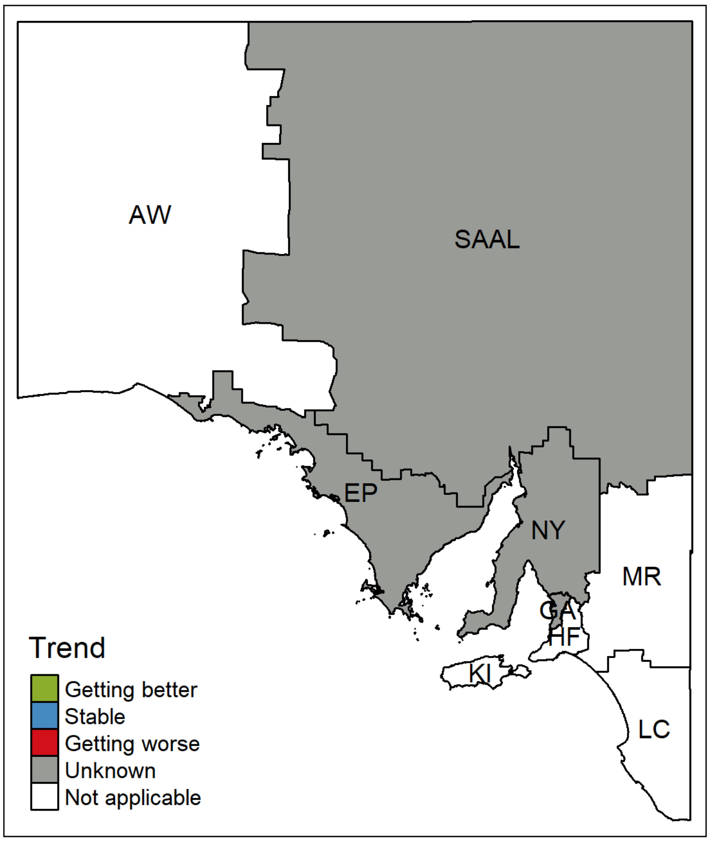

Figure 5.1: Trend for percentage cover of mangrove vegetation in each landscape region

5.2 Condition of mangrove vegetation percentage cover

Percentage cover estimates for 2020 are provided in Table 5.1. Statewide there was an estimated 14,200 hectares of mangrove vegetation (or 0.014% of South Australia). Regional results were 4,700 hectares in Eyre Peninsula (EP) (0.094% of the region), 5,800 hectares in Northern and Yorke (NY) (0.153% of the region), 1,700 hectares in South Australian Arid Lands (SAAL) (0.003% of the region) and 1,800 hectares in Green Adelaide (GA) (1.398% of the region). Hills and Fleurieu (HF), Alinytjara Wilurara (AW), Kangaroo Island (KI), Murraylands and Riverland (MR) and Limestone Coast (LC) do not have mangrove vegetation.

As there are no agreed benchmarks or thresholds relating to condition classes for percentage cover of mangrove vegetation it is not possible to assign condition to the 2020 estimates for mangrove vegetation.

Table 5.1: Estimates of 2020 value for percentage cover of mangrove vegetation at regional and state level

LSA	2020 estimate (hectares)	2020 percentage cover
HF	-	-
AW	-	-
EP	4,700	0.094
KI	-	-
NY	5,800	0.153
SAAL	1,700	0.003
MR	-	-
LC	-	-
GA	1,800	1.398
State	14,200	0.014

5.3 Information reliability for mangrove vegetation percentage cover

The overall reliability score for mangrove vegetation percentage cover was 3 out of 5, based on Table 5.2. This was classed as good.

The overall reliability score was the minimum of (each out of 5): currency, which was 5 (most recent information up to 3 years old); applicability, which was 3 (most data based on indirect indicators of the measure); spatial, which was 5 (from across the whole region/state (or whole distribution of asset within the region/state) using a stratified sampling design); and accuracy, which was 5 (almost perfect accuracy (say, kappa > 0.9). Here Kappa was 0.96.

Table 5.2: Information reliability scores for mangrove vegetation percentage cover

Title	Indicator	Currency	Applicability	Spatial	Accuracy	Reliability
Mangrove vegetation	percentage cover	5	3	5	5	3

6 Coastal saltmarsh

6.1 Trend in coastal saltmarsh percentage cover

Trend was assigned as unknown at all scales for percentage cover of coastal saltmarsh (Figure 6.1) due to the challenges resulting from improved sensors in Landsat 8 see data sources. Methods to deal with changing satellite technology are evolving and it is likely that future reporting will be able to retrospectively apply trends to percentage cover of coastal saltmarsh for the current reporting period see discussion.

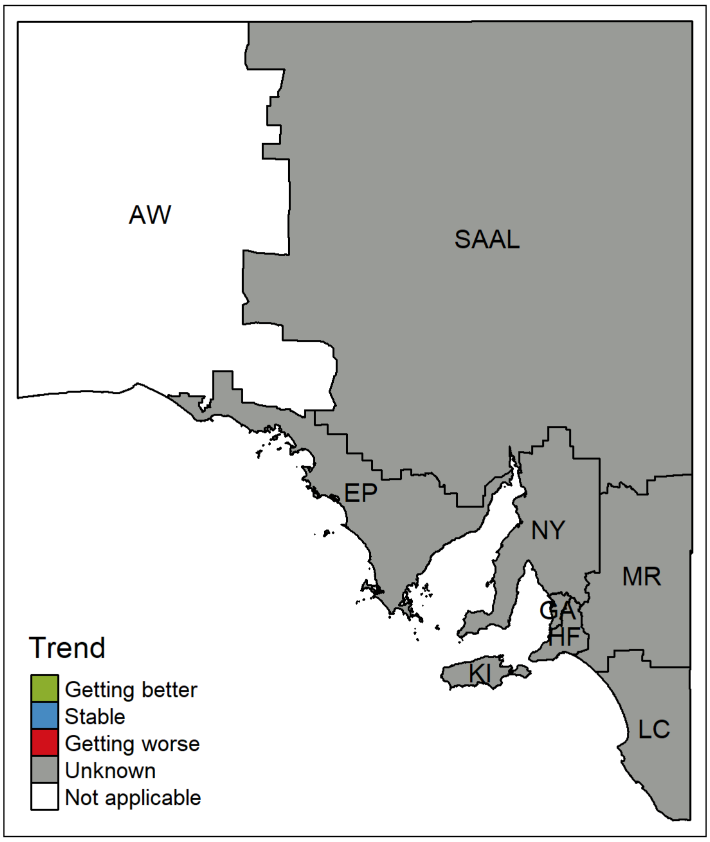

Figure 6.1: Trend for percentage cover of coastal saltmarsh in each landscape region

6.2 Condition of coastal saltmarsh percentage cover

Percentage cover estimates for 2020 are provided in Table 6.1. Statewide there was an estimated 18,700 hectares of coastal saltmarsh (or 0.019% of South Australia). Regional results were 300 hectares in Hills and Fleurieu (HF) (0.062% of the region), 6,100 hectares in Eyre Peninsula (EP) (0.122% of the region), 500 hectares in Kangaroo Island (KI) (0.111% of the region), 8,400 hectares in Northern and Yorke (NY) (0.221% of the region), 1,700 hectares in South Australian Arid Lands (SAAL) (0.003% of the region), 400 hectares in Murraylands and Riverland (MR) (0.007% of the region), 700 hectares in Limestone Coast (LC) (0.025% of the region) and 600 hectares in Green Adelaide (GA) (0.499% of the region). Alinytjara Wilurara (AW) does not have coastal saltmarsh.

As there are no agreed benchmarks or thresholds relating to condition classes for percentage cover of coastal saltmarsh it is not possible to assign condition to the 2020 estimates for coastal saltmarsh.

Table 6.1: Estimates of 2020 value for percentage cover of coastal saltmarsh at regional and state level

LSA	2020 estimate (hectares)	2020 percentage cover
HF	300	0.062
AW	-	-
EP	6,100	0.122
KI	500	0.111
NY	8,400	0.221
SAAL	1,700	0.003
MR	400	0.007
LC	700	0.025
GA	600	0.499
State	18,700	0.019

6.3 Information reliability for coastal saltmarsh percentage cover

The overall reliability score for coastal saltmarsh percentage cover was 3 out of 5, based on Table 6.2. This was classed as good.

The overall reliability score was the minimum of (each out of 5): currency, which was 5 (most recent information up to 3 years old); applicability, which was 3 (most data based on indirect indicators of the measure); spatial, which was 5 (from across the whole region/state (or whole distribution of asset within the region/state) using a stratified sampling design); and accuracy, which was 3 (moderate accuracy (say, kappa > 0.4). Here Kappa was 0.41.

Table 6.2: Information reliability scores for coastal saltmarsh percentage cover

Title	Indicator	Currency	Applicability	Spatial	Accuracy	Reliability
Coastal saltmarsh	percentage cover	5	3	5	3	3

7 Discussion

The trend and condition for wetlands, mangrove vegetation and coastal saltmarsh percentage cover have been identified as unknown despite the overall information reliability having a mean value of good.

Table 7.1: Summary of results for all SA Land Cover Layers based report cards

Title	2020 hectares	2020 percentage cover	Trend	Condition	Reliability
Wetlands	1,903,100	1.9	Unknown	Unknown	3
Native vegetation	86,085,000	87.8	Getting Worse	Unknown	3
Mangrove vegetation	14,200	0.014	Unknown	Unknown	3
Coastal saltmarsh	18,700	0.019	Unknown	Unknown	3

This is the first time the SA Land Cover Layers based report cards have not been assigned a trend. As detailed in the data sources this situation has arisen due to changes in satellite technology creating challenges for comparisons between current satellite sensors and previous satellite sensors. The extent to which changing sensors drove previous trends, rather than changing land cover, is unknown.

A trend has been assigned to terrestrial native vegetation cover, but this has been derived from the Australian Bureau of Statistics National Land Cover Accounts, rather than the SA Land Cover Layers.

In future, it is anticipated that the sensor challenges will be overcome, again allowing trends to be assigned. Approaches to achieve this are likely to include:

- improved alignment of satellite data time series to account for changing sensors
- instrument based models (rather than epoch based models) so that all satellite data comes from the same sensor
- individual class models to better understand the effect of sensor changes on an individual land cover class.

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