Carbon Sequestration from Targeted Revegetation in the Southern Yorke Peninsula Region

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Government of South Australia
Department of Environment, Water and Natural Resources

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Summary

The southern Yorke Peninsula region is recognised as a significant biodiversity hot spot in South Australia. To restore and conserve the unique and diverse ecosystems of the region the Yorke Peninsula community has undertaken a collaborative, landscape-scale planning approach to biodiversity conservation. The community is involved in a Conservation Action Planning (CAP) process to identify important biodiversity assets within the region, and developed a strategy for their future care and maintenance. The CAP process has identified several open woodland and mallee vegetation communities as important assets in the region.

Targeted revegetation is part of Southern Yorke Peninsula's integrated strategy to restore the extent and functionality of these plant communities. While these revegetation activities may be designed for ecological benefits, they also have the potential to provide co-benefits to the community and individual landholders through the sequestration of atmospheric carbon dioxide and access to carbon markets. Estimates of carbon sequestration rates from targeted revegetation activities in the region can assist planners and landholders to evaluate the potential economic value of these new assets through carbon markets.

The ability of revegetation activities to sequester carbon dioxide is strongly influenced by climate, soil, vegetation structure and time. These influences have been quantified from previous South Australian Government studies of carbon sequestration from revegetation, and the resulting spatial-temporal models have been recalibrated for five priority vegetation communities in the Southern Yorke Peninsula region. This report provides estimates of carbon sequestration rates from potential targeted revegetation activities for several open woodland and mallee plant communities at 25 and 45 years of age under historic climatic conditions. These models have also been used to explore the likely impact of several potential climate change scenarios on carbon sequestration, plant mortality and vegetation structure in the region.

The use of priority vegetation community types, pre-1750 vegetation mapping and local reference sites has more clearly defined the intended purpose, locations and vegetation structure of targeted revegetation activities in the region. Targeted revegetation criteria have facilitated more reliable:

- estimates of carbon sequestration rates from revegetation activities in cleared agricultural lands (average of +25% more carbon than using 'typical environmental plantings' estimates of Hobbs *et al.* 2015);
- indicators of expected changes in planted vegetation structure over time and influenced by changing climates; and
- evaluations of carbon market stocks resulting from revegetation activities in the region.

Future revegetation and conservation action planning activities in the region should also consider that:

- the mortality of plants on revegetation sites is significant over 45 years, and initial plant densities may need to be 2 or 3 times higher than desired rate at vegetation maturity;
- severe climate change has the potential to reduce average carbon sequestration rates by up to 24% over the next 45 years compared to historic climate averages, and make plant density in revegetation plant communities 11% lower;
- most cleared agricultural landscapes, with good soils and rainfall, would also have higher than average carbon sequestration rates if targeted by revegetation; and
- locations within existing native vegetation communities with higher than typical potential sequestration rates may provide potential indicators of other ecological values (e.g. source populations or refugia for plant and animals).

1 Introduction

1.1 Background

Through a Conservation Action Planning (CAP) process initiated in 2010 the Northern and Yorke Natural Resources Management (NRM) Board, South Australian (SA) Government (through the Department of Environment, Water and Natural Resources, Natural Resources Northern and Yorke, DEWNR NR NY), several non-government agencies, local government and many community groups identified priority vegetation communities for ecological restoration activities in the Southern Yorke Peninsula (Rogers 2013, Berkinshaw *et al.* 2014). The previous extent of native plant communities (Figure 1.1) and spatially explicit priorities linked to major conservation actions and objectives has been mapped by the SA Government and Greening Australia (Neagle 2008, Rogers 2013, Koch 2013, DEWNR 2015).

Revegetation of priority communities within cleared agricultural lands (Figure 1.2) is part of Southern Yorke Peninsula (SYP) Biodiversity CAP's integrated strategy for a collaborative, landscape-scale planning approach to biodiversity conservation in the region. To help facilitate greater adoption of revegetation activities on private lands in the region, the SYP Biodiversity CAP team provides information, support and advice to local landholders on re-establishing native vegetation and potential benefits of these activities to regional biodiversity, ecological systems and the community. While the purpose of most revegetation activities in the region is for ecological benefits, local landholders may increase their adoption of this landuse activity if better information on landuse planning, climate change impacts, carbon sequestration potential of revegetation and carbon markets were available.

The SA Government and Natural Resource Management Boards have worked with the University of Adelaide and CSIRO to improve their understanding of landuse planning and climate change adaptation through the Landscape Future Analysis Tool (LFAT) (Bryan et al. 2011; Meyer & Bryan 2013). The tool allows users to explore future scenarios of landuses, market prices and climate change within the region. Prior to 2014, estimates of carbon sequestration from revegetation within the LFAT system were based on the 3PG model (Landsberg *et al.* 2003) but were found to be insufficiently calibrated for reliable use in the agricultural regions of South Australia. In 2013-14, researchers from the Department of Environment, Water and Natural Resources (DEWNR) partnered with the University of Adelaide to update the carbon sequestration from revegetation models within the LFAT system (Hobbs *et al.* 2015).

In recent years, DEWNR and its partners have completed detailed surveys of 264 known-age revegetation sites across the agricultural region of South Australia and undertaken analyses to quantify climate, soil, planting design and age influences on carbon sequestration rates and vegetation structure (Hobbs *et al.* 2013). Those models were adapted and recalibrated to LFAT specifications of planting designs and climate change scenarios to create 36 standard carbon sequestration model outputs (Hobbs *et al.* 2015). This standard series of model outputs includes 3 representative planting designs with average plant densities based on historic observations, 3 timeframes and 4 climate scenarios. In mid-2014, the same standard model series were incorporated into the Carbon Planting Guidelines (CPG) (DEWNR 2014). These models represent carbon sequestration rates from revegetation using Kyoto-compliant perennial species (>2m high at maturity) and includes the above-ground and below-ground biomass trees, mallees and taller shrubs. Models do not include the biomass of low-medium height shrubs (<2m at maturity) or ground cover species.

1.2 Objectives

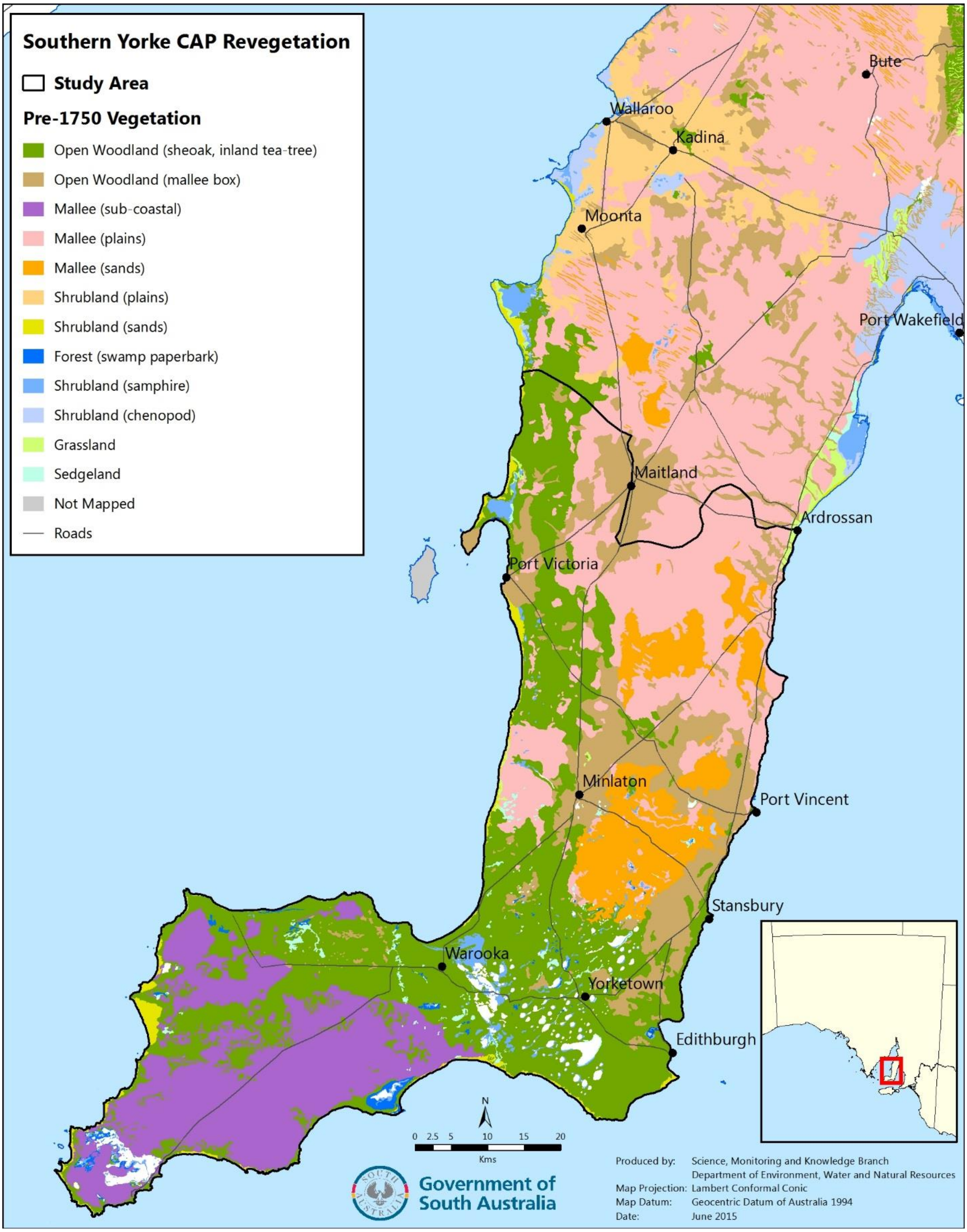
The objective of this project, as summarised by this report, was to undertake a desktop analysis of potential carbon sequestration rates from revegetation for Conservation Action Planning (CAP) priority vegetation communities (Berkinshaw *et al.* 2014) in the Southern Yorke Peninsula region using existing carbon sequestration models developed by DEWNR (Hobbs *et al.* 2013, 2015). The study area is based on the Southern Yorke sub-region of the Interim Biogeographic Regionalisation for Australia (IBRA Version 7, DotE 2012).

Targeted vegetation communities for this project were:

- Open Woodlands (with overstoreys dominated by sheoak (*Allocasuarina verticillata*), inland tea-tree (*Melaleuca lanceolata*) or mallee box (*Eucalyptus porosa*);
- Sub-coastal Mallee Communities; and
- Relictual Mallee Communities (on plains or deep sands).

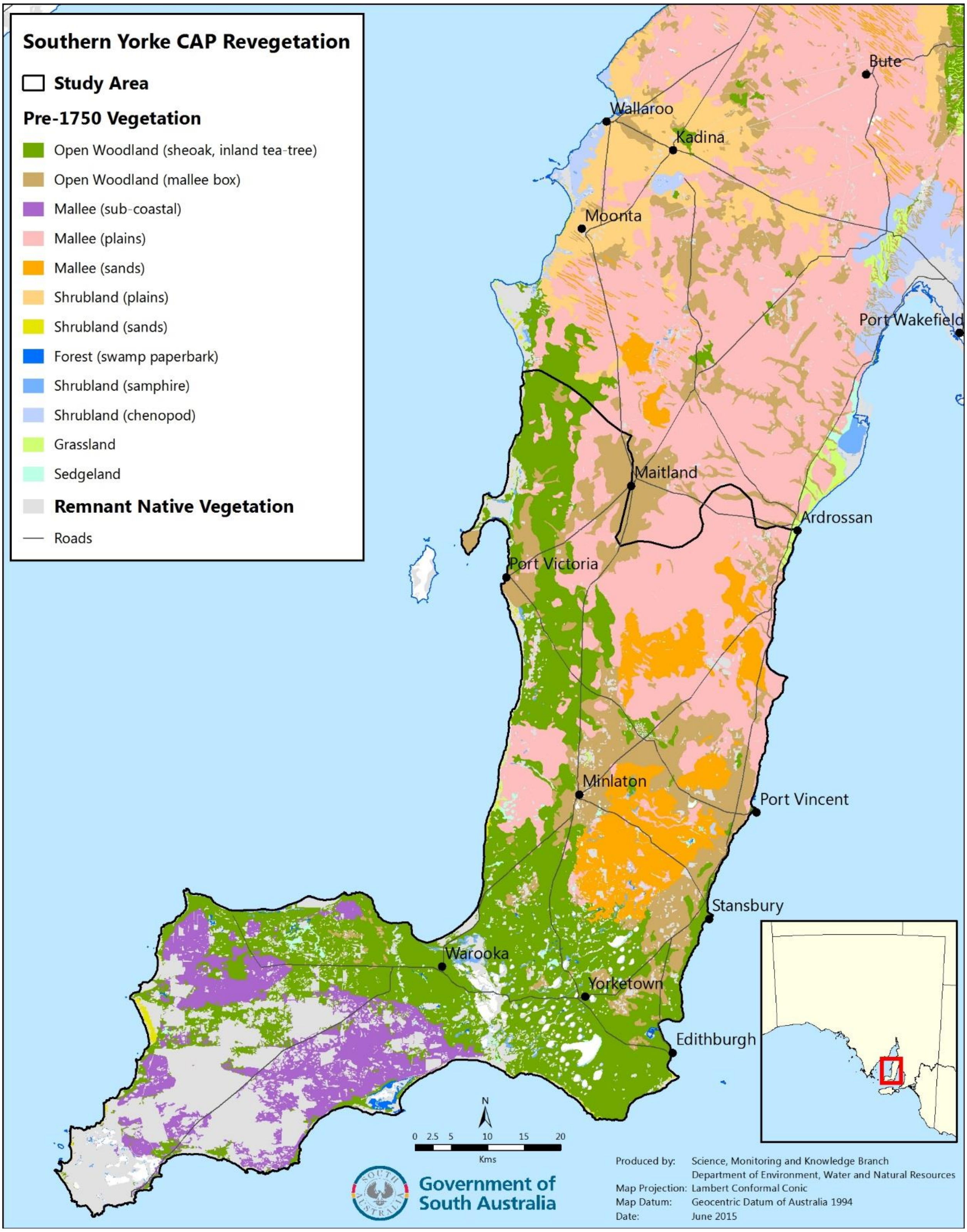
For each of these vegetation communities:

- Spatial analyses were based on DEWNR maps of the pre-1750 extent of CAP priority vegetation communities and cleared agricultural lands as illustrated by Figure 1.1 and Figure 1.2.
- DEWNR carbon models were locally calibrated using tree and tall shrub cover and plant density estimates from Bushland Condition Monitoring (BCM) sites provided by Nature Conservation Society of South Australia (unpublished data).
- The potential influence of a range of climate change scenarios on targeted revegetation activities was analysed over the next 25 to 45 years. Climate change scenarios investigated are consistent with those developed in the Landscape Futures Analysis Tool project (i.e. historic climate, +3 increasingly severe generic [i.e. non-specific Global Circulation Model] climate change scenarios; Meyer & Bryan 2013).



Source: DEWNR (2015).

Figure 1.1 Pre-1750 vegetation mapping in the Yorke Peninsula region



Source: DEWNR (2015).

Figure 1.2 Priority vegetation communities for cleared agricultural lands in the Southern Yorke Peninsula region

2 Methods

2.1 Targeted revegetation designs

Pre-1750 vegetation mapping groups (DEWNR 2015) and Bushland Condition Monitoring (BCM) data (NCSSA 2015) were aligned to Southern Yorke Peninsula (SYP) Conservation Action Planning (CAP) asset types (Berkinshaw *et al.* 2014). The CAP Open Woodlands were separated into "sheoak, inland tea-tree" and "mallee box" communities and the CAP Relictual Mallee Community split into mallee "plains" and "sands". Due to natural gradations with vegetation communities and pre-1750 vegetation mapping descriptions the "sheoak, inland tea-tree" community was not further divided.

The five targeted vegetation communities included in this study were:

- Open Woodland (sheoak, inland tea-tree);
- Open Woodland (mallee box);
- Mallee (sub-coastal);
- Mallee (plains); and
- Mallee (sands).

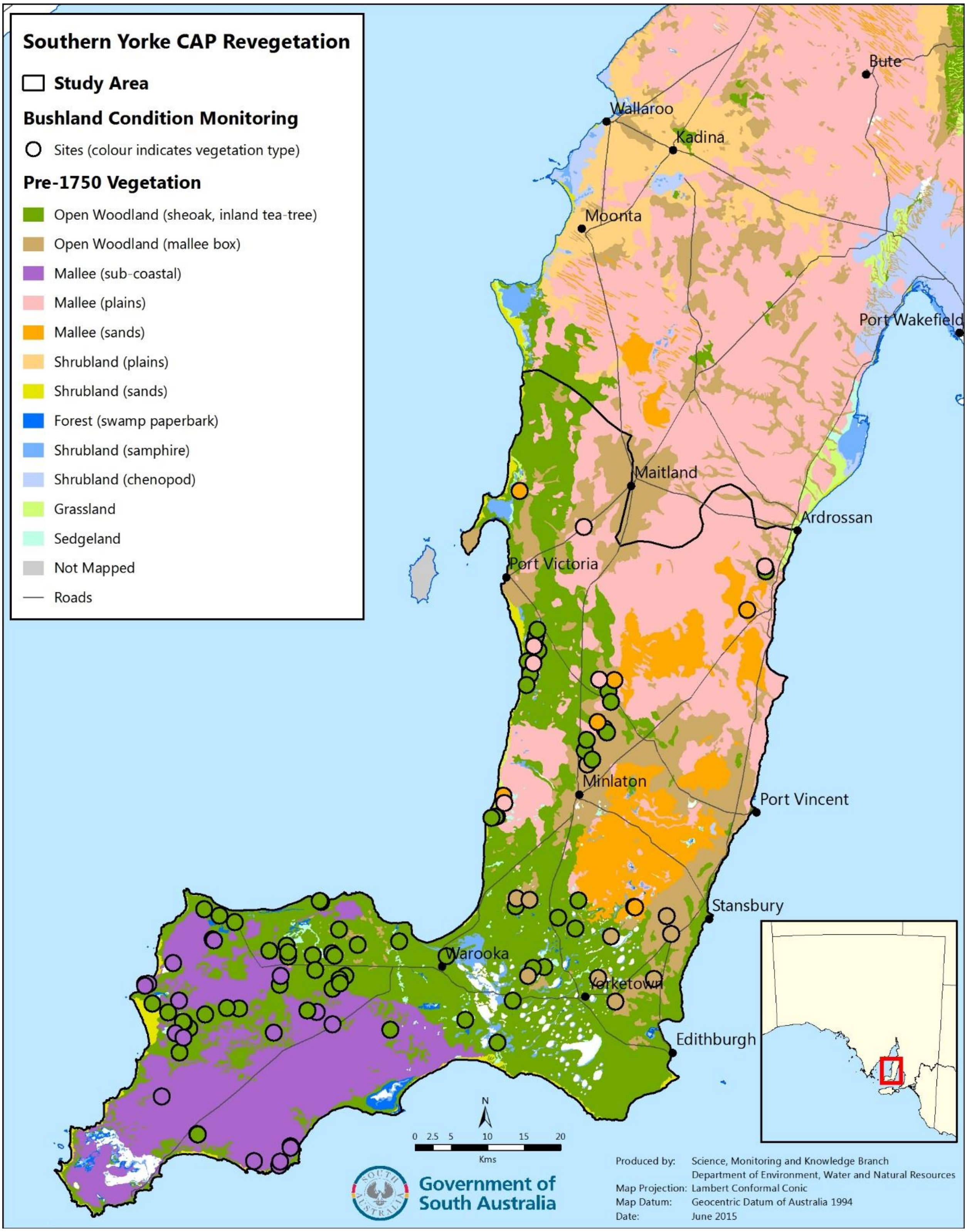
Carbon sequestration rates of revegetation sites are influenced by climatic conditions, soils, time and vegetation structure (plant density and tree/shrub ratios) (Hobbs *et al.* 2013, 2015). For this study, vegetation structure data from 108 Nature Conservation Society of South Australia's Bushland Condition Monitoring (BCM) sites (Figure 2.1) were used to define a reference or benchmark vegetation structure at a target age of 45 years for each of the priority vegetation types. The BCM data includes vegetation descriptive information, assessments of crown cover within each lifeform/height stratum and metrics of site condition (Appendix A). The BCM crown cover estimates of tall shrubs, mallees and trees by lifeform/height stratum, and crown area by height allometrics (Figure 2.2) of Hobbs *et al.* (2013) have been used to estimate the plant density (plants/ha) for each lifeform/height stratum (i.e. crown cover per hectare [m^2] divided by the average crown area per lifeform/height class). The total number of trees per hectare divided by total number of plants per hectares identifies the proportion of trees at each site. The typical vegetation structure (i.e. mean plant density and proportion of trees) for each targeted vegetation type was used define community-specific calibration data for carbon sequestration models.

Addition vegetation survey data (277 sites) from DEWNR's Biological Database of South Australia (BDBSA) were clustered to a similar vegetation classification system at those identified by Southern Yorke Peninsula CAP. Both BCM and BDBSA sites, classified by CAP vegetation community types, were compared against pre-1750 vegetation mapping groups to confirm spatial consistency between the datasets. These analyses confirmed that BCM calibration data was representative of other sites with the same vegetation as the five CAP targeted vegetation communities.

2.2 DEWNR Carbon sequestration models

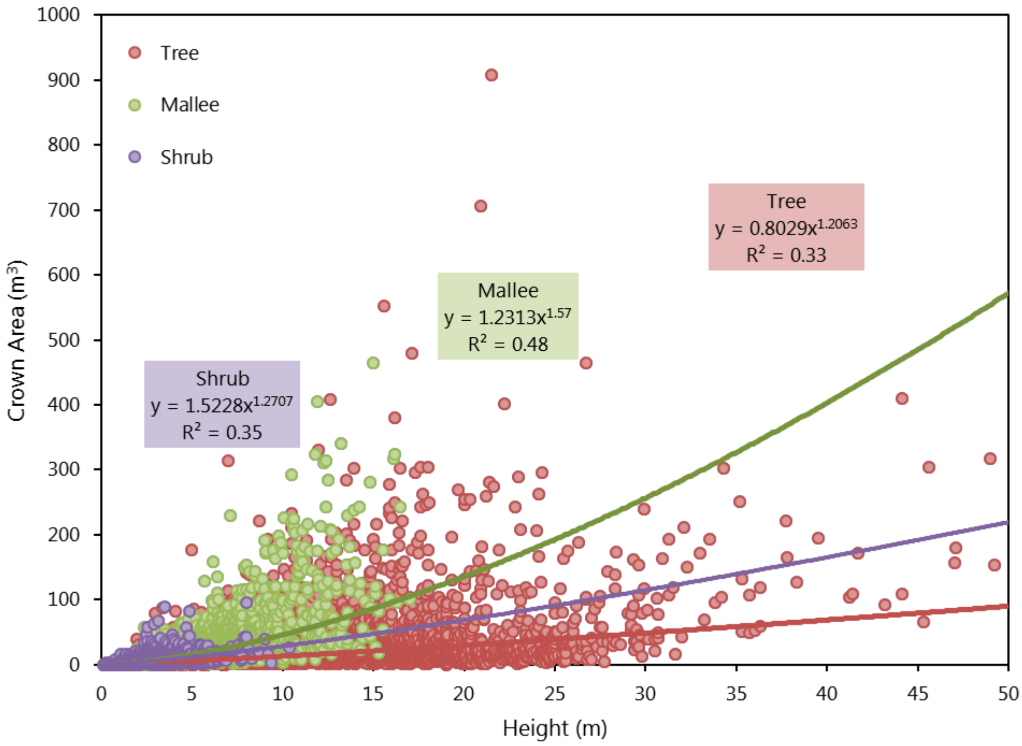
The development of DEWNR's carbon sequestration models and spatial applications has been documented in detail by Hobbs *et al.* (2013, 2015). The following is a concise description of that work and the key elements of the modelling process.

DEWNR and its partners have undertaken 264 surveys of above-ground biomass (AGB) of known-age revegetation sites across the agricultural regions of South Australia, including detailed surveys of below-ground biomass (BGB) of mallees and trees at two sites. Using this survey data and spatial environmental information (i.e. climate = ANUCLIM Version 6.1, Xu & Hutchison 2013; soils = ACLEP ASRIS format, McKenzie *et al.* 2012) it was possible to quantify the relationships between planting designs, climate, soils and time on typical carbon sequestration rates and plant densities over time. All spatial datasets used in these models have spatial resolution of 100 × 100 metres (1 ha).



Source: DEWNR (2015) and the Nature Conservation Society of SA (2015).

Figure 2.1 Bushland Condition Monitoring reference sites used to calibrate carbon sequestration models



Source: Hobbs *et al.* (2013), 16,586 observations.

Figure 2.2 Allometric relationships between plant height and crown area by life form group

Age, evaporation, proportion of trees, rainfall and soil water-holding capacity were found to influence revegetation site plant density spatially and over time ($n=264$, $r^2=0.24$, $p<0.0001$, $AIC_c=549.8$):

$$\log(PD_{all} + 1) = (-0.2983 \times \log(t + 1) - 1.3801 \times PE - 0.6827 \times PT + 0.0009736 \times MAR + 17.70) \times (0.0003704 \times W + 0.9346)$$

where,

PD_{all} = Plant density, all plants (plants/ha)
t = Age (years)
PE = Mean annual potential evaporation (mm/year)
PT = Proportion of trees (count of trees / count of all plants ≥2 m high at maturity)
MAR = Mean annual rainfall (mm/year)
W = Plant available water capacity, total (mm)

Revegetation site growth rates are influenced by rainfall, water infiltration rates, total plant density, clay content of the soil surface, shrub plant density, time and soil depth ($n=264$, $r^2=0.60$, $p<0.0001$, $AIC_c=370.4$):

$$\log(\Delta AGB + 1) = 0.003674 \times MAR + 0.4782 \times \log(KS_1 + 1) + 0.3092 \times \log(PD_{all} + 1) + 0.05543 \times CC_1 - 0.06986 \times \log(PD_s + 1) - 0.1959 \times \log(t + 1) + (0.0001750 \times MAR \times D_{nv}) - 4.422$$

where,

ΔAGB = Mean above-ground biomass productivity rate (dry matter t/ha/year)
MAR = Mean annual rainfall (mm/year)
KS_1 = Saturated hydraulic conductivity of the soil surface, layer 1 (mm/hour)
PD_{all} = Plant density, all plants (plants/ha)
CC_1 = Clay content of the soil surface, layer 1 (% by weight)
PD_s = Plant density, shrubs only, ≥2 m high at maturity (plants/ha)
t = Age (years)
D_{nv} = Depth of soil, suitable for native vegetation (m)

To determine the total carbon sequestration rates for any given site or scenario (i.e. planting design × timeframe × climate) the above-ground biomass is calculated for each hectare (i.e. AGB = rate × time). Below-ground (i.e. root) biomass (BGB_{site}) is estimated for each hectare from the average above-ground biomass of plants (i.e. AGB_{site} ÷ Plant density) using a generic allometric model developed from whole-plant destructive data (Hobbs *et al.* 2013; n=41, r^2=0.82, p<0.0001, AIC_c=41.6):

$$\log(BGB_{plant} + 1) = 0.7426 \times \log(AGB_{plant} + 1) + 0.6073$$

where,

AGB_{plant} = Above-ground biomass (kg/plant)
BGB_{plant} = Below-ground biomass (kg/plant)

Below-ground biomass of each hectare (BGB_{site}) is estimated from above-ground biomass (AGB_{site}) using the root to shoot ratio of average plants for each hectare (i.e. BGB_{plant}: AGB_{plant}). Total plant biomass for each hectare (i.e. AGB_{site} + BGB_{site}) is converted to elemental carbon stocks using a factor of 0.496 (Stein & Tobiasen 2007) and elemental carbon stock converted to converted to carbon dioxide equivalents (CO_2-e t/ha) using a factor of 3.67. The average carbon sequestration rate (CO_2-e t/ha/year) for the total above-ground and below-ground biomass is calculated by dividing the total carbon stock for each hectare by time.

2.3 Climate change

To maintain consistency with other climate change research conducted in South Australia by CSIRO and the University of Adelaide (Bryan *et al.* 2011; Summers *et al.* 2014), this study used the same four climate scenarios (i.e. rainfall and temperature variations) used in the "Landscape Futures Analysis" (LFA) project (Table 2.1). Estimates of changes to potential evaporation rates for the four climate scenarios were also included in the analysis, based on previous studies of the likely impact of climate change on crop productivity (Hayman *et al.* 2011) and water resources (Gibbs *et al.* 2011) in South Australia. Potential atmospheric carbon dioxide fertilization effects have not been included in these analyses or models.

Table 2.1 Climate change scenarios used to explore the influence of increases in temperature and potential evaporation, and decreases in annual rainfall, on carbon sequestration rates from revegetation

Climate change scenario	Rate of change 1990 to 2070		
	Mean annual temperature	Mean annual potential evaporation	Mean annual rainfall
S0 Baseline	Historic	Historic	Historic
S1 Mild warming & drying	+1 °C	+3%	-5%
S2 Moderate warming & drying	+2 °C	+6%	-15%
S3 Severe warming & drying	+4 °C	+8%	-25%

2.4 Southern Yorke Peninsula Carbon sequestration models

The average vegetation structure (i.e. plant density and proportion of trees and mallees [i.e. (trees + mallees)/(trees + mallees + taller shrubs)]) from the CAP priority vegetation reference sites has been used to recalibrate DEWNR carbon models for each vegetation type at a benchmark age of 45 years and under current climatic conditions. To account for local variations in plant density due to climate and soil influences on each vegetation type it was necessary to recalibrate the generic DEWNR plant density models to local conditions. Generic DEWNR plant density models were generated for each vegetation type using the average proportion of trees at reference sites. Ground-based estimates of plant density from BCM sites were compared to modelled generic plant density estimates for each reference site and average ratio used as a plant density correction factor for each vegetation type.

Although spatially variable due to climate and soil conditions for each vegetation type, all climate change and growth period models assume that the initial establishment rate (i.e. plant density and proportion of trees at 3 years) for each hectare is consistent with the benchmark scenario of 45 years and under current climatic conditions for each vegetation type.

Plant density and carbon sequestration rates are also influenced by time. Plant density on revegetation sites tends to decrease with time and average sequestration rates typically decrease as the revegetation site matures. For this study two timeframe scenarios (i.e. 25 years and 45 years) are included in modelled results.

Climate and soil variables (Xu & Hutchison 2013, McKenzie *et al.* 2012) which influence plant density and carbon sequestration rates (Hobbs *et al.* 2013, 2015) have been extracted from national climate and soil datasets (100 × 100 metres resolution) for the entire Yorke Peninsula region.

Plant density and carbon sequestration models were generated for each of the 40 scenarios (i.e. 5 vegetation types × 4 climates × 2 timeframes) across the whole Yorke Peninsula region at resolution of 100 × 100 metres (1 ha). Pre-1750 vegetation mapping polygons were converted to raster format at 100 × 100 metres resolution (1 ha) for spatial consistency and used to identify and extract the matching vegetation-specific plant density and carbon sequestration model data to create a composite map (100 × 100 metres resolution) of the five vegetation communities across the whole Yorke Peninsula region for each climate change scenario and timeframe.

3 Results

3.1 Reference sites

The typical vegetation structure (i.e. proportion of trees, plant density) of CAP priority plant communities is summarised in Table 3.1. The average ‘proportion of trees and mallees’ (i.e. (trees + mallees)/(trees + mallees + taller shrubs)) is lower (but highly variable) in the sand mallee (47%), sub-coastal mallee (61%) and sheoak/inland tea-tree woodland (67%) communities and more consistently high within the mallee box woodland (95%) and plains mallee communities (96%). The BCM data also indicate that sub-coastal mallee communities are also variable in their plant density values, but are typically more densely populated than the other four plant communities. Mallee box woodlands are typically the least densely populated plant community, with less than half of the plants per hectare of the sub-coastal mallee communities. There is a strong trend between soil type and mature plant density, where plant density decreases with increasing clay content in soils. Trends between BCM estimates and generic DEWNR model estimates of plant density show that targeted revegetation would typically have a lower number of plants per hectare than observed from historic revegetation activities in agricultural regions (Hobbs *et al.* 2015, Table 3.1).

Table 3.1 Summary of BCM Reference sites used for carbon model calibrations

Vegetation Community	Count	Mean Annual Rainfall (mm/year) ± s.d.	Proportion of Trees and Mallees ± s.d.	BCM Survey Plant Density (plants/ha) ± s.d.	Generic Model Plant Density (plant/ha) ± s.d.
Open Woodland (sheoak, inland tea-tree)	65	407 ± 27	0.67 ± 0.37	238 ± 203	407 ± 48
Open Woodland (mallee box)	10	395 ± 7	0.95 ± 0.1	161 ± 61	346 ± 23
Mallee (sub-coastal)	20	431 ± 21	0.61 ± 0.31	376 ± 274	439 ± 32
Mallee (plains)	7	375 ± 22	0.96 ± 0.08	166 ± 111	323 ± 49
Mallee (sands)	6	383 ± 19	0.47 ± 0.36	227 ± 147	504 ± 68

3.2 Southern Yorke Peninsula Carbon model calibrations

The typical vegetation structure of the BCM references sites has been used to recalibrate DEWNR carbon models to represent targeted revegetation activities in the region. These new calibrations are intended to represent, for each vegetation community, a mature vegetation state at 45 years of age under historic climate conditions (Table 3.2). It is acknowledged that the BCM sites represent a diverse range of vegetation states and ages, and that the typical calibration values used in carbon models will not account for all factors that influence vegetation structure and growth over time.

Table 3.2 Southern Yorke Peninsula Carbon model parameters

Vegetation Community	Proportion of Trees and Mallees	Proportion of Generic DEWNR Plant Density Model
Open Woodland (sheoak, inland tea-tree)	0.67	0.58
Open Woodland (mallee box)	0.95	0.47
Mallee (sub-coastal)	0.61	0.85
Mallee (plains)	0.96	0.53
Mallee (sands)	0.47	0.43

3.3 Southern Yorke Peninsula Carbon model outputs

Southern Yorke Peninsula carbon model parameters were included in DEWNR carbon modelling routines and applied to climate and soils spatial datasets for the entire Yorke Peninsula region for each of the 5 community types. Plant density surfaces for each model, timeframe (i.e. 25 and 45 years) and climate scenario (i.e. historic, mild, moderate and severe) were created prior to calculations of above-ground biomass growth, estimates of root biomass and carbon sequestration rates. The data have been constrained to the Yorke Peninsula region and composited to the specifications of the CAP Pre-1750 vegetation mapping. In the northern Yorke Peninsula region the "Shrubland (plains)" community (see Figure 2.1, outside the study area and lacking BCM calibration data) is represented by "Mallee (sub-coastal)" model due to similarities in their soil types. None of the models are used represent the minor, saline or treeless vegetation communities of the region (Table 3.3).

The expected spatial variations in plant density across the Yorke Peninsula region resulting from different vegetation structure of each targeted CAP vegetation community, climate and soil factors are illustrated by Figure 3.1 and Figure 3.2. Lower plant density values in year 45 compared to year 25 illustrate the mortality factor of plants over time. The *DEWNR Carbon Sequestration from Revegetation Estimator* tool (Version 1.1, Hobbs *et al*. 2013), downloadable from the DEWNR website, can be used to more thoroughly explore the influences of climate, soil conditions and time on plant mortality rates in revegetation communities (Figure 3.3). Typically only 48% of the plants established by the third year after planting will survive to year 45 under historic climate conditions (Table 3.4).

Carbon sequestration rates are also spatially influenced by climate, soils, age, plant density and the proportions of trees in targeted revegetation communities (Figure 3.4 and Figure 3.5). Deep soils or moderate-depth soils with higher rainfall are typically the most productive. Average carbon sequestration rates are higher at 25 years compared to 45 years due to early access to stored soil moisture resulting from agricultural uses, residual fertiliser effects and lower competition between plants for resources in the early years.

Southern Yorke Peninsula summaries of average plant density for all modelled vegetation communities, climate change scenarios and timeframes for targeted revegetation on cleared agricultural lands are presented in Table 3.4. The percentage of each community type which exists as native remnant vegetation is highly variable across the region compared to its pre-1750 extent (i.e. 3.5% to 51.0%, Table 3.4). Maps representing the average plant density and carbon sequestration rates after 45 years and for all climate change scenarios in cleared agricultural lands within the Yorke Peninsula region are presented in series Figure 3.6 to Figure 3.13. These results show that carbon sequestration rates from revegetation activities in the region are strongly influenced by different targeted communities, timeframes and climates.

Mallee communities on plains and sub-coastal environments generally sequester around 27% more carbon per year than open woodland communities within the region. As climates become warmer and drier fewer revegetation plants persist and the average carbon sequestration rate over the first 45 years will decrease (i.e. mild climate -5.6%, moderate climate -14.6%, severe climate -22.5%).

Table 3.3 Extent of Southern Yorke Peninsula carbon modelling

Vegetation community	Region		Cleared lands		Remnants
	Area (ha)	Mean annual rainfall (mm/year)	Area (ha)	Mean annual rainfall (mm/year)	
Modelled					
Open Woodland (sheoak, inland tea-tree)	158212	401	137822	399	12.9%
Open Woodland (mallee box)	57397	395	53148	395	7.4%
Mallee (sub-coastal)	78409	438	38459	434	51.0%
Mallee (plains)	70494	397	67999	397	3.5%
Mallee (sands)	38786	403	37447	403	3.5%
Summary	**403298**	**407**	**334875**	**403**	**17.0%**
Not modelled					
Shrubland (sands)	7555	396	305	399	96.0%
Forest (swamp paperbark)	2658	418	146	417	94.5%
Shrubland (samphire)	6697	394	622	397	90.7%
Shrubland (chenopod)	103	382	12	381	88.3%
Grassland	959	357	99	357	89.7%
Sedgeland	3107	402	475	399	84.7%
Summary	**21079**	**397**	**1659**	**397**	**92.1%**

Table 3.4 Targeted revegetation average modelled plant density and carbon sequestration rates, and the influences of climate change and time in cleared landscapes within the Southern Yorke Peninsula region

Targeted revegetation community	Initial plant density (year 3)	Plant density (plants/ha)							
		Climate change scenario							
		Historic		Mild		Moderate		Severe	
		Timeframe (years)							
		25	45	25	45	25	45	25	45
Open Woodland (sheoak, inland tea-tree)	523	350	251	343	242	335	232	328	224
Open Woodland (mallee box)	395	264	188	259	181	252	174	247	167
Mallee (sub-coastal)	798	539	387	528	374	515	358	504	344
Mallee (plains)	466	313	222	307	214	299	205	293	197
Mallee (sands)	525	353	251	346	242	337	231	330	223

Targeted revegetation community	Hectares	Average carbon sequestration rate (CO_2-e t/ha/year)							
		Climate change scenario							
		Historic		Mild		Moderate		Severe	
		Timeframe (years)							
		25	45	25	45	25	45	25	45
Open Woodland (sheoak, inland tea-tree)	137 822	5.04	3.49	4.89	3.29	4.65	2.96	4.42	2.66
Open Woodland (mallee box)	53 148	5.90	4.18	5.73	3.95	5.47	3.58	5.22	3.25
Mallee (sub-coastal)	38 459	6.21	4.39	6.03	4.15	5.74	3.75	5.47	3.38
Mallee (plains)	67 999	6.28	4.45	6.10	4.22	5.82	3.84	5.57	3.49
Mallee (sands)	37 447	5.58	3.91	5.42	3.69	5.15	3.32	4.91	2.99

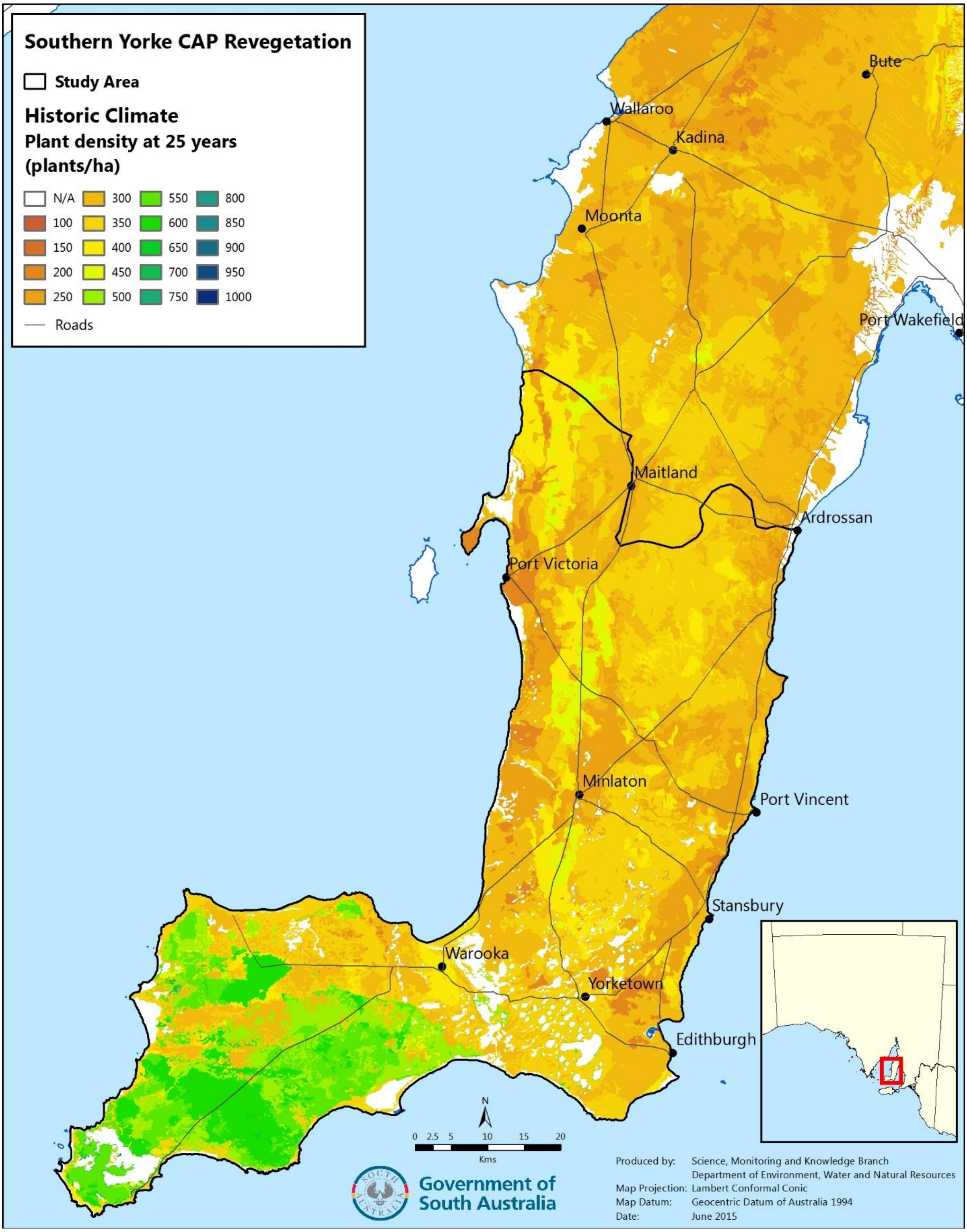


Figure 3.1 Plant density of revegetation at 25 years under historic climatic conditions

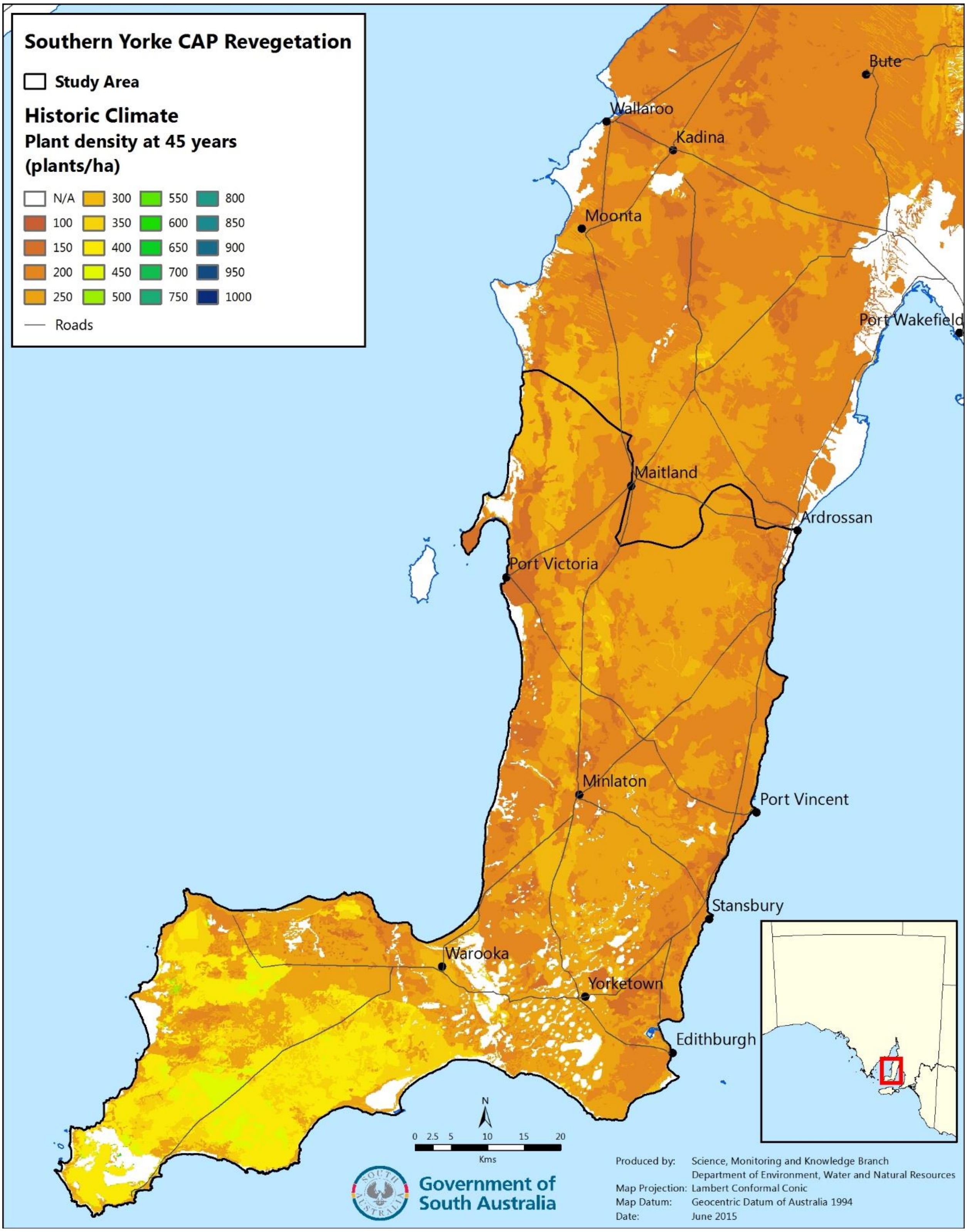


Figure 3.2 Plant density of revegetation at 45 years under historic climatic conditions

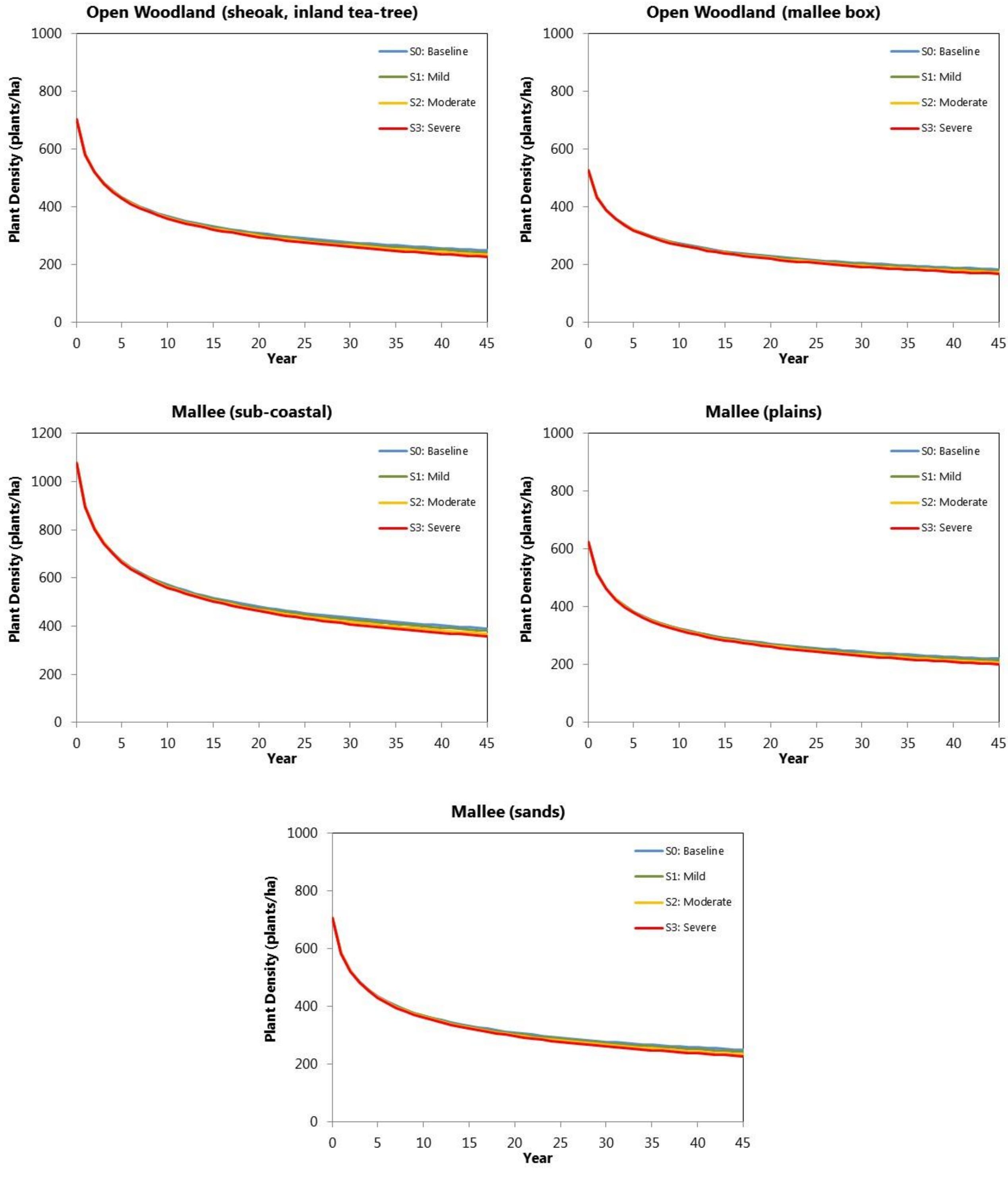


Figure 3.3 Average changes in plant density in targeted revegetation communities with time and climate change

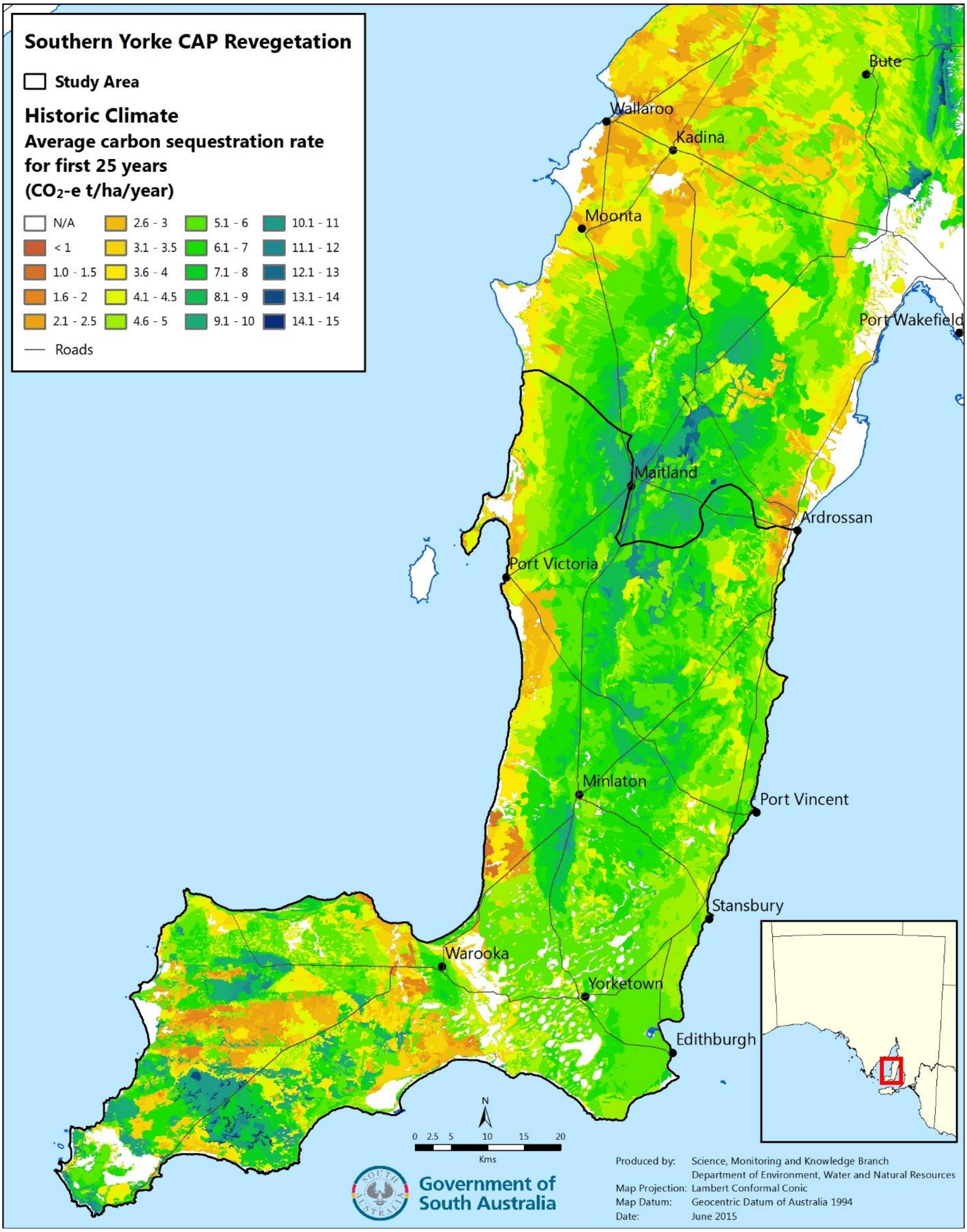


Figure 3.4 Carbon sequestration rate of revegetation over 25 years under historic climatic conditions

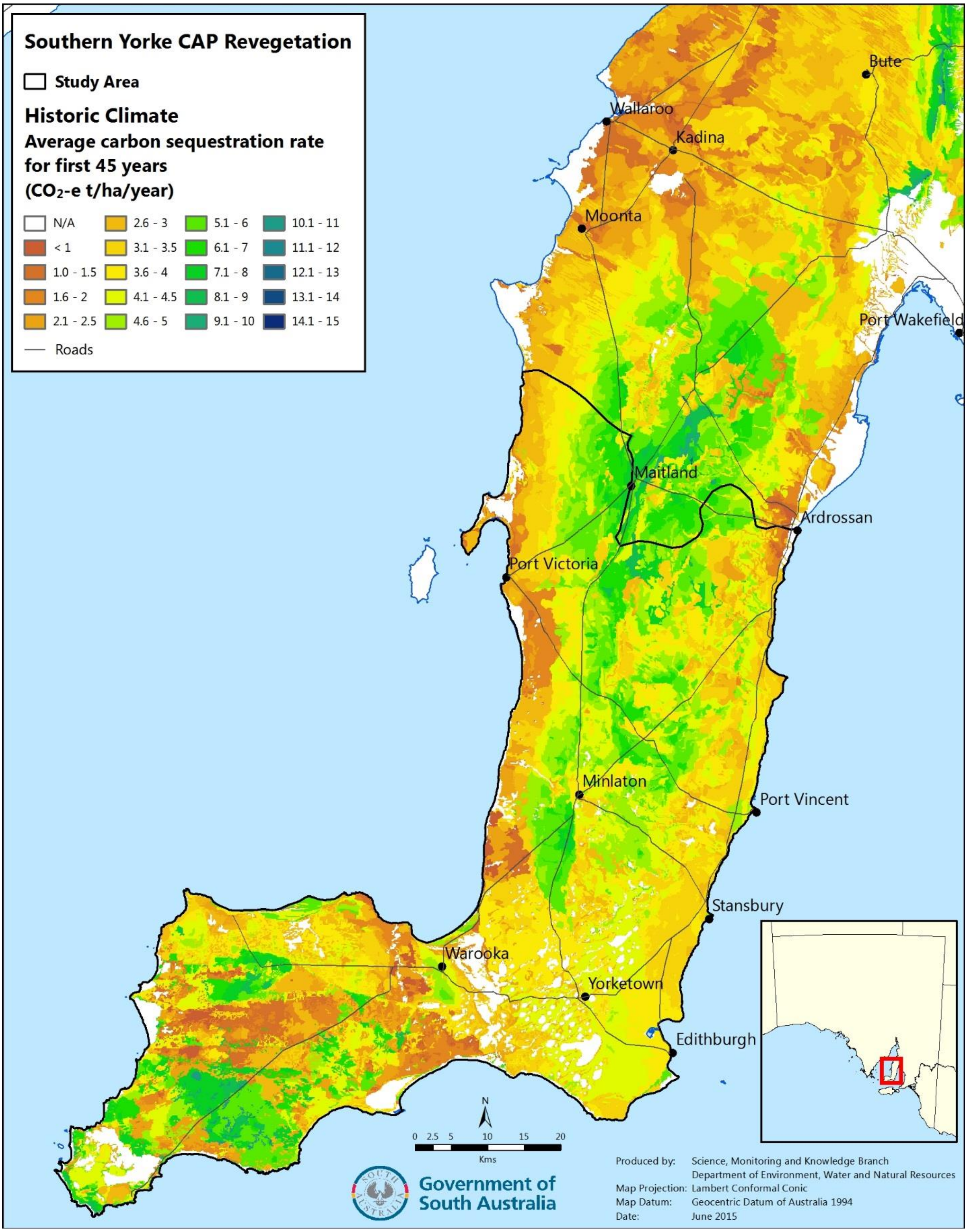


Figure 3.5 Carbon sequestration rate of revegetation over 45 years under historic climatic conditions

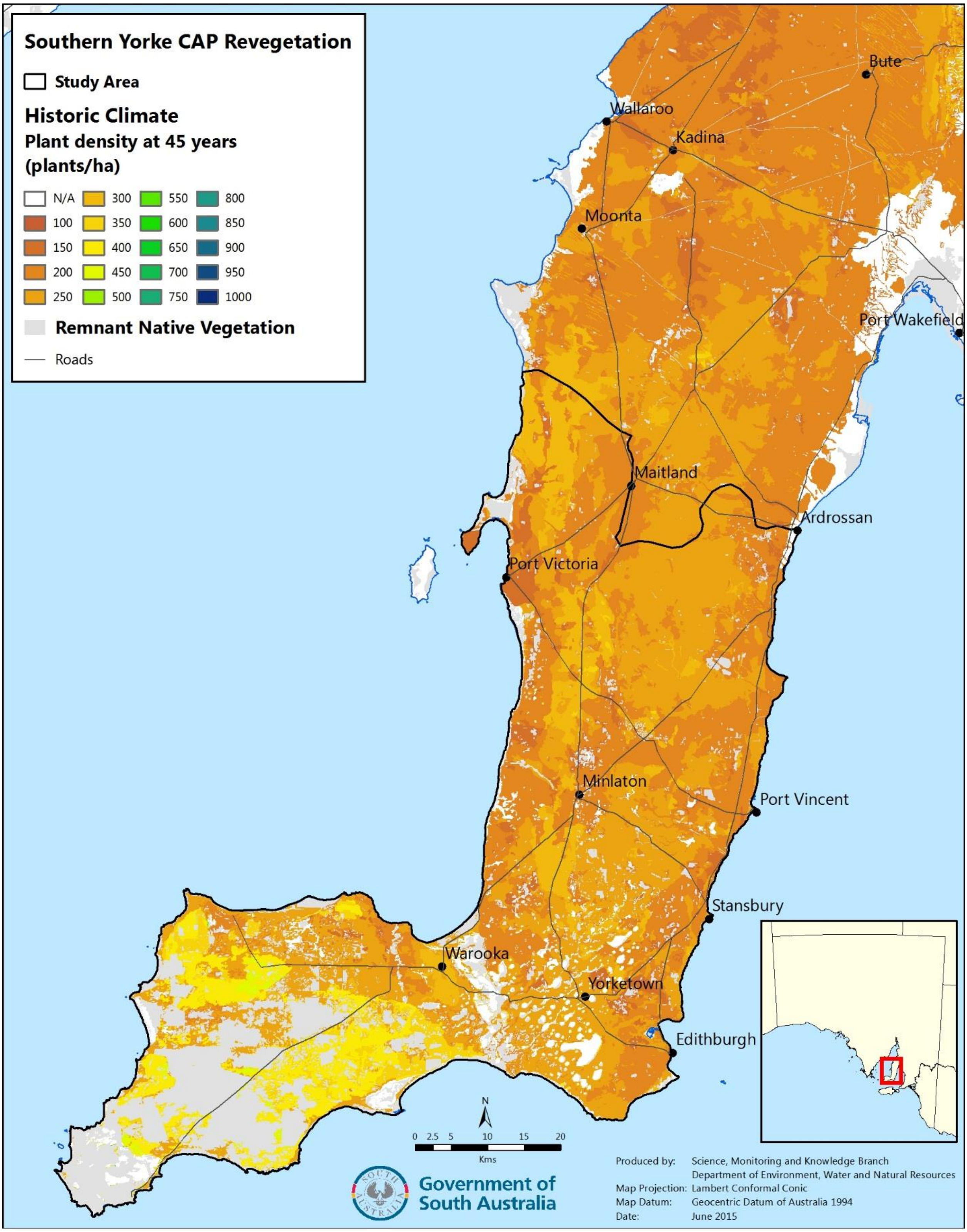


Figure 3.6 Plant density of targeted revegetation under historic climatic conditions

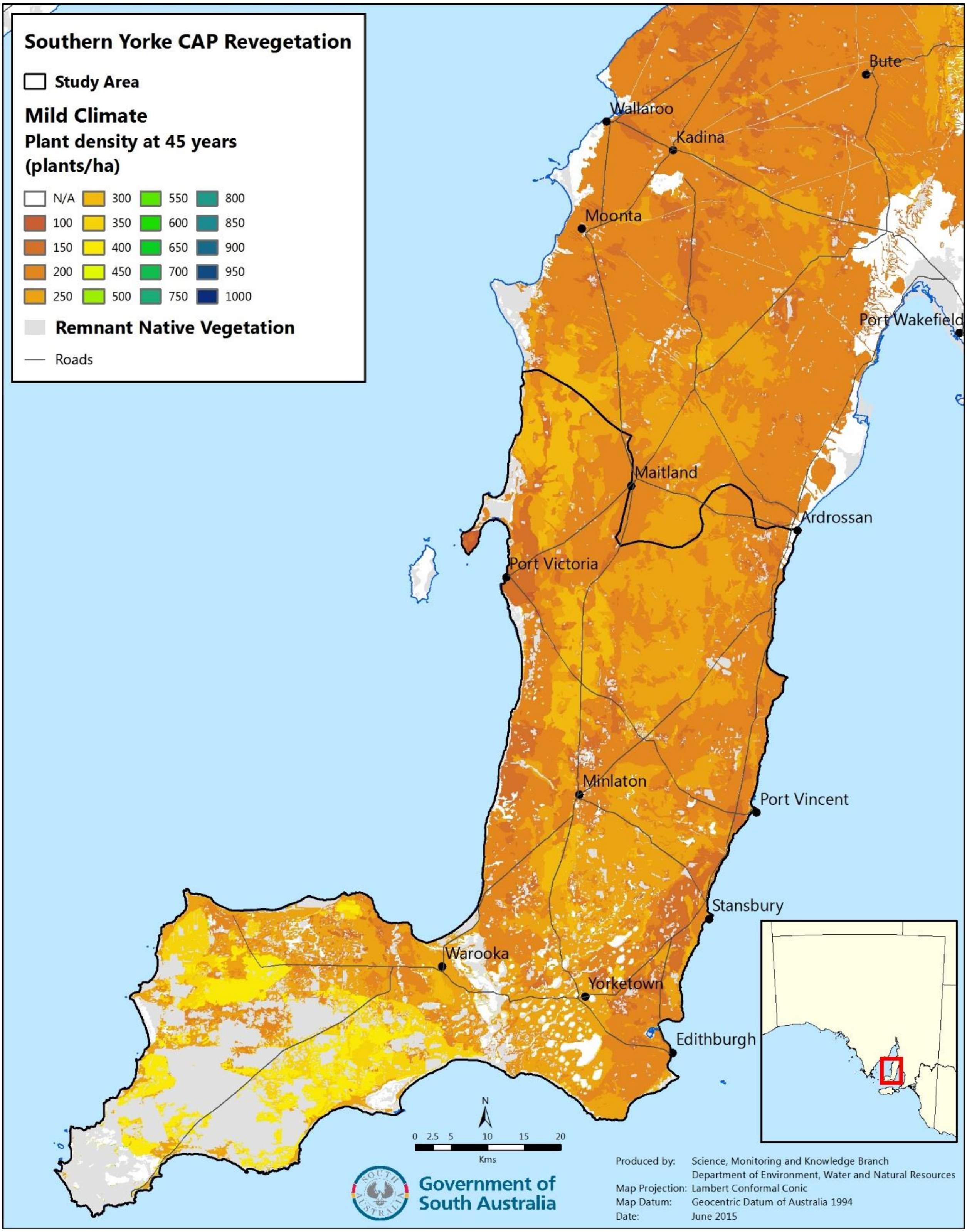


Figure 3.7 Plant density of targeted revegetation under mild climate change

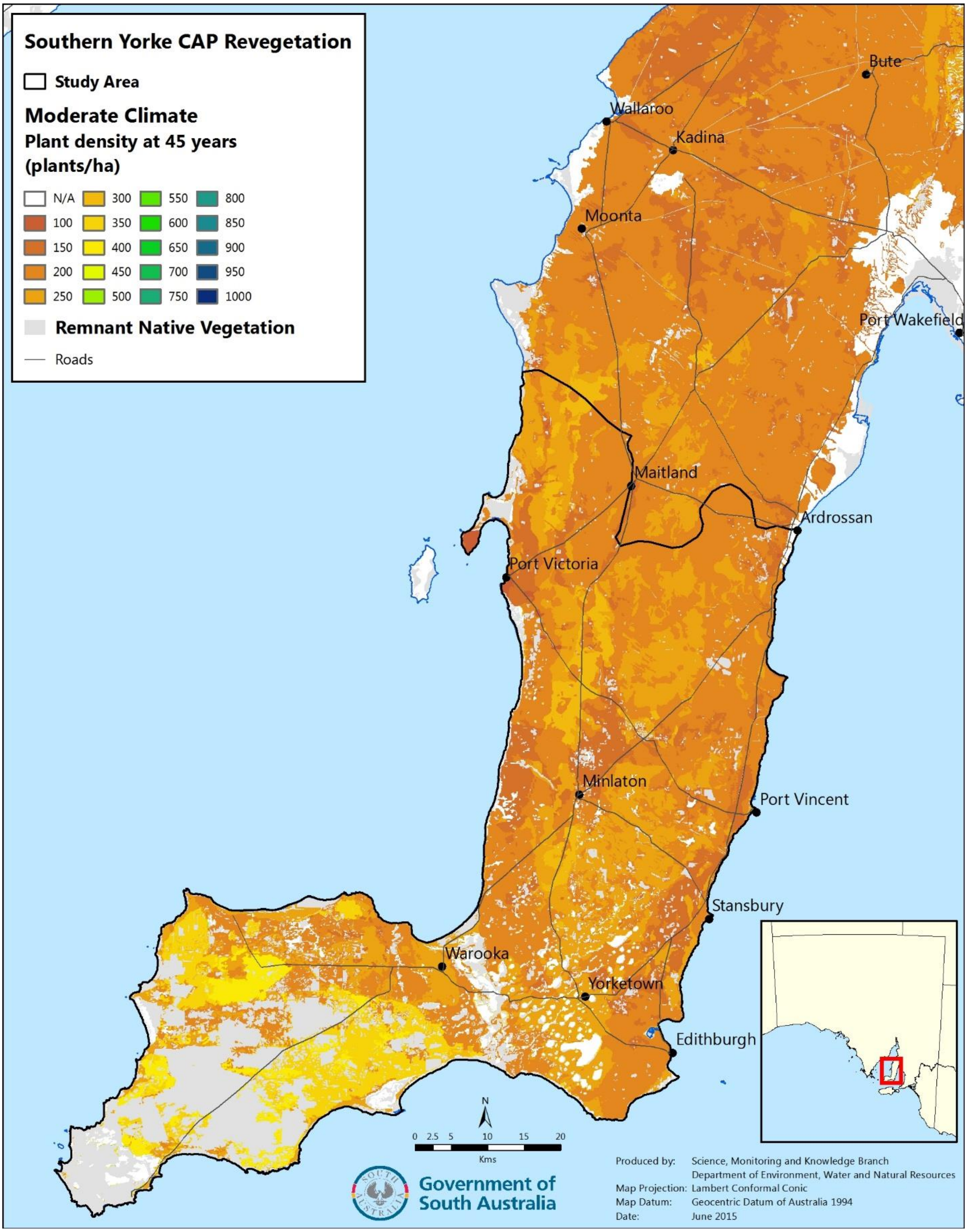


Figure 3.8 Plant density of targeted revegetation under moderate climate change

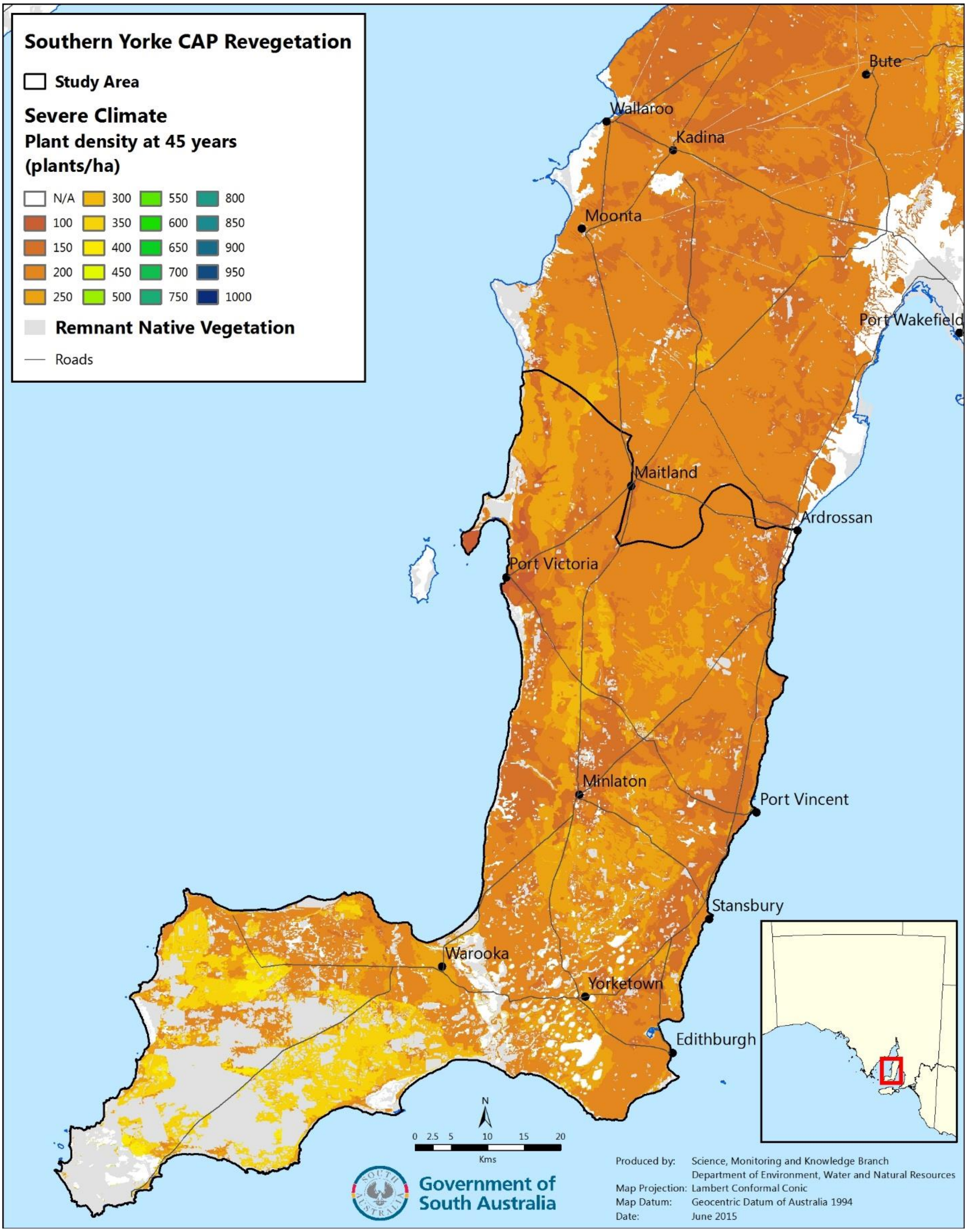


Figure 3.9 Plant density of targeted revegetation under severe climate change

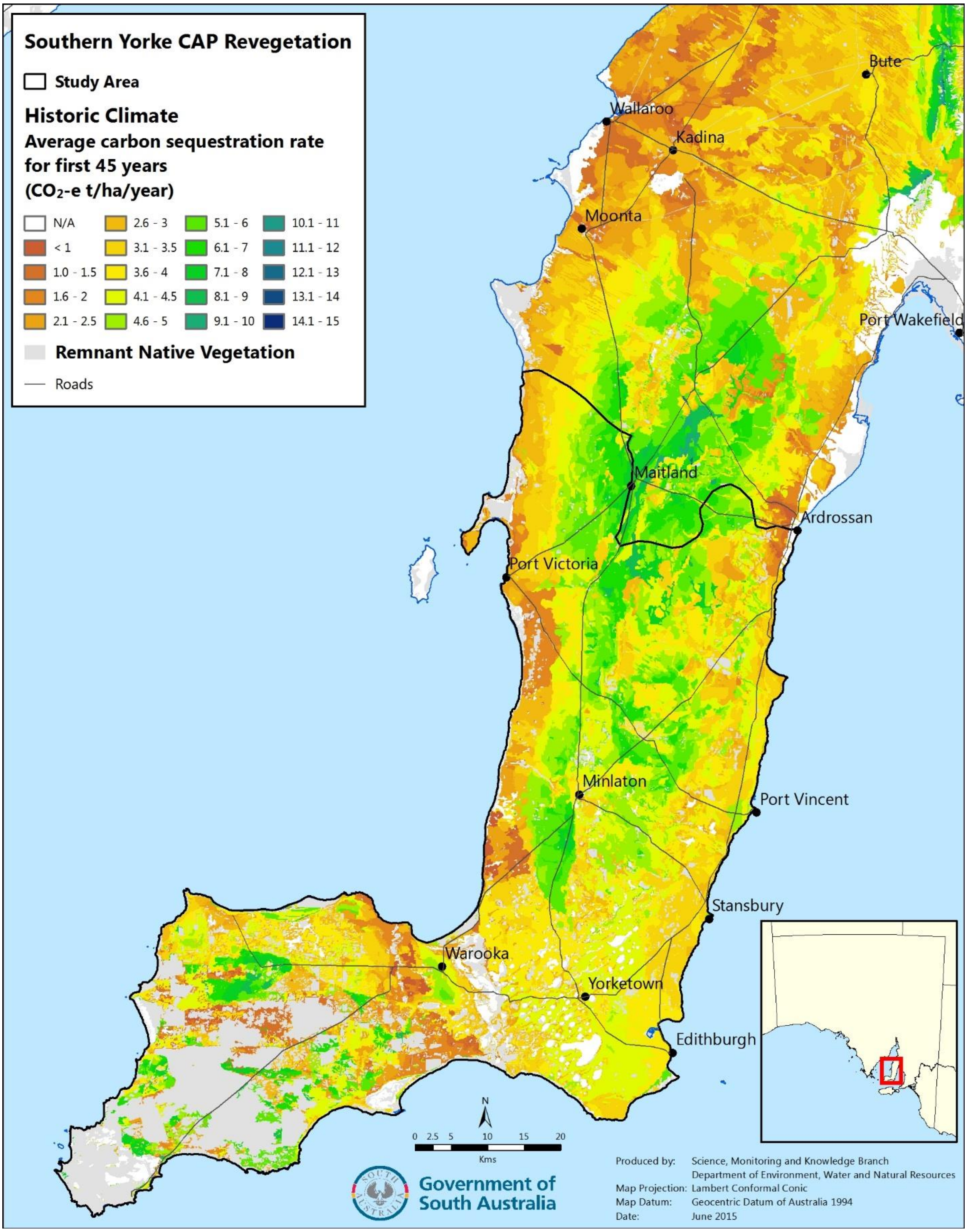


Figure 3.10 Carbon sequestration rate of targeted revegetation under historic climatic conditions

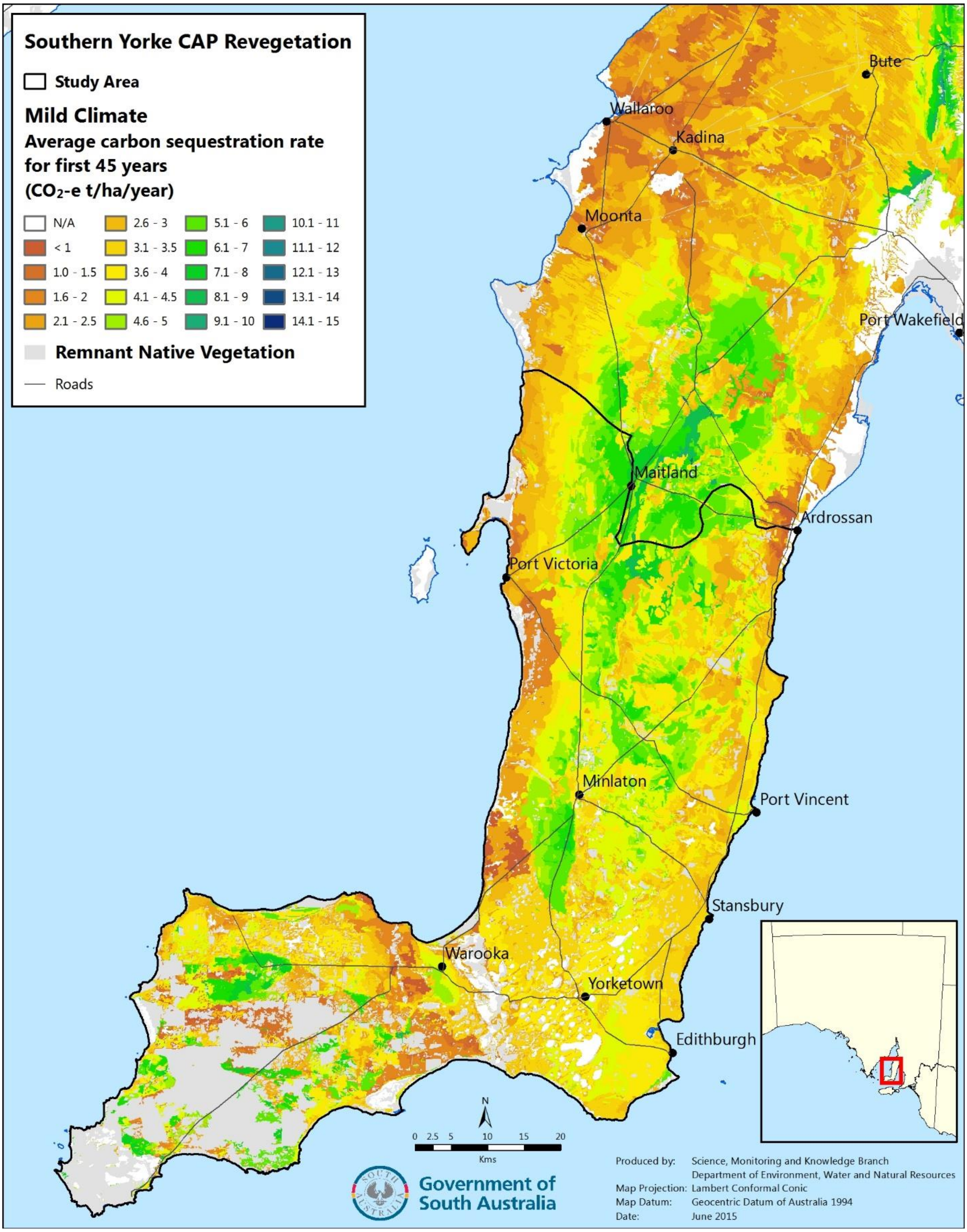


Figure 3.11 Carbon sequestration rate of targeted revegetation under mild climate change

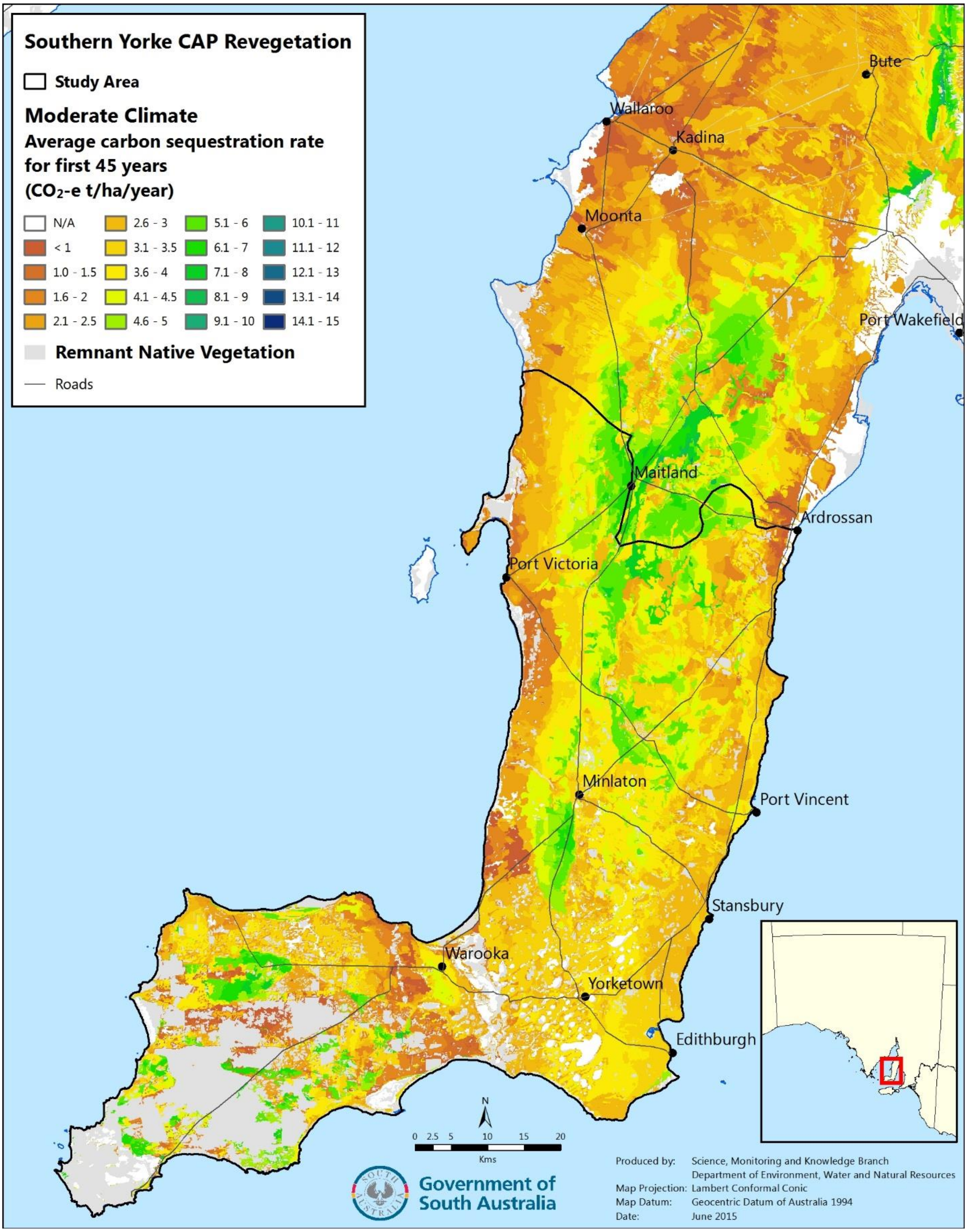


Figure 3.12 Carbon sequestration rate of targeted revegetation under moderate climate change

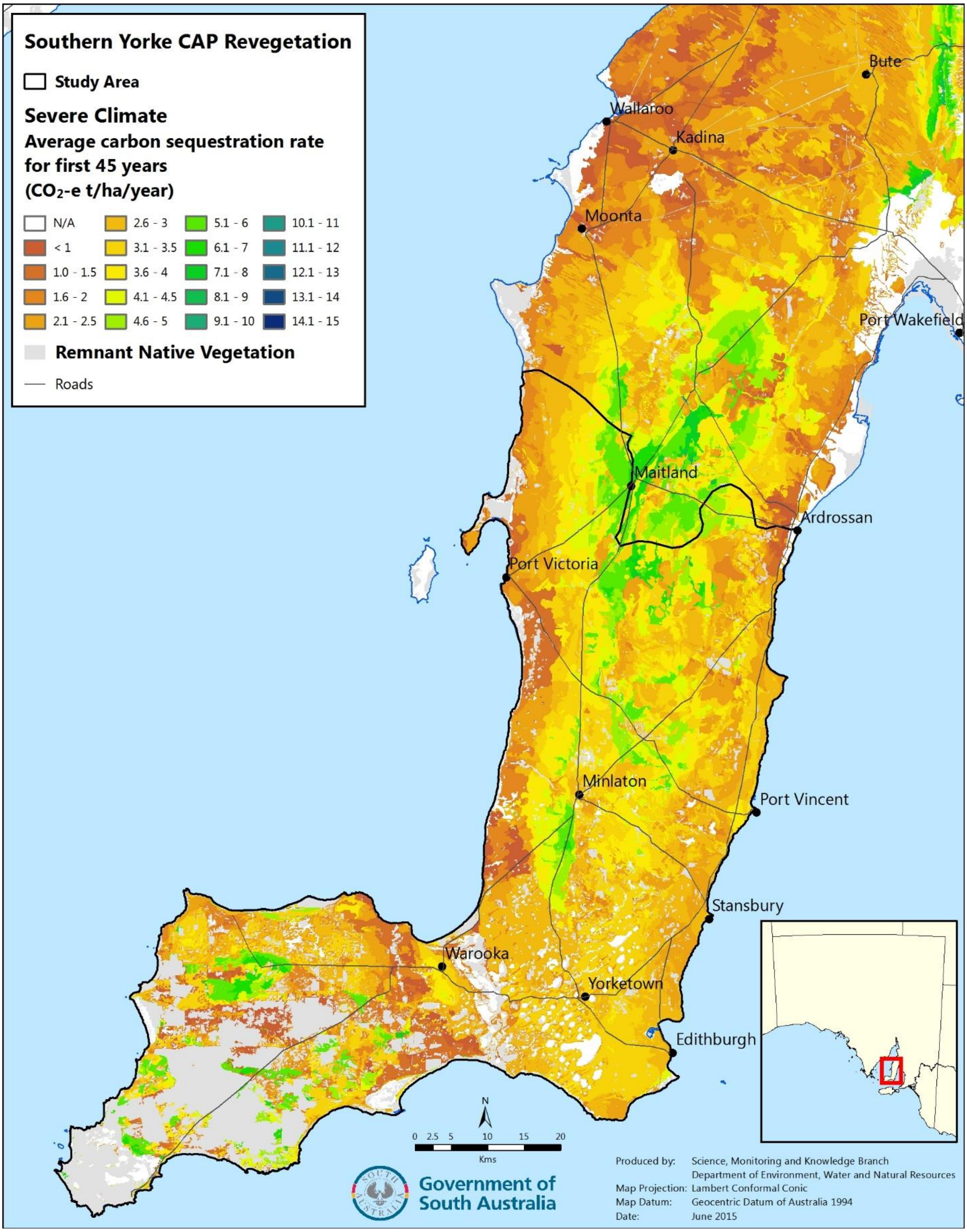


Figure 3.13 Carbon sequestration rate of targeted revegetation under severe climate change

4 Conclusions

The locally-calibrated carbon sequestration models for Conservation Action Planning (CAP) priority vegetation communities in the Southern Yorke Peninsula region provide a significant refinement of DEWNR's generic carbon sequestration models for targeted revegetation using trees, mallees and tall shrubs in the region. The models do not account for the biomass held in plants that do not grow greater than 2 metres in height. In plant communities with significant densities of small to medium height shrubs these model outputs should be considered conservative in terms of total perennial plant densities and total carbon sequestration.

Under historic climate conditions the estimated carbon sequestration rates of targeted revegetation designs across the Southern Yorke Peninsula region are typically 25% higher than the 45-year-old typical "tree-dominated environmental planting (88% trees)" designs presented by Hobbs *et al.* (2013, 2015) and used in the Landscapes Futures Analysis Tool (LFAT) and Carbon Planting Guidelines. However, these increases are variable across the community types: sheoak/inland tea-tree woodlands (+31%); mallee box woodlands (+26%); sub-coastal mallee (+9%); plains mallee (+18%); and sandy mallee (+44%). The differences between generic estimates (Hobbs *et al.* 2013, 2015) and targeted design estimates (this report) highlight the value of undertaking this more detailed study in Southern Yorke Peninsula region.

Spatial patterns of higher carbon sequestration rates within the Southern Yorke is closely correlated with the location of land already cleared of native vegetation for agricultural purposes. Deeper and fertile soils are generally the most productive for both annual cropping and native plant biomass. However, the sub-coastal mallee communities with deeper but less fertile soils are also highly productive for revegetation species but less suitable for agriculture. Locations within existing native vegetation communities with higher than typical potential sequestration rates may provide potential indicators of other ecological values (e.g. source populations or refugia for plant and animals).

The models also indicate the potential consequences of a range of climate change scenarios on vegetation structure and carbon sequestration in the region. In progressively warmer and drier climates the vegetation structure of plant communities can be expected to become sparser with up to 11% fewer plants per hectare than under historic climates. Under severe climate change conditions average sequestration rates and carbon stocks are likely to be reduced by between 22 to 24% compared to historic conditions.

New and targeted revegetation activities in the region should recognise that the mortality rate of new plants is naturally high in the early years within a revegetation site, and good management practices (e.g. weed & pest control) can reduce those losses. Even after good initial establishment the survival of plants at 45 years of age is approximate only 48% of healthy plants established by the end of the third year. Warming and drying climates are likely to increase plant mortality and additional planting stock might be required to offset climate induced losses.

The outputs generated from this project can provide an indication of carbon dioxide equivalents sequestered by revegetation activities in the region. This information may assist in economic evaluations of carbon market values from revegetation in the region, but more detailed analyses of the establishment, management, investment and compliance costs, environmental conditions, and market risks should be included in any economic evaluations of revegetation for carbon trading purposes.

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Appendices

Appendix A – Southern Yorke Peninsula CAP reference sites

Vegetation Community / BCM Site Name	Mean Annual Rainfall (mm/ year)	Cover (%) by Lifeform Group [nominal height]: Tall Shrubs > 2m [2.5m]	Small Mallee < 5m [3.5m]	Small Trees < 5m [3.5m]	Medium Trees 5 - 15m [10m]	Tall Mallee > 5m [7.5m]	Tall Trees > 15m [23m]	Mallee (unspecified) [5m]	Total Cover	Estimated Plant Density (plants/ha): Total	Tall Shrubs	Trees & Mallees	Proportion of Trees and Mallees
Open Woodland (sheoak, inland tea-tree)													
ARD-PAVA-2	371			7	4				11	223	0	223	1.00
BLA-HAYW-A-1	427	33		0.7					33.7	696	676	19	0.03
CAR-BRID-1	417	5		4	10				19	290	102	187	0.65
COR-BARG-A-1	409			5	10				15	215	0	215	1.00
COR-BARM-A-2	433			1	20				21	182	0	182	1.00
COR-COLR-A-2	409	2		4	11				17	236	41	195	0.83
COR-HAWR-A-1	412	1.5		17.5	1.5				20.5	523	31	493	0.94
COR-LBCP-1	399	30		4	15				49	841	615	226	0.27
COR-PENT-1	400	12		4	4				20	387	246	141	0.36
COR-RAME-A-1	440	1		8					9	240	21	220	0.91
COR-TREA-A-1	428	0.5		4	1				5.5	128	10	118	0.92
COR-TREA-A-2	432	0.75		5	12				17.75	246	15	230	0.94
COR-TREA-B-1	424	0.5		2	15				17.5	181	10	171	0.94
CUR-COOM-A-1	393	2		0.8	12				14.8	156	41	115	0.74
DAL-FURD-A-1	417	1		1	1				3	56	21	35	0.63
DAL-KEMJ-A-1	420	15						2.5	17.5	324	307	16	0.05
DAL-WEBT-A-1	419	7.5		5	2.5				15	311	154	157	0.50
DAL-WILP-A-1	420	2.5			1				3.5	59	51	8	0.13
HAR-ROHD-B-1	390	2			8				10	103	41	62	0.60
HAR-SHER-A-1	400	1.5		1	9				11.5	128	31	97	0.76
HAR-THOC-A-1	398	2		2	17				21	228	41	187	0.82
HAR-THOM-A-1	402	0.2		1	12				13.2	125	4	120	0.97
KOO-ALEP-1	382	4		1	1				6	117	82	35	0.30
KOO-COOA-A-2	399			0.5	10				10.5	91	0	91	1.00
KOO-TWEG-A-1	398	0.02	2	1	3	12			18.02	115	0	115	1.00
MEE-BUTG-1	435	1						2	3	33	21	13	0.39
MIN-BUTC-A-1	387	0.5	2			15			17.5	84	10	74	0.88
MIN-BUTK-B-1	370			0.8	8				8.8	84	0	84	1.00
MIN-CLIV-A-1	395	20		0.5	15				35.5	540	410	130	0.24
MIN-COOS-A-1	391			0.05	3				3.05	25	0	25	1.00
MIN-NANJ-A-1	371	0.8		1	8				9.8	106	16	89	0.85
MIN-NANK-A-1	372	1		2					3	75	21	55	0.73
MIN-SHOM-A-1	388	0.2		4	3				7.2	137	4	133	0.97
MOO-THOC-A-1	406	0.1		2	6				8.1	103	2	101	0.98
POI-CANB-A-1	453	1		4	1				6	138	21	118	0.85
POI-MASK-A-1	428	3			4				7	92	61	31	0.34
POR-CATE-A-1	403			10	10				20	352	0	352	1.00
RIC-MCSD-A-1	356	1		12	0.5				13.5	354	21	334	0.94
STA-ANDR-A-2	404	6						1	7	129	123	6	0.05
STA-ANDR-A-2	404	4							4	82	82	0	0.00
TUR-MURR-1-2	405			0.01	25				25.01	194	0	194	1.00
WAR-BALG-1	402	25		4	4				33	653	512	141	0.22
WAR-COOG-A-2	450	19.5		0.2					19.7	405	400	6	0.01
WAR-COOG-A-3	449	0.2		2	17				19.2	191	4	187	0.98
WAR-GORJ-A-1	441			4	2				6	125	0	125	1.00
WAR-KROM-A-1	399			4	4				8	141	0	141	1.00
WAR-METM-A-2	453	0.5	10	25	0.5	0.5			36.5	816	10	806	0.99
WAR-PARN-A-1	451	1		15					16	433	21	412	0.95
WAU-LIEM-B-1	359			3					3	82	0	82	1.00
WAU-MCSD-B-1	357	0.5			0.2				0.7	12	10	2	0.13
WAU-MCSD-D-1	356	4		0.01					4.01	82	82	0	0.00
WAU-MUMD-A-1	358	0.05		3					3.05	83	1	82	0.99
WAU-NEWB-A-1	358		0.5		0.2	2			2.7	14	0	14	1.00
WAU-NEWN-A-1	358	1		10	5				16	334	21	314	0.94
WHI-FURD-A-2	417	25	0.1	0.1	1				26.2	524	512	12	0.02
WHI-HICM-A-1	442	30		0.01	0.05				30.06	616	615	1	0.00

Vegetation Community BCM Site Name	Mean Annual Rainfall (mm/ year)	Cover (%) by Lifeform Group [nominal height]								Estimated Plant Density (plants/ha)			Proportion of Trees and Mallees
		Tall Shrubs > 2m [2.5m]	Small Mallee < 5m [3.5m]	Small Trees < 5m [3.5m]	Medium Trees 5 - 15m [10m]	Tall Mallee > 5m [7.5m]	Tall Trees > 15m [23m]	Mallee (unspecified) [5m]	Total Cover	Total	Tall Shrubs	Trees & Mallees	
WHI-HICM-A-2	434	10	0.1	5					15.1	344	205	139	0.40
WHI-HUBT-2-1	451			10	40				50	585	0	585	1.00
WHI-KEMJ-A-2	421	17							17	348	348	0	0.00
WHI-WILA-B-1	417	2		1.5	0.03				3.53	82	41	41	0.50
WUR-BALT-A-1	430	1		4					5	130	21	110	0.84
WUR-LEED-A-1	419	0.1		1	1				2.1	37	2	35	0.95
WUR-PARR-A-1	427	5		15	3				23	538	102	435	0.81
YOR-GUTP-A-1	398	1		0.1	2				3.1	39	21	18	0.47
YOR-TWAA-A-1	399			0.8	9				9.8	92	0	92	1.00
Average	**407**	**4.70**	**0.23**	**3.44**	**5.42**	**0.45**	**0.00**	**0.08**	**14.33**	**238**	**96**	**141**	**0.67**
Open Woodland (mallee box)													
BRE-FAGV-A-1	392	4.0		1.0	20.0				25	264	82	182	0.69
COO-JOHE-A-1	405			1	25				26	221	0	221	1.00
HAR-ROHD-A-1	389	0.5		0.5	18				19	163	10	153	0.94
MIN-COOS-B-1	392			1	15	0.1			16.1	144	0	144	1.00
STA-ANDL-A-1	388	0.1		0.05	10				10.15	81	2	79	0.97
STA-BRUJ-A-1	390	1		1	20				22	203	21	182	0.90
WOO-DODC-A-1	403			1	20				21	182	0	182	1.00
WOO-GILB-A-1	388			3	5				8	121	0	121	1.00
YOR-ADEL-A-1	404	0.2		0.8	18				19	166	4	161	0.98
YOR-ROSE-A-1	398			1	5				6	66	0	66	1.00
Average	**395**	**0.58**	**0.00**	**1.04**	**15.60**	**0.01**	**0.00**	**0.00**	**17.23**	**161**	**12**	**149**	**0.95**
Mallee (sub-coastal)													
COR-TIMI-1-1	417	4	1	10	40	0.5			55.5	680	82	598	0.88
COR-TIMI-2-1	417	40	25			15			80	1155	820	336	0.29
DAL-HENS-A-1	456	7.5			5			60	72.5	582	154	428	0.74
DAL-LAUJ-A-1	418	15	2			2			19	337	307	30	0.09
DAL-LAUJ-B-1	416	15	2.5			0.5			18	338	307	30	0.09
DAL-SHED-A-1	414	5						25	30	265	102	162	0.61
DAL-SMIN-A-1	404	1						20	21	150	21	130	0.86
DAL-WEBM-A-1	421	7.5						15	22.5	251	154	97	0.39
FOU-MURV-A-1	460	4	25						29	366	82	284	0.78
FOU-MURV-B-1	454		10						10	114	0	114	1.00
FOU-WILA-A-1	445	25	18			1			44	720	512	208	0.29
FOU-WILA-B-1	448	4	35						39	480	82	398	0.83
GLE-MSEC-C-1	409	3	20						23	289	61	227	0.79
GLE-PHIR-1-1	405	4	2	0.8		2			8.8	134	82	52	0.39
GLE-PHIR-1-2	403	4				0.8			4.8	85	82	3	0.03
HIL-BENP-B-1	452	5	12	3					20	321	102	219	0.68
MEE-BUTG-2	435	4		4				75	83	679	82	597	0.88
WAR-BUTN-A-1	450	0.5	5	1					6.5	95	10	84	0.89
WAR-METM-A-1	457	1	1			20			22	101	21	80	0.80
WHI-HUBT-1-1	446	2	5	10					17	373	41	332	0.89
Average	**431**	**7.58**	**8.18**	**1.44**	**2.25**	**2.09**	**0.00**	**9.75**	**31.28**	**376**	**155**	**220**	**0.61**
Mallee (plains)													
ARD-PAVB-1	374			4				20	24	240	0	240	1.00
MIN-BUTK-A-1	371					5			5	17	0	17	1.00
MTR-REDB-A-1	412		0.1			20			20.1	70	0	70	1.00
SKI-BRIV-1	397			5				28	33	319	0	319	1.00
WAU-LIEM-A-1	358	2	5	0.01		25			32.01	184	41	143	0.78
WAU-MCSD-C-1	358					25			25	86	0	86	1.00
WAU-NEWN-B-1	357	0.5	13	3		2			18.5	247	10	237	0.96
Average	**375**	**0.36**	**2.59**	**1.72**	**0.00**	**11.00**	**0.00**	**6.86**	**22.52**	**166**	**7**	**159**	**0.96**
Mallee (sands)													
ARD-ALDR-1	388	20						5	25	442	410	32	0.07
CHE-SCHR-A	368	2			2			15	19	154	41	113	0.73
KOO-BUTR-A-1	390					10			10	34	0	34	1.00
KOO-REDC-A-1	395	4	0.5	0.5		25			30	187	82	105	0.56
PEA-MOOS-A-1	351	15	0.5	1		4			20.5	354	307	47	0.13
STA-ANDR-A-1	403	6						10	16	188	123	65	0.35
Average	**383**	**7.83**	**0.17**	**0.25**	**0.33**	**6.50**	**0.00**	**5.00**	**20.08**	**227**	**161**	**66**	**0.47**

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