Carbon Sequestration from Targeted Revegetation in the WildEyre Region

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Summary

WildEyre is a landscape scale conservation program which aims to restore and conserve the unique and diverse ecosystems within central northwest Eyre Peninsula through systematic planning processes and extensive community engagement. A Conservation Action Planning (CAP) process has identified sheoak, red gum, mallee box/native pine and mallee plant communities as priorities for conservation and restoration with the region. Targeted revegetation is part WildEyre's integrated strategy to restore the extent and functionality of these plant communities. While these revegetation activities may be designed for ecological benefits they can also provide co-benefits to the community and individual landholders through the sequestration of atmospheric carbon dioxide and access to 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 four priority revegetation communities in the WildEyre region. This report provides estimates of carbon sequestration rates from targeted revegetation of sheoak, red gum, mallee box/native pine 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 has facilitated more reliable:

- estimates of carbon sequestration rates from revegetation activities in cleared agricultural lands;
- 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;
- that severe climate change has the potential to reduce average carbon sequestration rates by up to 30% over the next 45 compared to historic climate averages, and make revegetation plant communities 10% sparser;
- that most cleared agricultural landscapes, with good soils and rainfall, would also have higher carbon sequestration rates if targeted by revegetation; and
- locations with higher than typical sequestration rates within existing native vegetation may have additional ecological values (e.g. source populations or refugia for plant and animals).

1 Introduction

1.1 Background

Through a Conservation Action Planning (CAP) process the WildEyre team has identified significant vegetation communities within central northwest of Eyre Peninsula and identified priority communities for conservation and ecological restoration activities (WildEyre 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 Greening Australia (Koch 2013). Revegetation of priority communities within cleared agricultural lands (Figure 1.2) is part of WildEyre's integrated strategy for landscape scale conservation in the region. To help facilitate greater adoption of revegetation activities on private lands in the region the WildEyre 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 could be provided for the region.

Eyre Peninsula's Natural Resource Management Board has worked with the University of Adelaide and CSIRO to improve their understanding of landuse planning and climate change adaption 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), Science Monitoring and Knowledge (SMK) were contracted by the University of Adelaide to update the carbon sequestration from revegetation models within the LFAT system (Hobbs *et al.* 2014).

In recent years, DEWNR SMK researchers had 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.* 2014). This standard series of DEWNR SMK 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 and Environmental Planting Guidelines (CEPG) (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

Undertake a desktop analysis of potential carbon sequestration rates from revegetation for four Conservation Action Planning (CAP) priority vegetation communities in the WildEyre region using existing carbon sequestration models developed by DEWNR Science Monitoring and Knowledge.

Targeted vegetation communities for this project include:

- Sheoak Grassy Woodland ("sheoak");
- Red Gum Woodland ("red gum");
- Mallee Box and Native Pine Woodland ("MB&NP"); and
- Coastal-Inland Limestone Plains Mallee ("mallee").

Spatial analyses to be based on maps of the pre-1750 extent of CAP priority vegetation communities provided by Greening Australia (Figure 1.1).

DEWNR carbon models to be 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.

Investigate the potential influence of a range of climate change scenarios on targeted revegetation activities over the next 25 to 45 years. Climate change scenarios to be investigated are to be consistent with those developed in the Landscape Futures Analysis Tool project (i.e. historic climate, +3 increasingly severe).

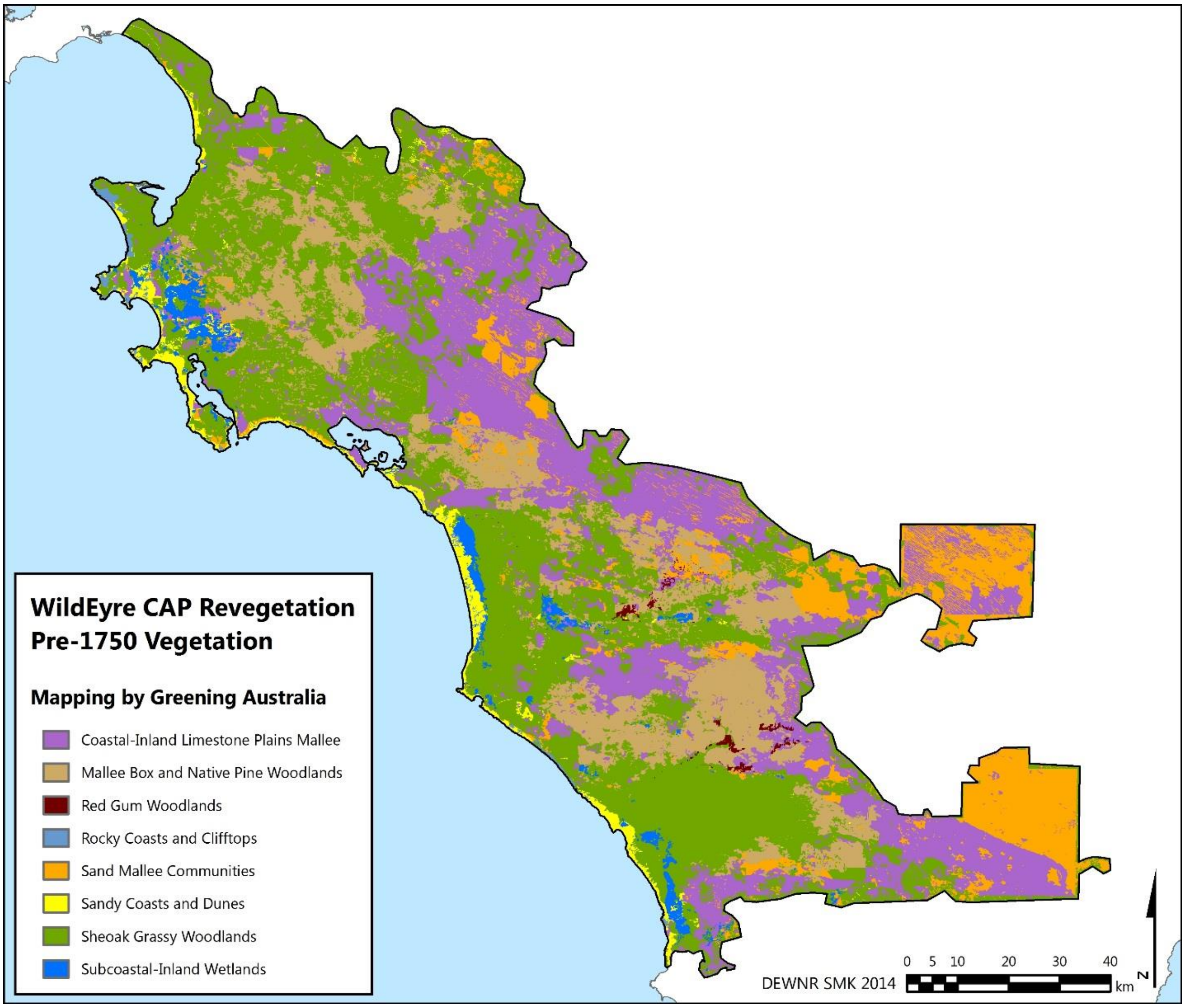


Figure 1.1 Pre-1750 vegetation mapping in the WildEyre region

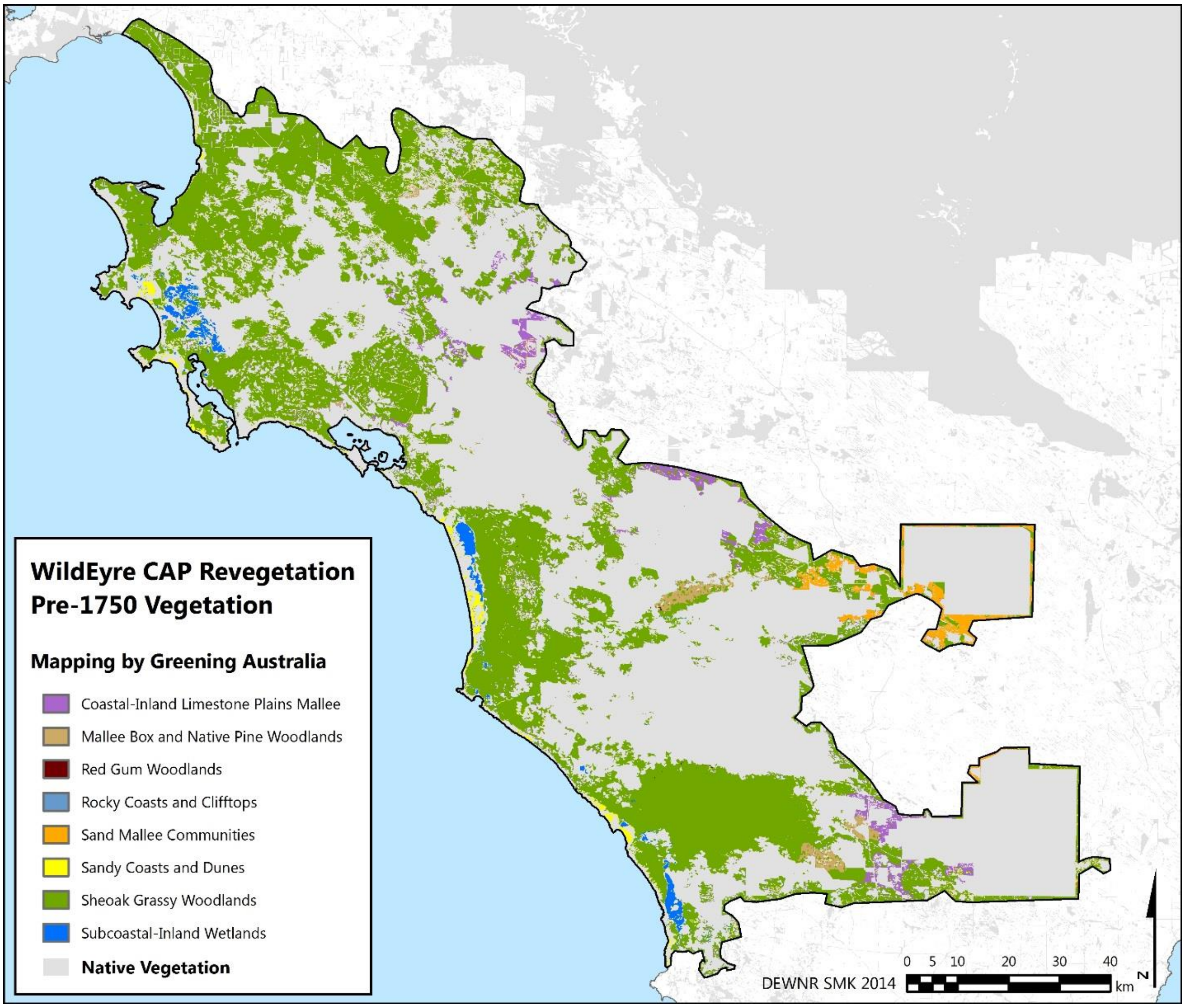


Figure 1.2 Existing native vegetation and pre-1750 vegetation communities for cleared agricultural lands in the WildEyre region

2 Methods

2.1 Targeted revegetation designs

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, 2014). For this study, vegetation structure data from 68 Nature Conservation Society of South Australia's Bushland Condition Monitoring (BCM) sites (68 sites, Figure 2.1) have been used to define a reference or benchmark vegetation structure at a target age of 45 years for each of the four 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 (m2) 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 (575 sites) from DEWNR's Biological Database of South Australia (BDBSA) was clustered to the same vegetation classification system at those identified by WildEyre (Koch 2013), and a similar vegetation structure analysis (as above) was performed for comparisons. Due to the broader cover class classification system of the BDBSA data the BDBSA and BCM vegetation structure analyses are not directly comparable. The BDBSA analyses were used as indicators of consistency vegetation structure differences between the four CAP targeted vegetation types, and indicators of the degree of similarity of other WildEyre vegetation types to the four CAP targeted community types. These analyses confirmed that BCM calibration data was representative of other sites with the same vegetation as the four CAP targeted vegetation communities, and that the vegetation structure of the Sand Mallee Communities was sufficiently similar to the Coastal-Inland Limestone Plains Mallee that the same carbon models could be applied for both community types in the WildEyre region.

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, 2014). The following is a concise description of that work and the key elements of the modelling process.

Researchers at DEWNR 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).

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)

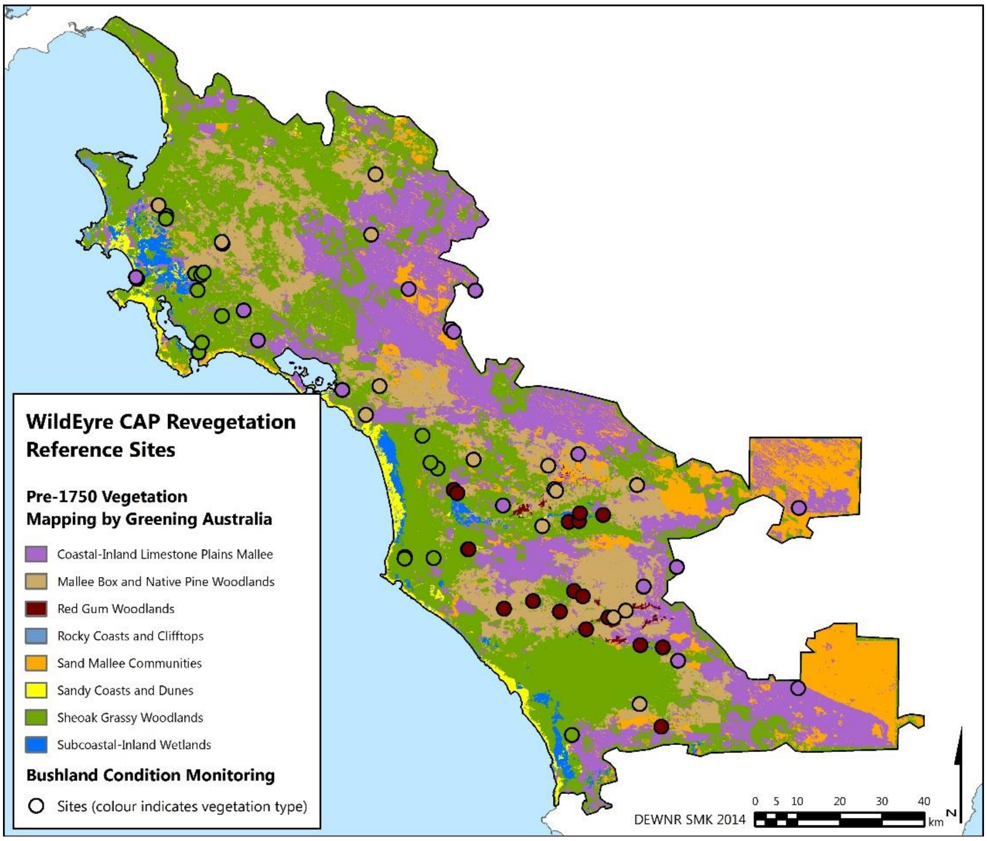
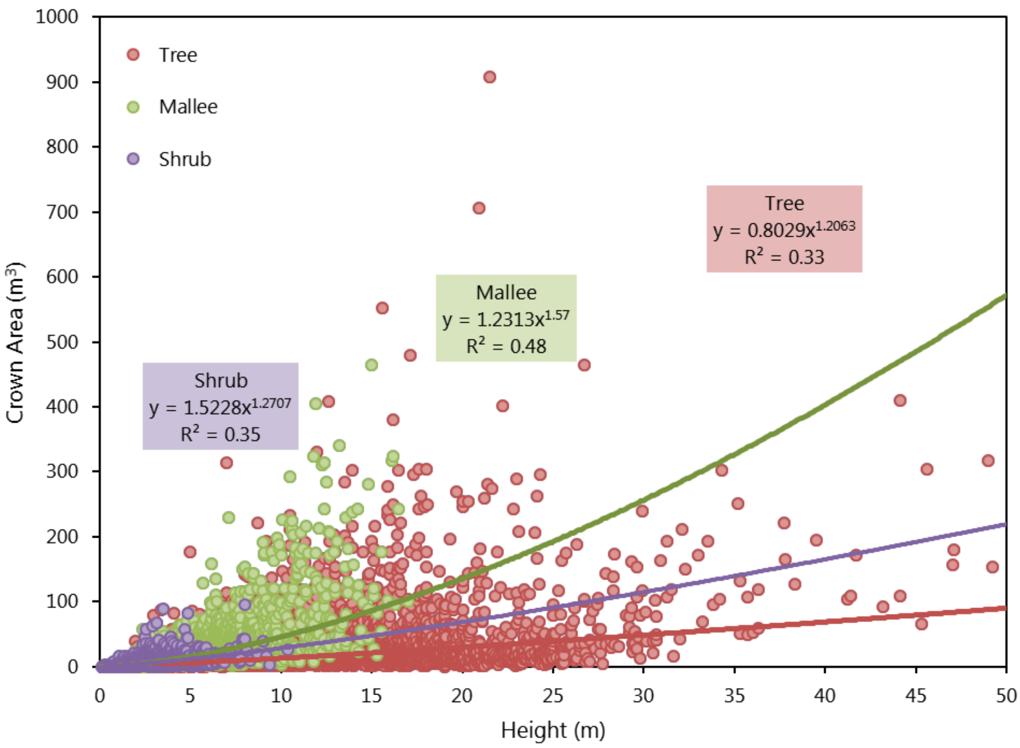


Figure 2.1 Reference sites used to calibrate carbon sequestration models



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

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

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 as in the "Landscape Futures Analysis" (LFA) project (Table 2.1). Additional to LFA rainfall and temperature variations, estimates of changes to potential evaporation rates for the four climate scenarios have been included, 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 WildEyre Carbon sequestration models

The average vegetation structure (i.e. plant density and proportion of trees) 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 reference site proportion of trees data. Ground-based estimates of plant density 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, 2014) have been extracted from the national dataset (100 × 100 metres resolution) for the entire Eyre Peninsula Natural Resource Management (NRM) region.

Plant density and carbon sequestration models were generated for each of the 32 scenarios (i.e. 4 vegetation types × 4 climates × 2 timeframes) across the Eyre Peninsula region at resolution of 100 × 100 metres (1 ha). Within the WildEyre region pre-1750 vegetation mapping (30 × 30 metres resolution) has been used to identify and extract the matching vegetation-specific plant density and carbon sequestration model data to create a composite map (30 × 30 metres resolution) for the WildEyre region for each climate change scenario and timeframe. DEWNR native vegetation polygon mapping was converted to a 30 m grid coverage for the WildEyre region to identify locations with potential for revegetation activities.

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 is lowest (but highly variable) in mallee communities (82%) and consistently highest within sheoak communities (98%). The BCM data also indicates that mallee communities are also diverse in their plant density values, but are typically more densely populated than the other three plant communities. Red gum communities are the most sparsely populated with less than half of the plants per hectare of the mallee communities. Trends between BCM estimates and generic DEWNR model estimates of plant density show that targeted revegetation would typically have a higher number of plants per hectare than historic revegetation activities (i.e. generic DEWNR model data). The red gum community however is in contrast to this trend, with fewer plants per hectare than expected given the climate and soils of that community type.

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.
Coastal-Inland Limestone Plains Mallee	17	362 ± 30	0.82 ± 0.34	426 ± 300	300 ± 38
Mallee Box and Native Pine Woodland	15	358 ± 19	0.94 ± 0.13	300 ± 178	249 ± 29
Red Gum Woodland	19	377 ± 15	0.89 ± 0.19	179 ± 124	287 ± 22
Sheoak Grassy Woodland	17	383 ± 24	0.98 ± 0.05	273 ± 204	247 ± 40

3.2 WildEyre Carbon model calibrations

The typical vegetation structure of the BCM references sites have 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 WildEyre Carbon model parameters

Vegetation Community	Model Short Name	Proportion of Trees and Mallees		Generic DEWNR Plant Density Model	
		Factor	Class	Factor	Class
Coastal-Inland Limestone Plains Mallee	Mallee	0.82	Moderate	1.42	Very High
Mallee Box and Native Pine Woodland	MB&NP	0.94	High	1.20	High
Red Gum Woodland	Redgum	0.89	Moderate	0.62	Very Low
Sheoak Grassy Woodland	Sheoak	0.98	Very High	1.10	Moderate

3.3 WildEyre Carbon model outputs

WildEyre carbon model parameters were included in DEWNR carbon modelling routines and applied to climate and soils spatial dataset for the entire Eyre Peninsula region for 4 representative model types (i.e. "Mallee", "MB&NP, "Redgum" and "Sheoak"). 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 has been constrained to the WildEyre region and composited to the specifications of the CAP Pre-1750 vegetation mapping. Due to similarities in vegetation structure between Coastal-Inland Limestone Plains Mallee and the Sand Mallee Communities (identified from DEWNR BDBSA data) the "Mallee" model has also been applied to Sand Mallee Communities. None of the models are used represent Sandy Coasts and Dunes, Rocky Coasts and Clifftops or Subcoastal-Inland Wetlands vegetation communities (Table 3.3).

Figure 3.1 and Figure 3.2 illustrate the expected spatial variations in plant density across the WildEyre region resulting from different vegetation structure of each targeted CAP vegetation community, climate and soil factors. 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 3.5).

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.

WildEyre regional summaries of average plant density for all modelled vegetation communities, climate change scenarios and timeframes are presented in Table 3.4. Summaries for targeted revegetation on cleared agricultural lands for all modelled vegetation communities, climate change scenarios and timeframes are presented in Table 3.5. Maps representing the average plant density and carbon sequestration rates after 45 years and for all climate change scenarios in cleared agricultural lands with the WildEyre region are presented in series Figure 3.6 to Figure 3.13.

Table 3.3 Extent of WildEyre carbon modelling

Vegetation community	Region		Cleared lands	
	Area (ha)	Mean annual rainfall (mm/year)	Area (ha)	Mean annual rainfall (mm/year)
Modelled				
Coastal-Inland Limestone Plains Mallee	316 605	352	17 377	346
Mallee Box and Native Pine Woodlands	205 140	364	9 186	362
Red Gum Woodlands	3 456	371	82	373
Sand Mallee Communities	134 044	346	12 923	340
Sheoak Grassy Woodlands	495 238	368	426 624	366
Summary	**1 154 483**	**360**	**466 192**	**364**
Not modelled				
Rocky Coasts and Clifftops	5 335	386	90	391
Sandy Coasts and Dunes	29 264	381	5 948	385
Subcoastal-Inland Wetlands	24 210	384	9 052	387
Summary	**58 809**	**383**	**15 090**	**386**

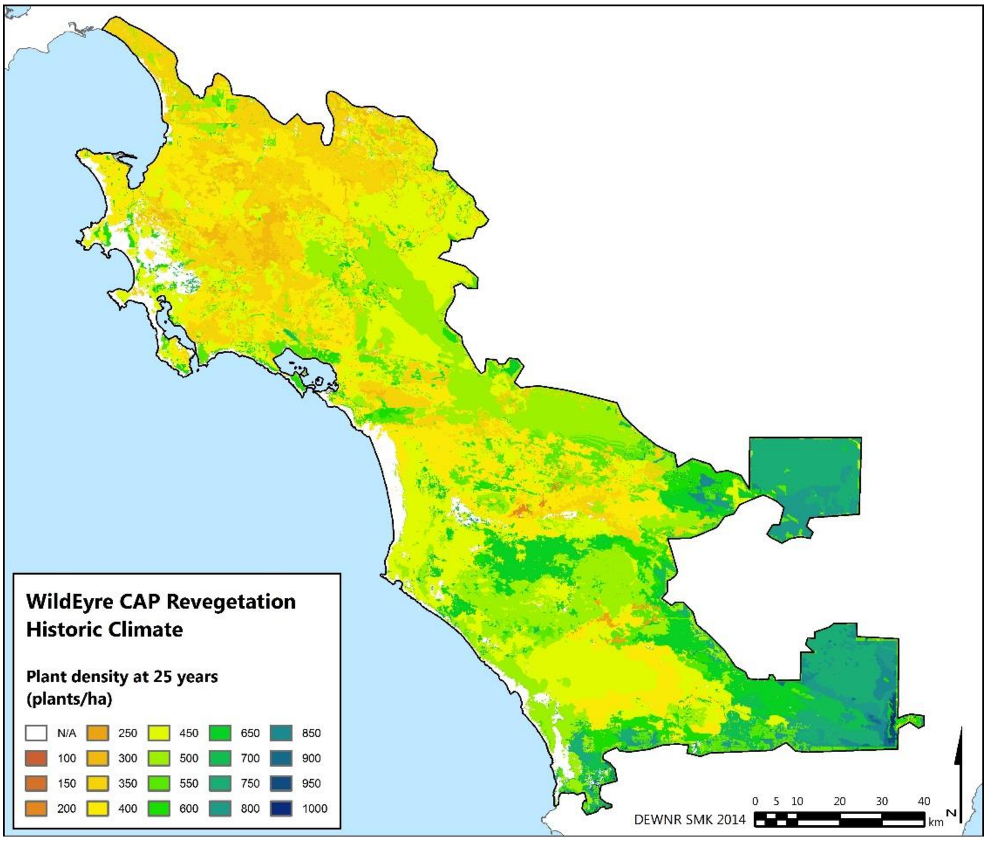


Figure 3.1 Plant density of revegetation at 25 years under historic climatic conditions.

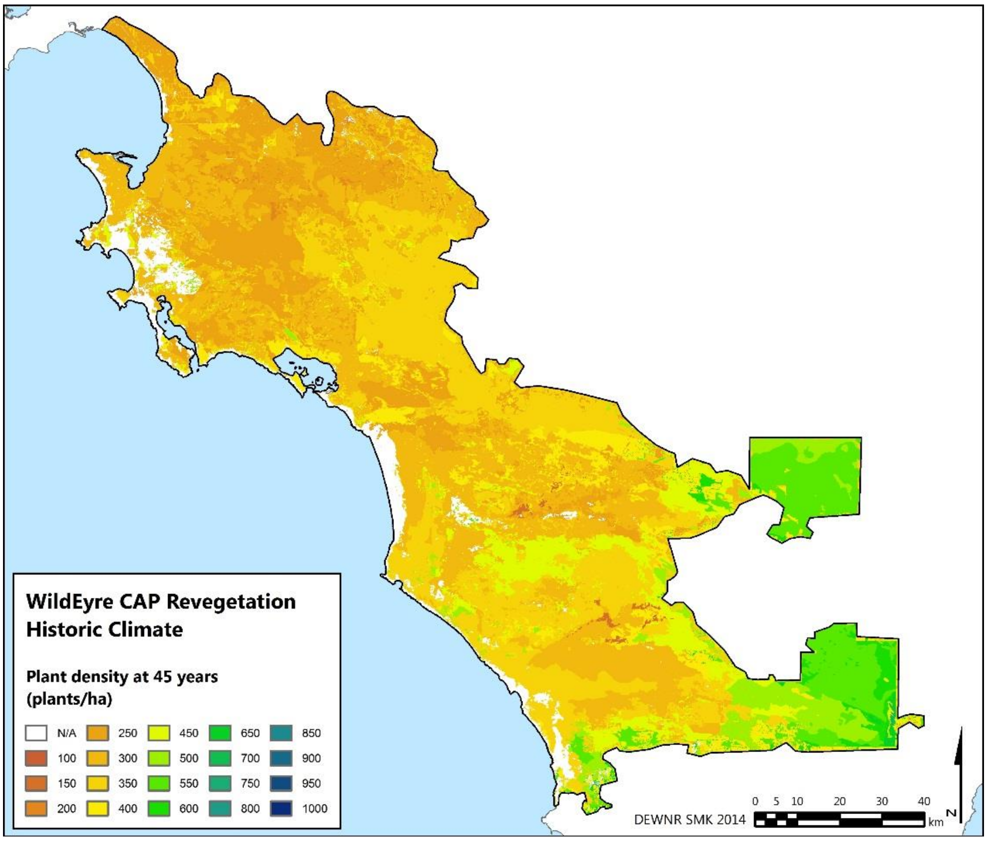


Figure 3.2 Plant density of revegetation at 45 years under historic climatic conditions

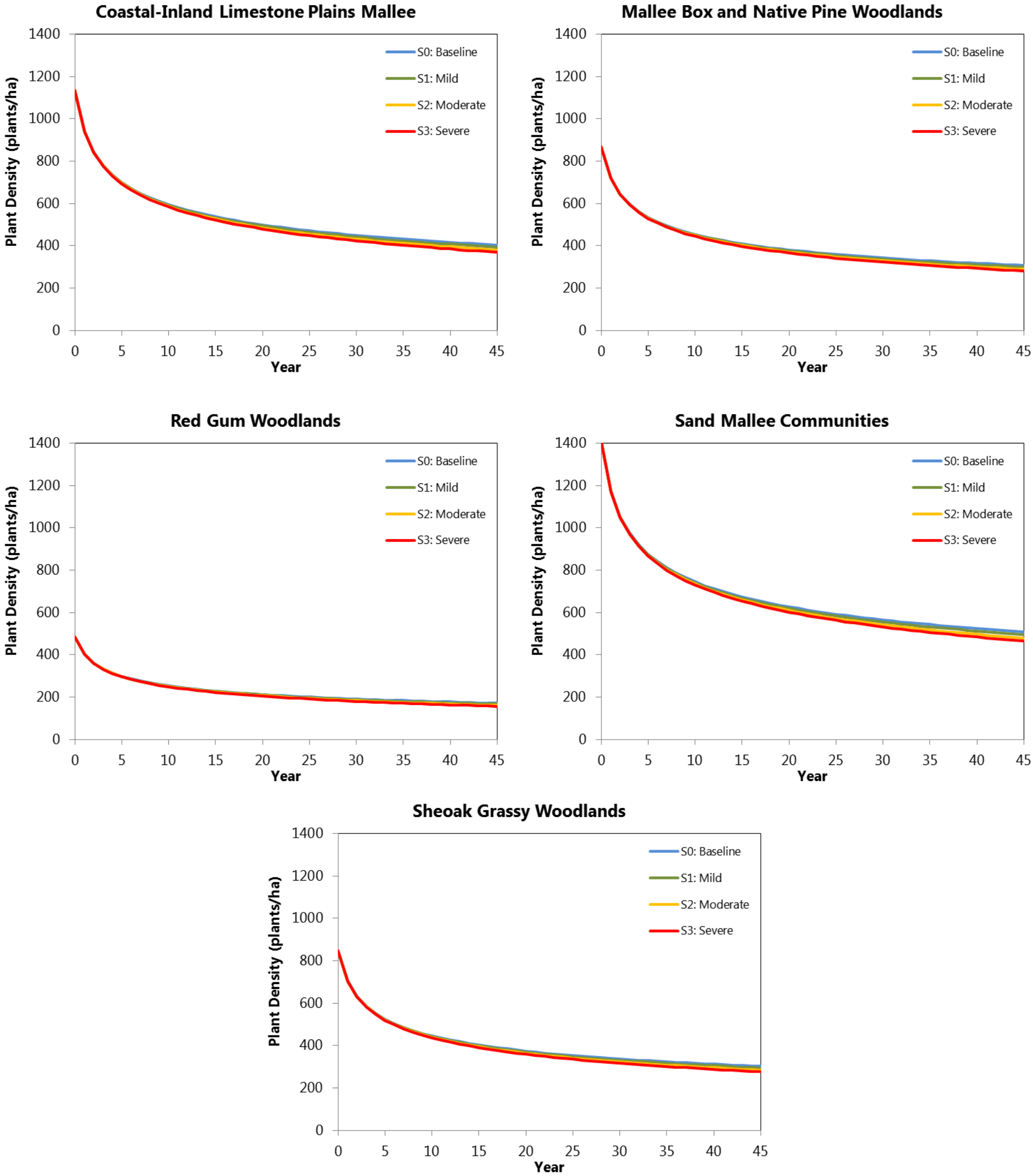


Figure 3.3 Average changes in plant density in targeted revegetation communities with time and climate change

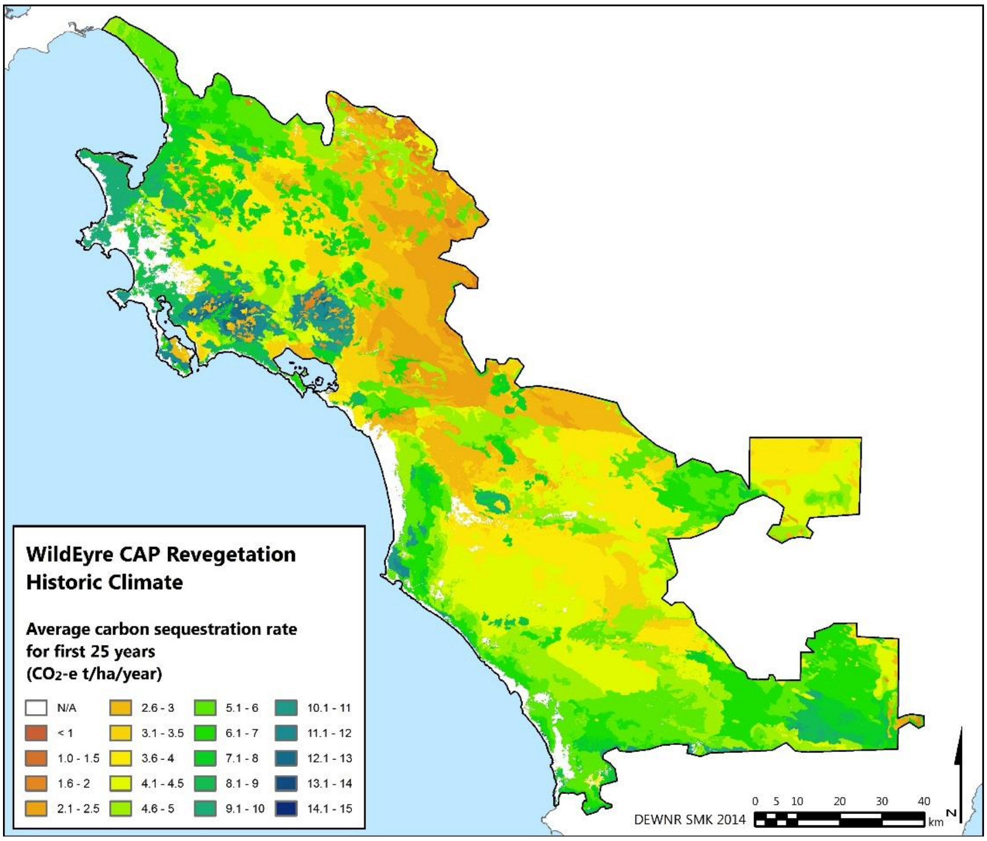


Figure 3.4 Carbon sequestration rate of revegetation over 25 years under historic climatic conditions.

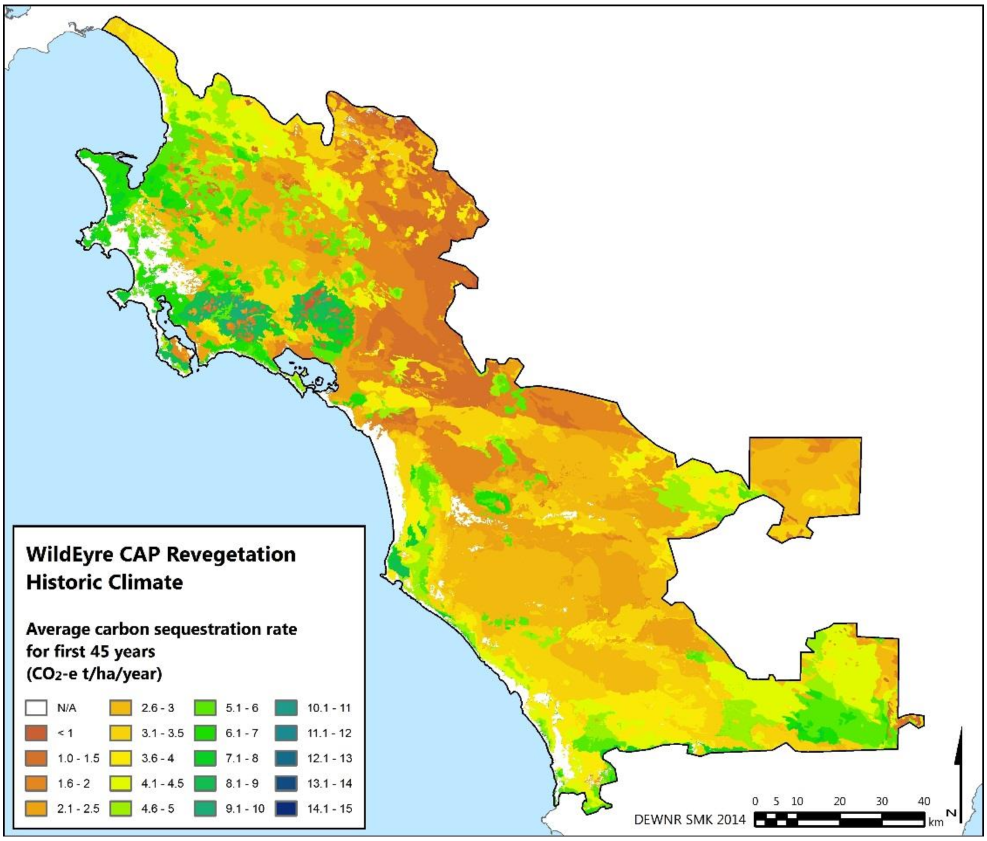


Figure 3.5 Carbon sequestration rate of revegetation over 45 years under historic climatic conditions.

Table 3.4 Regional average modelled plant density and carbon sequestration rates, and the influences of climate change and time on vegetation communities in the WildEyre region

	Initial plant density	Plant density (plants/ha)							
		Climate change scenario							
		Historic		Mild		Moderate		Severe	
		Timeframe (years)							
Regional vegetation community	(year 3)	25	45	25	45	25	45	25	45
Coastal-Inland Limestone Plains Mallee	860	574	412	564	399	551	382	540	370
Mallee Box and Native Pine Woodlands	639	424	305	416	295	407	283	399	274
Red Gum Woodlands	344	228	165	224	159	219	153	215	148
Sand Mallee Communities	1009	684	487	672	471	656	452	644	437
Sheoak Grassy Woodlands	628	421	301	414	292	404	279	396	270
		Average carbon sequestration rate (CO_2-e t/ha/year)							
		Climate change scenario							
		Historic		Mild		Moderate		Severe	
		Timeframe (years)							
Regional vegetation community	Hectares	25	45	25	45	25	45	25	45
Coastal-Inland Limestone Plains Mallee	316 605	4.14	2.77	4.01	2.59	3.81	2.32	3.62	2.06
Mallee Box and Native Pine Woodlands	205 140	4.04	2.71	3.91	2.54	3.71	2.26	3.52	2.01
Red Gum Woodlands	3 456	3.25	2.13	3.14	1.97	2.96	1.73	2.79	1.50
Sand Mallee Communities	134 044	4.79	3.25	4.65	3.07	4.43	2.77	4.23	2.51
Sheoak Grassy Woodlands	495 238	5.75	4.03	5.58	3.82	5.33	3.47	5.09	3.15

Table 3.5 Targeted revegetation average modelled plant density and carbon sequestration rates, and the influences of climate change and time in cleared landscapes within the WildEyre region

	Initial plant density	Plant density (plants/ha)							
		Climate change scenario							
		Historic		Mild		Moderate		Severe	
		Timeframe (years)							
Targeted revegetation community	(year 3)	25	45	25	45	25	45	25	45
Coastal-Inland Limestone Plains Mallee	843	562	404	552	391	540	376	530	363
Mallee Box and Native Pine Woodlands	645	427	308	419	298	410	286	402	276
Red Gum Woodlands	361	240	173	236	167	230	160	226	155
Sand Mallee Communities	1053	716	508	702	491	686	471	673	455
Sheoak Grassy Woodlands	632	424	303	416	293	406	281	398	271
		Average carbon sequestration rate (CO_2-e t/ha/year)							
		Climate change scenario							
		Historic		Mild		Moderate		Severe	
		Timeframe (years)							
Targeted revegetation community	Hectares	25	45	25	45	25	45	25	45
Coastal-Inland Limestone Plains Mallee	17 377	4.20	2.82	4.07	2.64	3.87	2.36	3.68	2.11
Mallee Box and Native Pine Woodlands	9 186	4.50	3.07	4.36	2.89	4.15	2.60	3.95	2.33
Red Gum Woodlands	82	3.22	2.08	3.11	1.92	2.92	1.68	2.74	1.46
Sand Mallee Communities	12 923	5.16	3.54	5.01	3.35	4.79	3.05	4.59	2.77
Sheoak Grassy Woodlands	426 624	5.93	4.18	5.77	3.96	5.51	3.60	5.27	3.28

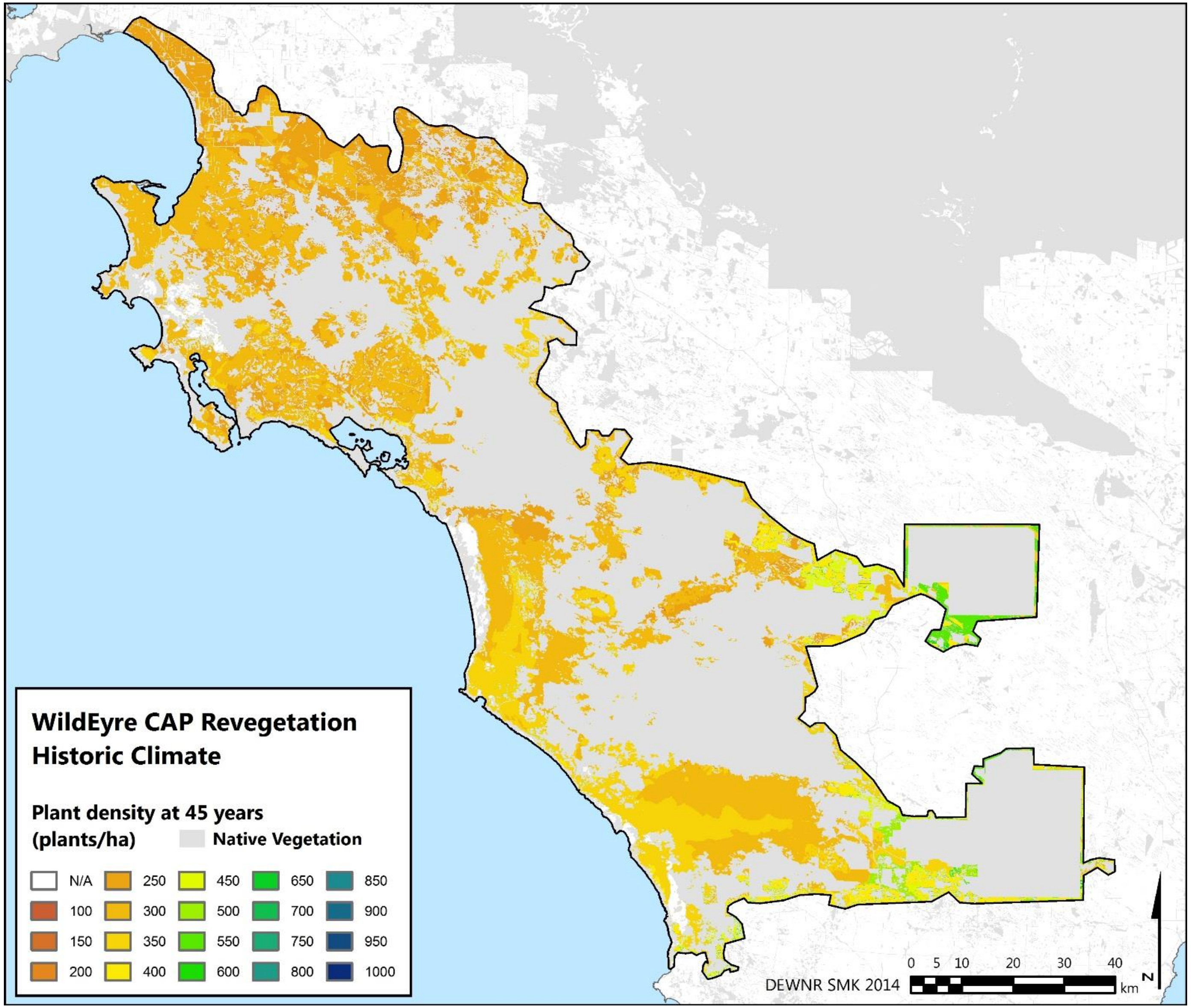


Figure 3.6 Plant density of targeted revegetation under historic climatic conditions.

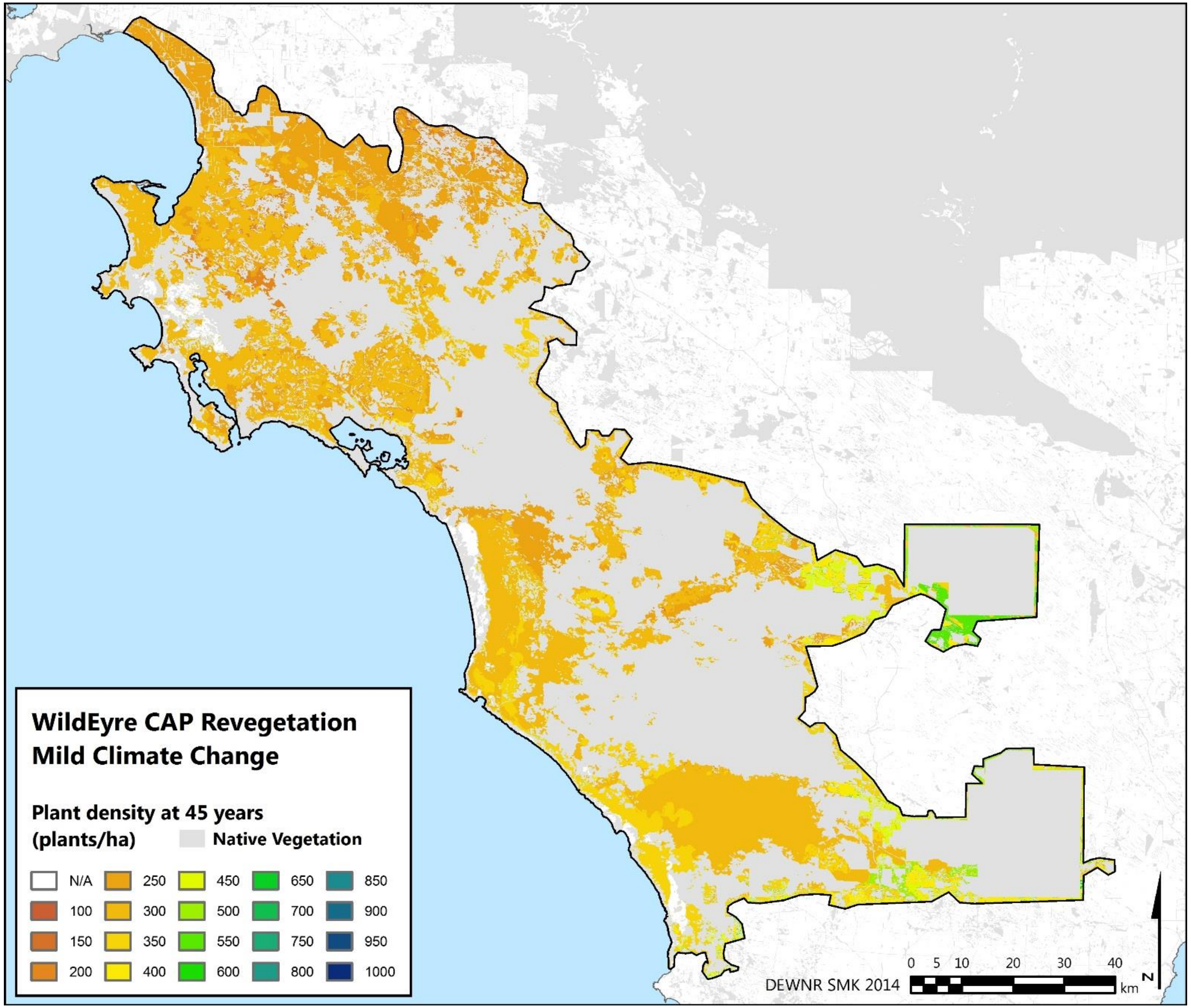


Figure 3.7 Plant density of targeted revegetation under mild climate change.

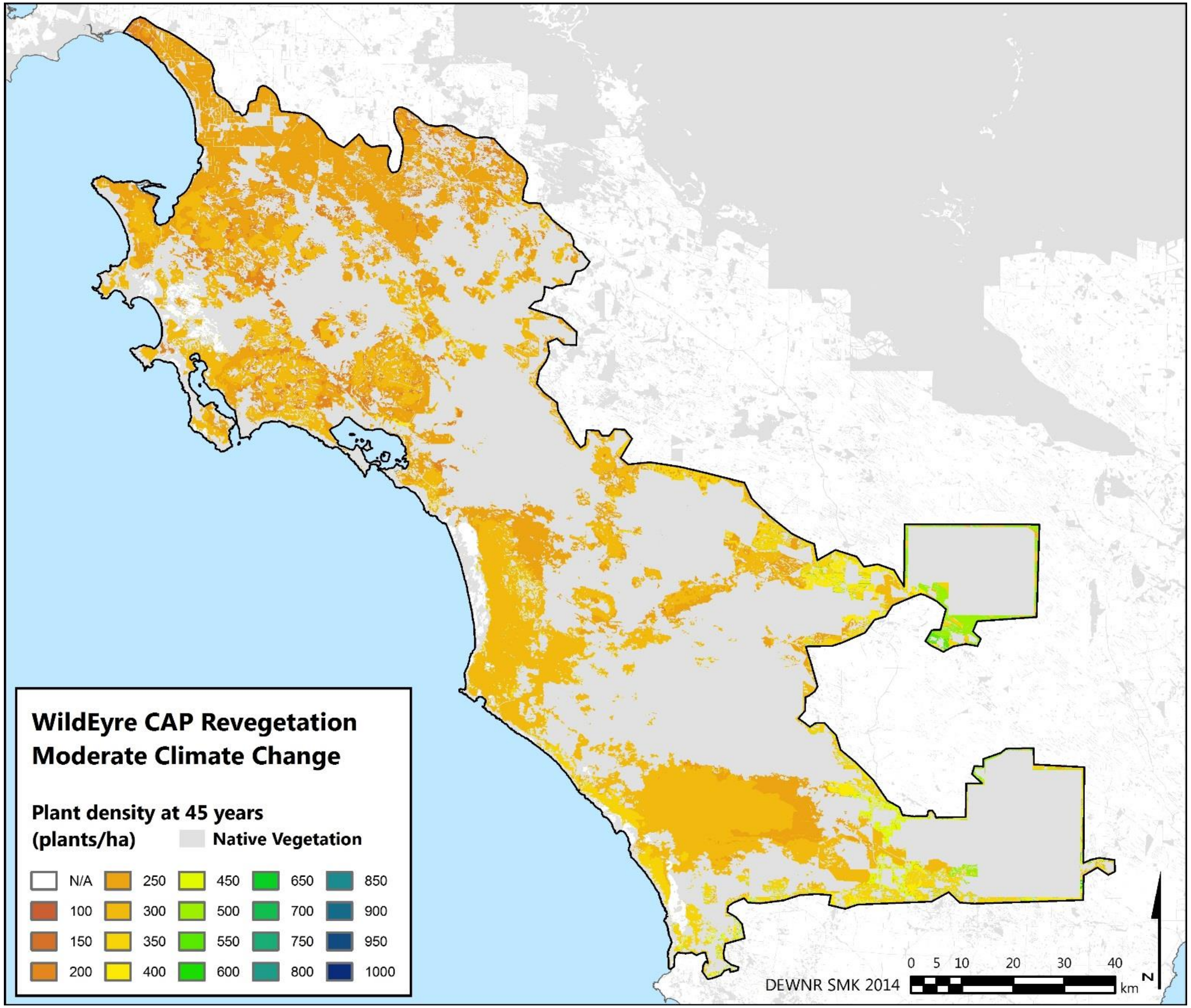


Figure 3.8 Plant density of targeted revegetation under moderate climate change.

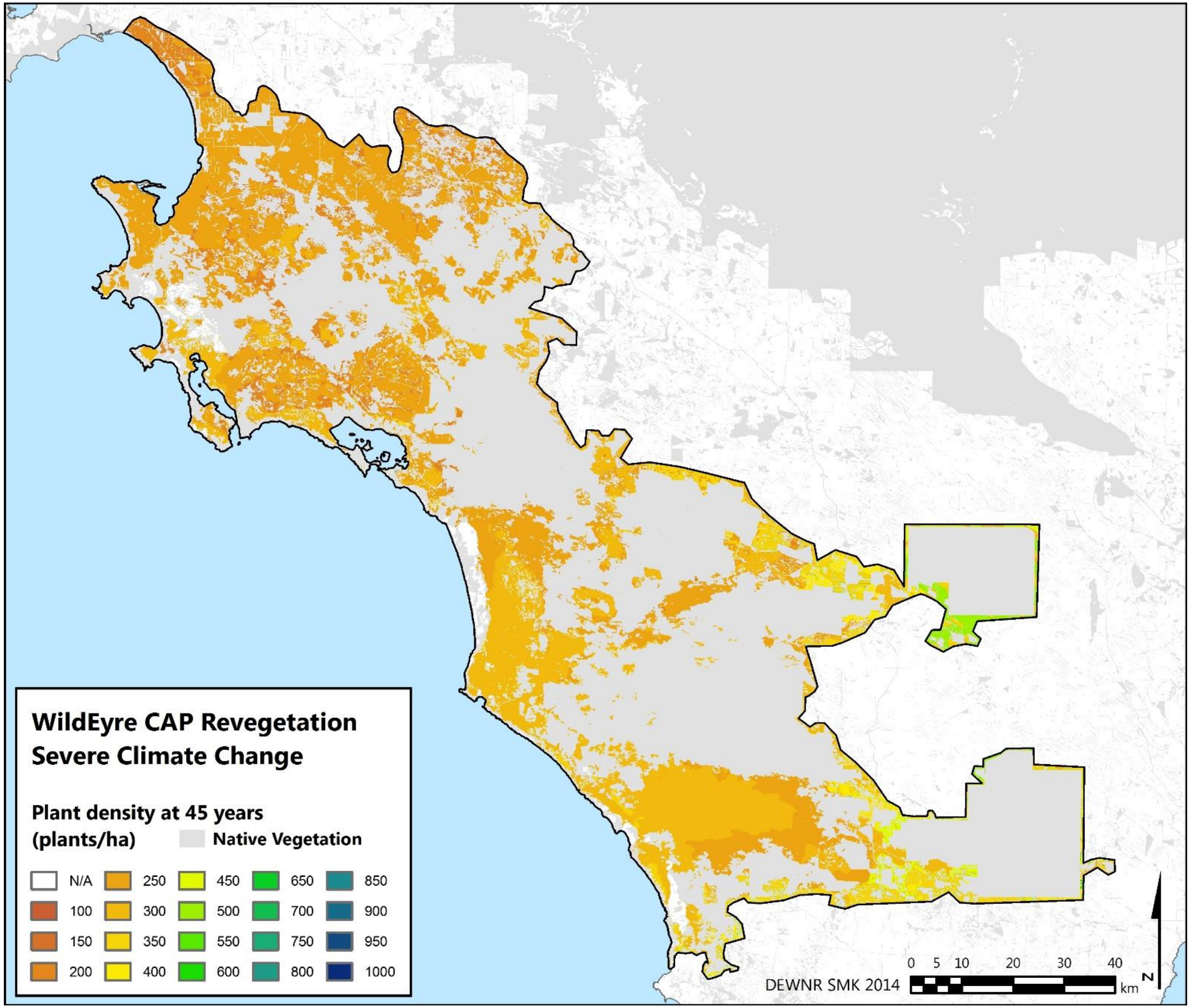


Figure 3.9 Plant density of targeted revegetation under severe climate change.

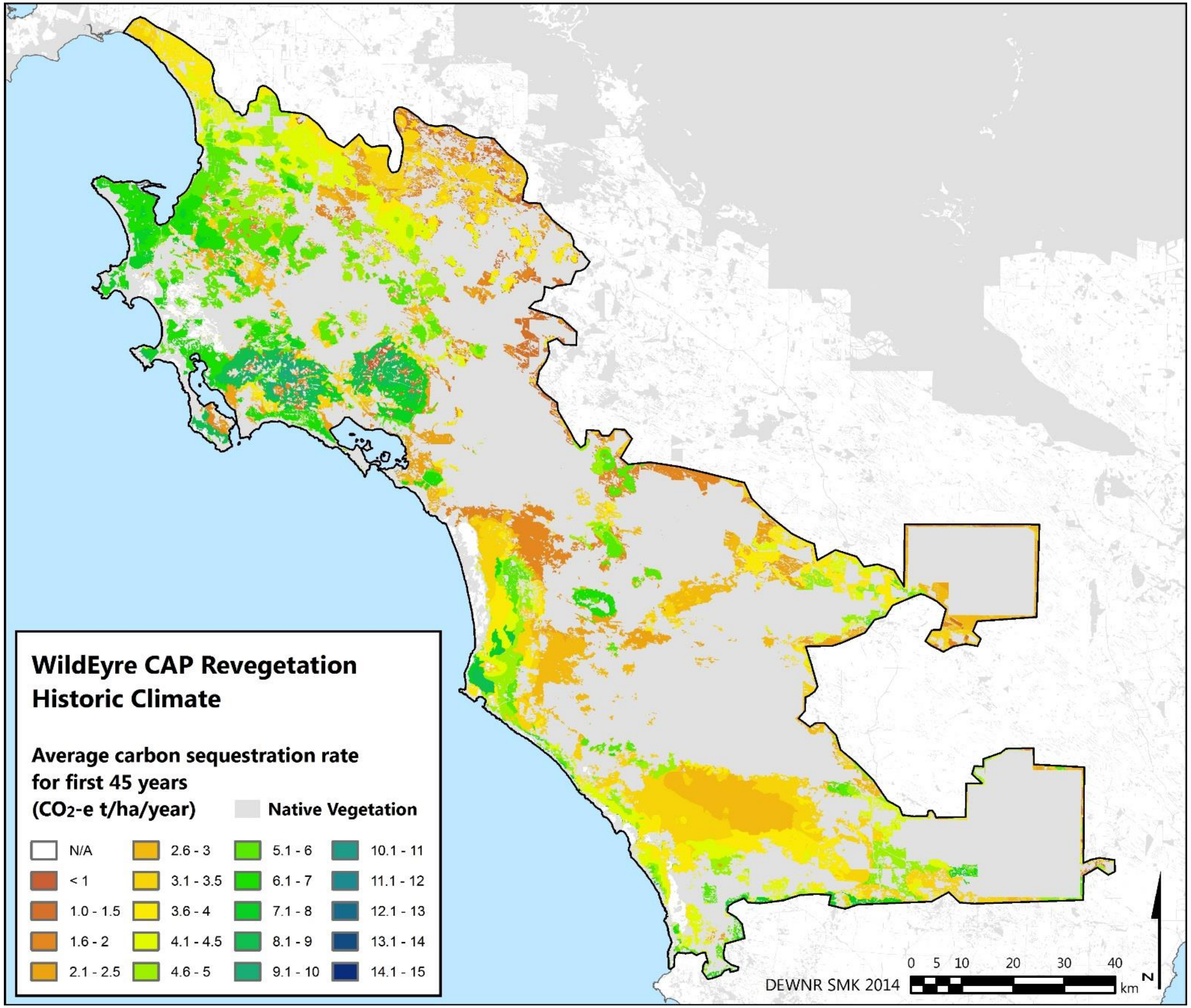


Figure 3.10 Carbon sequestration rate of targeted revegetation under historic climatic conditions.

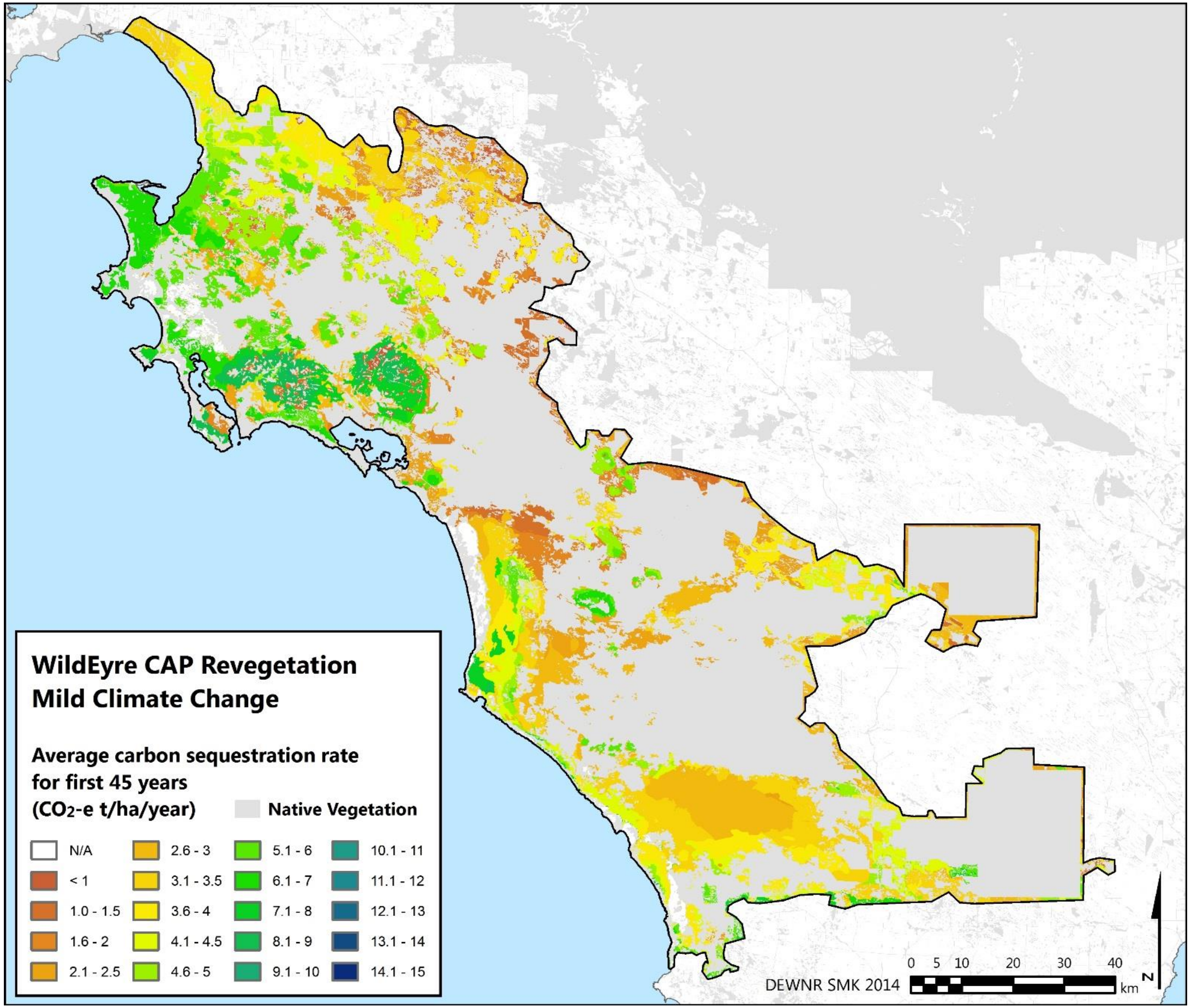


Figure 3.11 Carbon sequestration rate of targeted revegetation under mild climate change.

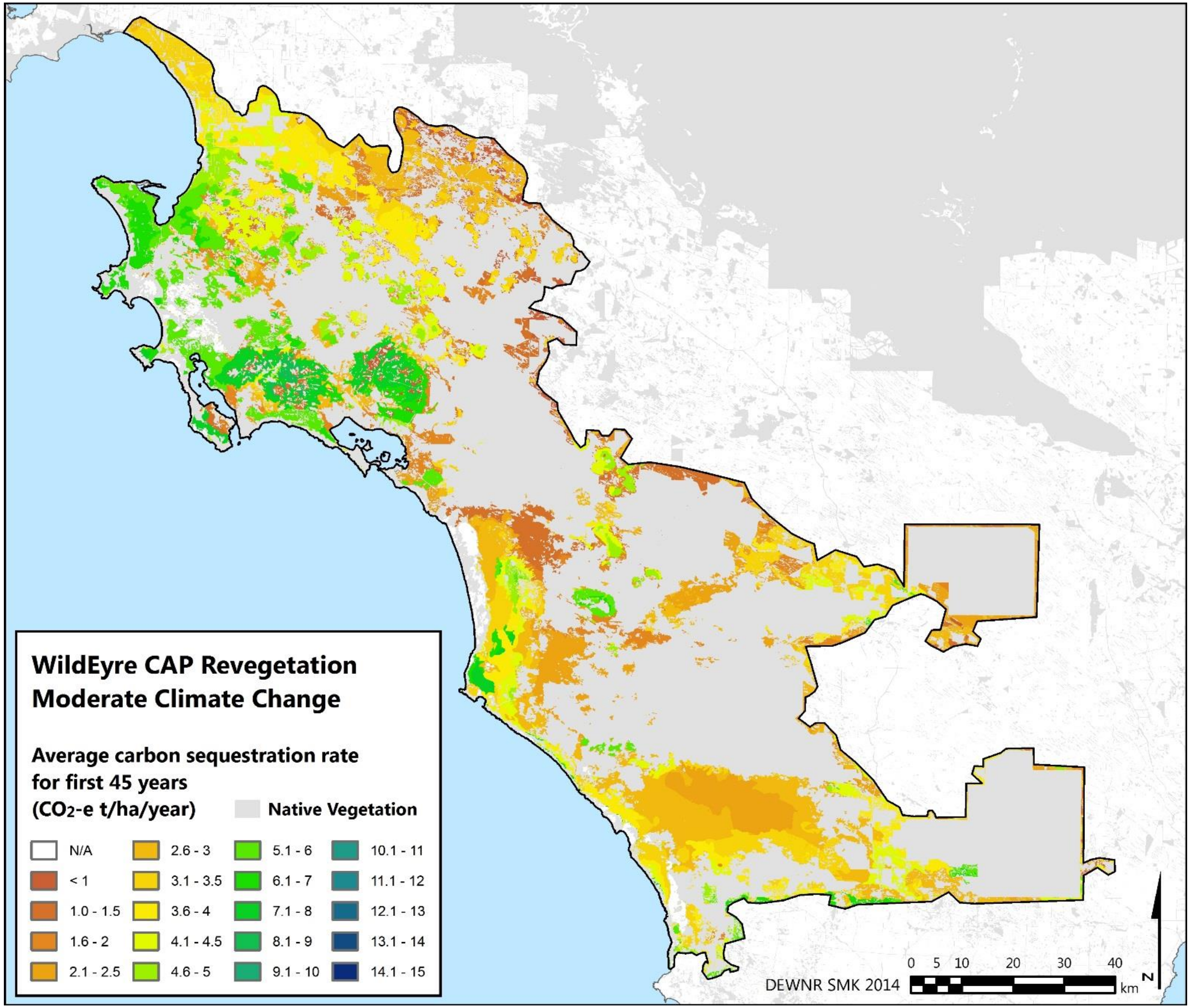


Figure 3.12 Carbon sequestration rate of targeted revegetation under moderate climate change.

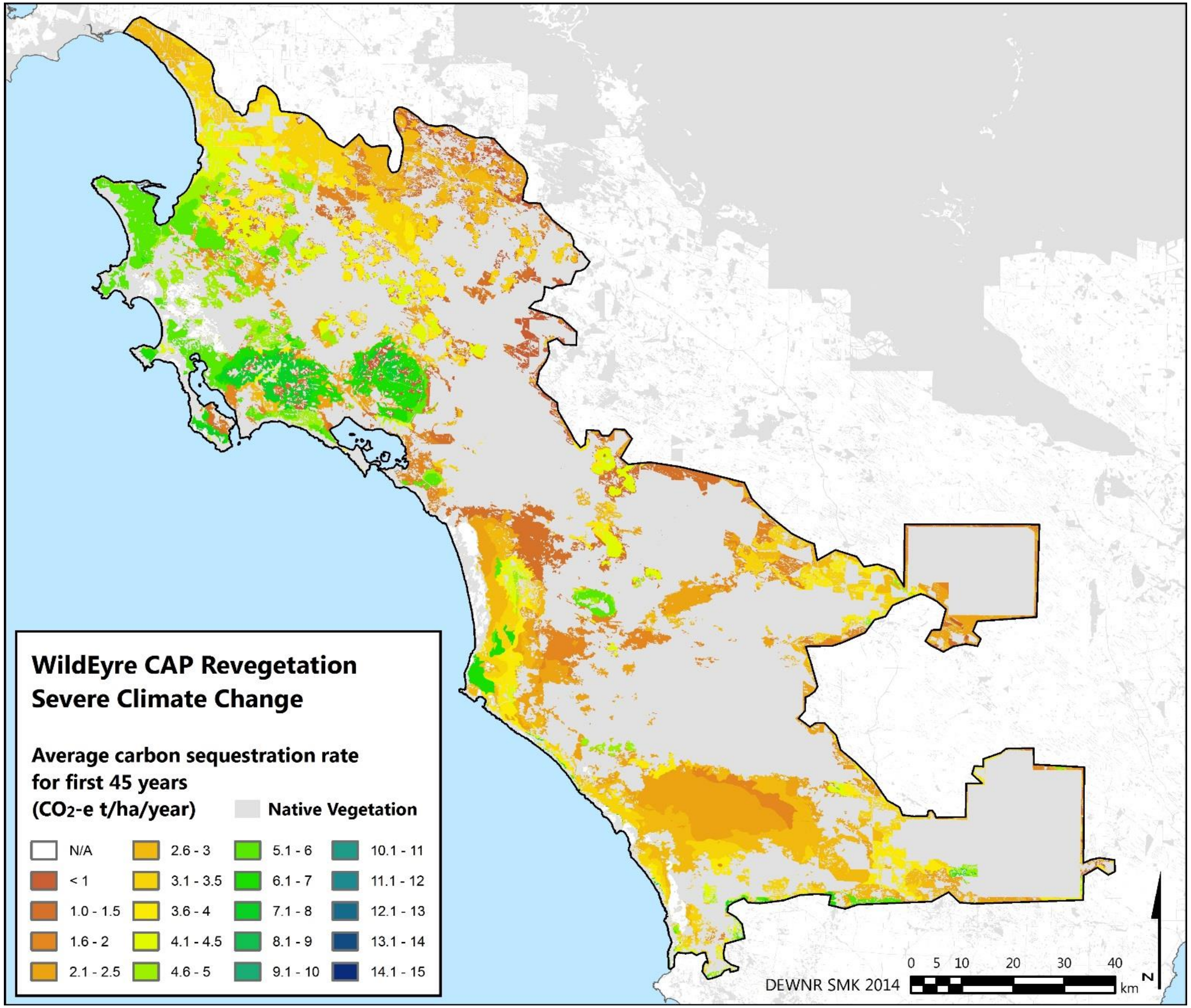


Figure 3.13 Carbon sequestration rate of targeted revegetation under severe climate change.

4 Conclusions

The locally-calibrated carbon sequestration models for Conservation Action Planning (CAP) priority vegetation communities in the WildEyre region presented in this report 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 carbon sequestration rates of targeted revegetation designs across the WildEyre region are between 17% (mallees, mallee box & native pine) to 23% (sheoak) higher than 45 year old typical "tree-dominated environmental planting (88% trees)" designs presented by Hobbs *et al.* (2013, 2014) and used in the Landscapes Futures Analysis Tool (LFAT). However, the red gum community is 24% less productive than the LFAT models, partially due to lower than expected plants per hectare and harder soils in these communities.

Inspections of the spatial patterns of WildEyre carbon sequestration models with high sequestration rates and the location of land already cleared of native vegetation for agricultural purposes show strong correlations. Deeper and fertile soils are most productive for both annual cropping and native plant biomass, especially in CAP sheoak communities. Locations with higher than typical sequestration rates within existing native vegetation communities may have additional ecological values (e.g. source populations or refugia for plant and animals).

The models also provide indications of 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 10% 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 30% compared to historic conditions.

New and targeted revegetation activities in the region should recognise that the mortality rate of new plants is 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 research 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 – WildEyre CAP reference sites

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	
Coastal-Inland Limestone Plains Mallee													
CAL-CASJ-A-1	418							15	15	97	0	97	1.00
CAL-CASM-A-1	382		25						25	284	0	284	1.00
KAR-HICP-A-1	359			30		20			50	893	0	893	1.00
LOC-BWCP-A-1	368					15		30	45	246	0	246	1.00
LOC-BWCP-A-2	368		8	5		10		23	46	412	0	412	1.00
LOC-DUTR-A-1	361					50		15	65	269	0	269	1.00
LOC-HACP-A-1	340					30		30	60	298	0	298	1.00
MIN-BRAJ-A-1	318					20		40	60	328	0	328	1.00
MIN-BRAJ-B-2	325		50			10			60	602	0	602	1.00
MTD-OBRS-A-1	324							20	20	130	0	130	1.00
MTW-MWCR-A-1	424							20	20	130	0	130	1.00
POL-AWCD-D-1	346			2		30		50	82	482	0	482	1.00
POR-KUCP-A-1	334							25	25	162	0	162	1.00
SCE-GRAJ-A-1	382	40						35	75	1047	820	227	0.22
SCE-GRAJ-B-1	381	30				10		25	65	812	615	197	0.24
TOO-SIVM-A-1	376	5			15	0.1			20.1	219	102	117	0.53
VEN-BRIJ-A-1	354	40				1			41	823	820	3	0.00
Average	**362**	**28.75**	**27.67**	**12.33**	**15.00**	**17.83**	**0.00**	**27.33**	**45.54**	**426**	**139**	**287**	**0.82**
Mallee Box and Native Pine Woodland													
BAS-DEWN-CP-7	375	2	1	10	5	7			25	390	41	349	0.89
LOC-BWCP-B-1	372			2	10				12	132	0	132	1.00
MAR-CASJ-C-1	364							20	20	130	0	130	1.00
MTW-NEWN-CP-3	356			0.1		15			15.1	54	0	54	1.00
PAL-FUSP-A-1	344	5	4	2	12				23	296	102	193	0.65
PKE-HOFP-B-1	344				50				50	387	0	387	1.00
POL-AWC-CP-8	353			5	10	5			20	232	0	232	1.00
POL-AWCD-A1	358			8	8				16	282	0	282	1.00
POL-AWCD-B2	359			5	60				65	602	0	602	1.00
POL-DINJ-CP-9	372		1	5	5	3			14	198	0	198	1.00
POO-MUDT-A-1	313	0.05		6	10				16.05	243	1	242	1.00
POO-SIDK-A-1	343	10	2	5	15	8			40	509	205	304	0.60
PTK-HASC-A1	357			10	50				60	662	0	662	1.00
SHE-REYJ-CP-1	398			0.001		50			50.001	172	0	172	1.00
STR-FLIN-A-1	366	1		5	7				13	212	20	192	0.90
Average	**358**	**3.61**	**2.00**	**4.85**	**20.17**	**14.67**	**0.00**	**20.00**	**29.28**	**300**	**25**	**275**	**0.94**
Red Gum Woodland													
BRA-BVWR-A1	386			5	5		15		25	219	0	219	1.00
BRA-BVWR-A-2	386	2		1	15				18	185	41	144	0.78
COL-MCCS-A-1	363	3			5				8	100	61	39	0.39
COL-RVWR-A-1	362	10		5	15				30	459	205	254	0.55
COO-BASC-A-1	368			0.01	2		20		22.01	72	0	72	1.00
COR-KENK-A-1	401	1.6		0.5	12				14.1	139	33	107	0.76
COU-BUCR-A-1	357			1	10		3		14	113	0	113	1.00
KAP-AGAS-E-1	385			1	6				7	74	0	74	1.00
KAP-AGAS-F-1	395	3		1.5	10				14.5	180	61	119	0.66
KAP-GREI-A-1	393		0.2	1	20	1			22.2	188	0	188	1.00
KAP-WANM-G-1	398	1		0.1	6				7.1	70	20	49	0.71
MUR-WATC-A-1	374	0.1		2	15				17.1	173	2	171	0.99
PKE-HOFP-A-1	344				15				15	116	0	116	1.00
POL-BUTR-B-1	365						65		65	184	0	184	1.00
POL-BUTR-C-1	362			1	25		2		28	227	0	227	1.00
POR-AGAS-G-1	383			1	12.5				13.5	124	0	124	1.00
POR-BACP-H-1	377			0.1	15				15.1	119	0	119	1.00
SHE-AGAS-A-1	383			2			20		22	112	0	112	1.00
TOO-MURD-A-1	382			10	35				45	546	0	546	1.00
Average	**377**	**2.96**	**0.20**	**2.01**	**13.15**	**1.00**	**20.83**	**0.00**	**21.19**	**179**	**22**	**157**	**0.89**

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	
Sheoak Grassy Woodland													
BAB-MONR-A-1	385			10	25				35	468	0	468	1.00
BAI-MCCR-B-1	384			12					12	330	0	330	1.00
BRA-GILK-A-1	434	0.2		5					5.2	142	4	137	0.97
CAL-CACP-A-1	375			10					10	275	0	275	1.00
ELL-MAYD-A1	394			25					25	687	0	687	1.00
ELL-MAYN-A-1	395			1	3				4	51	0	51	1.00
ELL-TRED-A-1	355				30				30	232	0	232	1.00
ELL-TREK-A-1	357				25				25	194	0	194	1.00
ELL-TREK-B-1	364			25					25	687	0	687	1.00
MAR-CASJ-A-1	364			8	3				11	243	0	243	1.00
POR-CACP-A-1	374	0.5	0.01		10	0.5			11.01	90	10	79	0.89
POR-CACP-A-2	378			20					20	550	0	550	1.00
POR-CASJ-A-1	394	0.5		2					2.5	65	10	55	0.84
POR-KENJ-A-1	373			7					7	192	0	192	1.00
SHE-NOSW-S-3	441	0.1		5	5				10.1	178	2	176	0.99
STR-SAWA-S-10	367			1	12				13	120	0	120	1.00
STR-SAWA-S-12	368			3	8				11	144	0	144	1.00
Average	**383**	**0.33**	**0.01**	**9.57**	**13.44**	**0.50**	**0.00**	**0.00**	**15.11**	**273**	**2**	**272**	**0.98**