Woody Biomass Productivity and Potential Biomass Industries in the Upper South East

A report for the
SA Centre for Natural Resource Management

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Executive Summary

The natural resources of South Australia's Upper South East provide the backbone of a diverse range of ecosystems, agricultural pursuits, industries and communities. However, the region is significantly affected by the natural resource management issues of dryland salinity, and ecosystem fragmentation/degradation. The loss of perennial vegetation cover has contributed substantially to these natural resource management issues and it is well recognised that there is a role for agroforestry, perennial farming systems and habitat re-creation to alleviate some of these problems. Woody biomass industries can provide both environmental services and economic opportunities through the development of commercial revegetation in the Upper South East.

This report outlines the range of woody biomass industries that can potentially service the Upper South East region. Some industry types, such as fodder shrubs for livestock, pulpwood and firewood, already exist in the region and could be significantly expanded with little or no new investment in industrial infrastructure. New industries based on bioenergy and *Eucalyptus* oil or combined in an Integrated Tree Processing plant (eg. Narrogin WA oil mallee plant) have strong potential in the region but may require significant investment in new infrastructure to proceed.

Any woody biomass industry development is dependant on the selection of species which match both industry product and yield specifications, and can produce sufficient economic volumes of biomass in the region. Information on plantation productivities in the Upper South East is limited to a few trials of forestry species primarily aimed at long-cycle hardwoods for lumber production. Production rates of species aimed at short-cycle woody biomass crops are poorly known. To determine the biomass production rates and product yields in current and future plantations we have developed robust allometric relationships between simple plant measurements (biometrics) and their stemwood volumes, total above-ground biomass and carbon contents.

This study provides very strong allometric relationships between simple measures of plant morphology and standing plant biomass (r^2=0.88). Simple classifications of species groups and lifeforms can improve the predictive capability of these models by a further 4%. Data from the Upper South East and River Murray Corridor biomass studies provide robust relationships that can be applied across a wider range of species and environments in South Australia. Using these relationships we have been able to revisit data collected from other farm forestry trials and rapidly evaluate the primary productivity of other plantations in the region. Using productivity data from groups of species that match pulpwood, bioenergy, oil mallee, fodder shrubs and habitat re-creation industries, we have built spatial models of woody biomass production and carbon sequestration potential for each industry type.

In the Upper South East region there are 1.39 million hectares of land currently used for annual cropping and livestock grazing that could potentially be used for woody biomass crops. Leakage of water from the current cropping/grazing farming systems contributes on average around 26 millimetres of recharge every year which equates to 360 Gigalitres across the entire region. Plantations of woody crops on these landscapes would virtually eliminate recharge, greatly reduce the progression of dryland salinity, reduce wind erosion risk and provide additional biodiversity benefits. Additional benefits would also be gained from atmospheric carbon dioxide sequestration. The environmental benefits of revegetation have been quantified for each Hundred subdivision in the

region. A combination of dryland salinity, wind erosion and habitat loss risk indices were used to identify which districts would most benefit from woody perennial crops - these are focussed on the central part of study area, near the town of Tintinara and including lands to the west of Keith.

Existing broadacre annual cropping and livestock grazing provide an average gross margin return of around $121 per hectare (based on average returns 1996-2005). As could be expected with annual-based crops and pastures these returns are highly variable over time, ranging from losses of over $-200/ha to profits of over $400/ha in good seasons. Woody perennial crops provide more consistent returns as the robust woody crops generally survive droughted conditions and can make the most of unseasonal rainfalls. Our integrated spatial analysis of plantation productivity and farm economics (Regional Industry Potential Analysis) for several industry types show that expanded pulpwood industries could provide annual equivalent returns of between $132 - 1006/ha (region average range = $415 - 476/ha). Firewood industry average annual returns for the region would be in the vicinity $229 - 280/ha, and fodder shrubs in Autumn would be worth $147/ha. The prospective industries of bioenergy and Eucalyptus oil extraction based on new infrastructure at Keith would provide annual returns of around $380 - 433/ha, and single purpose carbon sequestration planting would create annual returns up to $43/ha (average $10 - 12/ha) for habitat and oil mallee plantings but could be higher than $500/ha (average $370/ha) for permanent woodlots of Sugargum (*Eucalyptus cladocalyx*) or similar species.

Several of the woody biomass industries analysed here could provide economic returns which are competitive with existing cropping and grazing landuses in the region. Rather than a total displacement of existing annual cropping and grazing systems in the Upper South East region, we envisage these new woody biomass industries will provide new options and opportunities for farmers and existing industries of the region. These new options can be strategically placed to become an integral part of a healthy mosaic of new woody perennial-based and existing annual-based primary industries. In our landscapes that are subject to the risks of rising water tables, dryland salinity, soil erosion, habitat loss, climate change, and economic and community sustainability, there appears to be a sound future for woody perennial cropping in the Upper South East region.

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Acknowledgements

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1. Introduction

The natural resources of South Australia's South East provide the backbone of a diverse range of ecosystems, agricultural pursuits, industries and vibrant communities. However, the landscapes and landuses in the region are affected by a number of both inherent and human induced natural resource management (NRM) issues. The Upper South East region (see Figure 1; Figure 2) is typified by low topography, poor water drainage, high water tables, inherently high soil and groundwater salt loads, and a history of substantial clearing of native vegetation for agriculture. It faces significant NRM issues of water table induced salinity, dryland salinity, habitat and biodiversity loss, and wind erosion. The loss of perennial vegetation cover has contributed substantially to these NRM issues and it is well recognised that there is a role for agroforestry, perennial farming systems and habitat re-creation to alleviate some of the problems faced in the region.

The integrated management of our natural resources is a high priority for South Australians and is notably reflected in recent developments of policy and legislation in the State. The State Strategic Plan's objectives of "*growing prosperity, improving wellbeing, attaining sustainability, fostering creativity, building communities and expanding opportunity*" (SA Government 2004) are strongly connected to our ability to manage our natural resources for the future benefit of all South Australian. The SA *Natural Resources Management Act 2004* provides the underlying structure for government activities to better manage our natural resources. Overall state goals for NRM are detailed in the *State Natural Resources Management Plan* (SADWLBC 2006). The *State NRM Plan* identifies a 50 year vision for NRM in South Australia, and sets out policies, milestones and strategies to achieve that vision (SADWLBC 2006).

State NRM Plan Vision: South Australia, a capable and prosperous community, managing natural resources for a good quality of life within the capacity of our environment for the long term.

- ***Goal 1: Landscape scale management that maintains healthy natural systems and is adaptive to climate change***
- ***Goal 2: Prosperous communities and industries using and managing natural resources within ecologically sustainable limits***
- ***Goal 3: Communities, governments and industries with the capability, commitment and connections to manage natural resources in an integrated way***
- ***Goal 4: Integrated management of biological threats to minimise risks to natural systems, communities and industry***

Figure 1 - The focus area of the Upper South East biomass study.

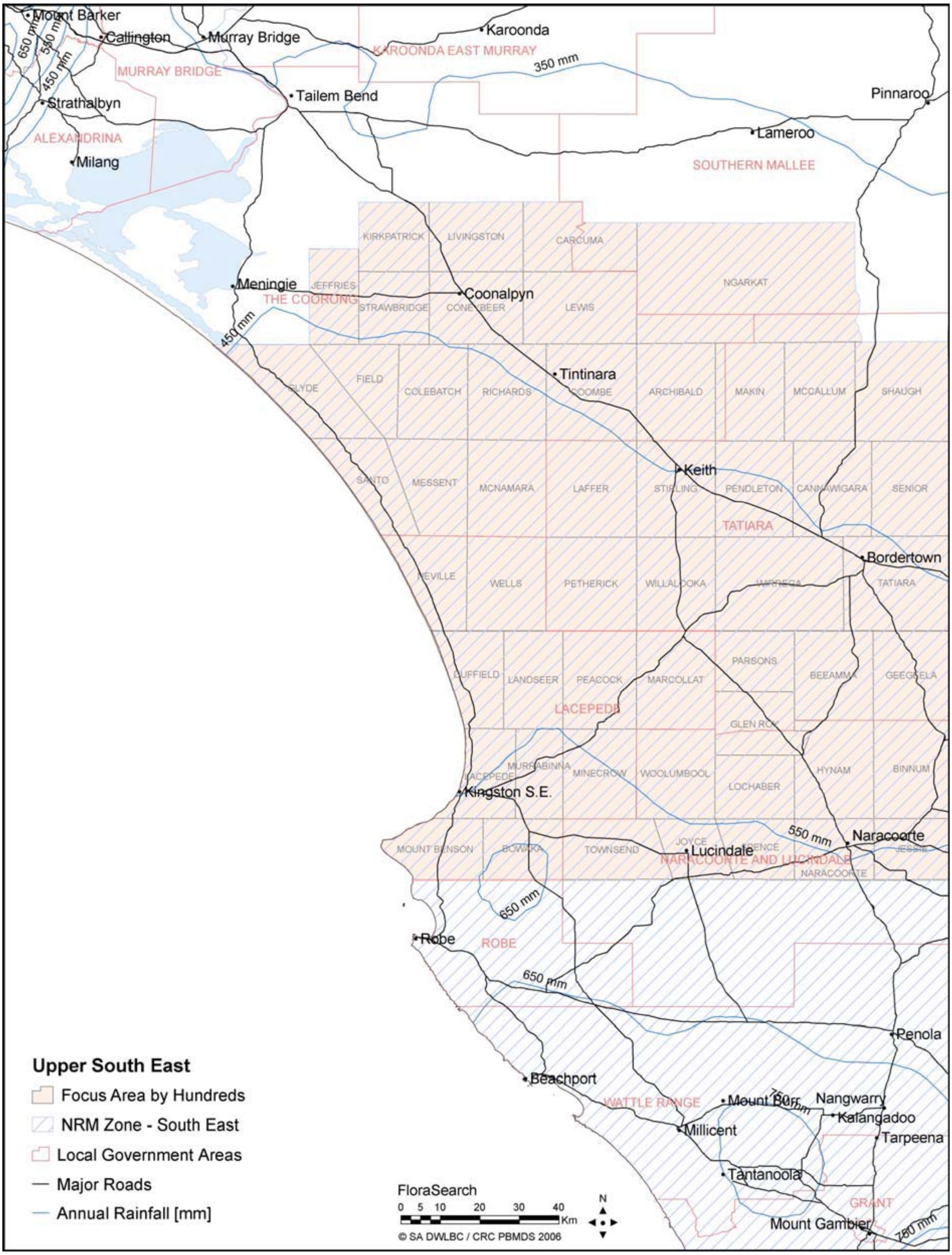
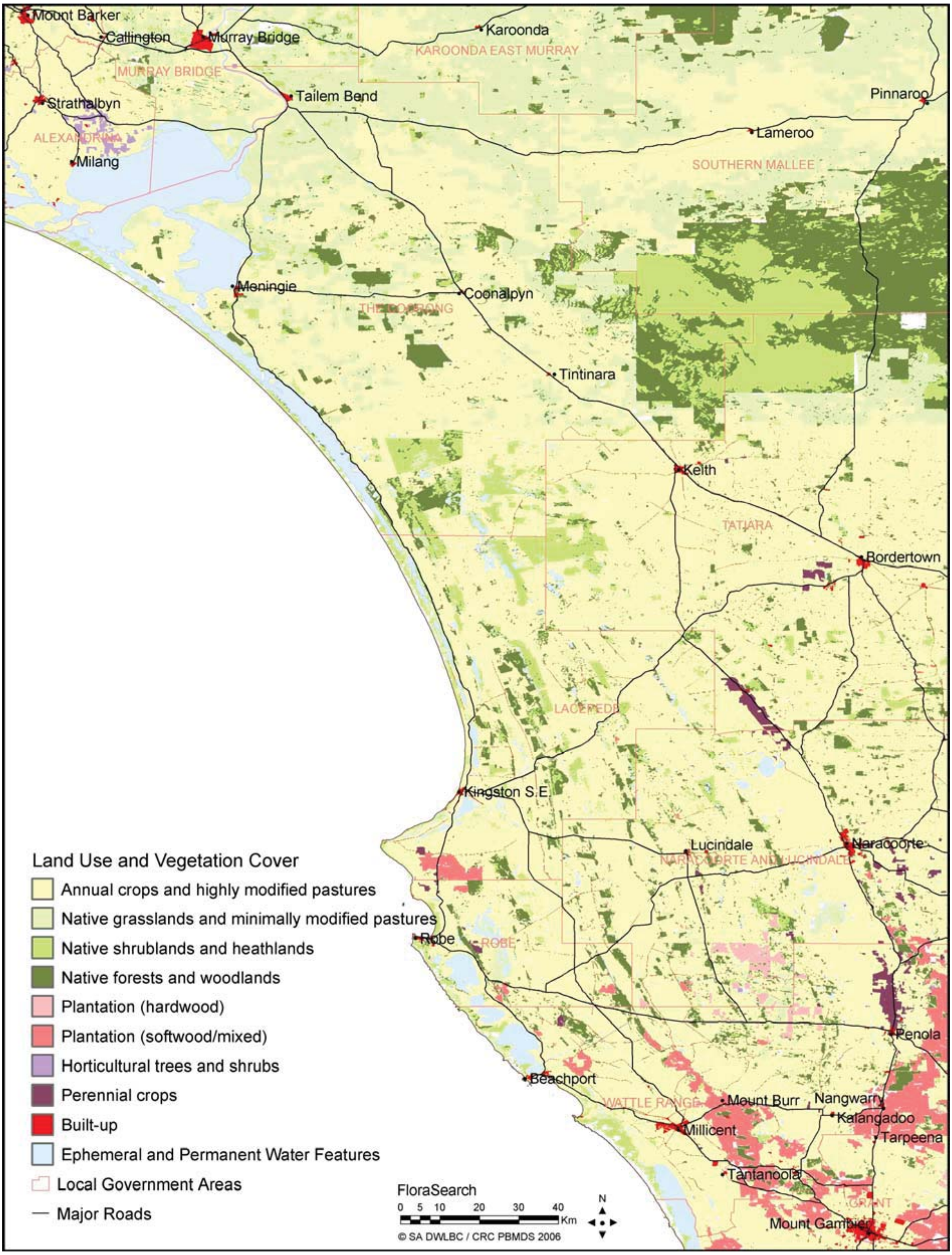


Figure 2 - Landuse and vegetation cover types in the Upper South East region.



(Source: BRS 2003)

Supporting the State NRM Plan are a series of Regional Plans. Many of the existing regional plans were developed prior to the state plan; however, these are currently being reviewed and will be redeveloped in the near future. The current *South East Natural Resource Management Plan* (SENRCC 2003) was developed to "*provide the strategic framework for achieving the vision for natural resources management in the South East. The framework will be used to facilitate integrated approaches to the management of the region's natural resources and to attract investment to address priority issues*". In light of legislative changes and the new *State NRM Plan* a new regional plan for South East is currently being developed (SENRMB 2006).

The new *South East Regional Natural Resource Management Plan* (SENRMB 2006) will set out the vision for the management of the South East Region's soil and water, landscapes, seascapes and biodiversity, and detail the action needed to achieve that vision. It aims to create an integrated and innovative plan to protect the natural values and health of the Region, while promoting a strong long term regional economy and social future. The new plan will incorporate many features of the current NRM plan and other related resource management plans, will be updated with new natural resource condition information, and seek community and industry input into economic directions and management for the future. The process to develop the plan has been designed *"to create opportunities for innovative thinking, accessing the best science and involving the right people to contribute to plan development"*.

Supporting the development of the "best science" for NRM is the SA Centre for Natural Resource Management (SACNRM 2006) which develops and maintains partnerships with NRM Regional Groups, scientists and researchers, business and industry, governments and agencies, so that integrated natural resource management across South Australia is based on world-class research and development. The CNRM aims to create more sustainable environments through the development of new technologies and industries which benefit the environment and are economically sustainable. The CNRM undertakes a number of key research-related roles, including oversight of the South Australian R&D component of the National Action Plan (NAP) for Salinity and Water Quality. The CNRM identifies and negotiates supplementary funding and co-investment sources for NRM research, from both the public and private sectors. It has strong partnerships and linkages with business and industry stakeholders provide enhanced co-investment opportunities. The CNRM identified the need to better understand the ecosystem services and economic potential of farm forestry (agroforestry), woody perennial farming systems and revegetation in the Upper South East and subsequently contracted the FloraSearch group to conduct the research contained within this report.

The priority setting for FloraSearch's research into biomass industries in the Upper South East Region is based on the key natural resource management issues that can be alleviated or addressed by revegetation activities such as agroforestry, woody perennial farming systems (including fodder shrubs) and habitat creation. The current *South East NRM Plan* (SENRCC 2003) identifies a wide range of NRM issues for the region, its goals and proposed activities. The following is a subset of those issues, goals and activities which relate to the Upper South East sub-region and issues which may be addressed by revegetation of agricultural lands:

Dryland Salinity
Goal - To manage and reduce the spread and severity of dryland salinity and optimise the productivity of saline lands.

- Groundwater recharge reduced by increasing the water holding capacity of soil, increasing groundcover, establishing deep rooted species, establishing healthy plant growth and reducing pondage of surface waters.
- Ecosystems enhanced and conserved.

Waterlogging
Goal - To reduce the impact of waterlogging on agricultural land whilst recognising the value of protecting and/or reinstating historic wetlands for biodiversity.

- Alternative production systems, which are tolerant of waterlogged areas further researched.

Soil Acidity
Goal - To reduce the rate of soil acidification in sandy soils and implement amelioration techniques to reduce the impact of soil acidification in affected areas.

- Slowing the rate of acidification by reducing nitrate leaching through planting perennial grasses and avoiding excess use of nitrogen fertilisers, recycling non-acid nutrients, rotating stock, and reducing the use of fertilisers containing large amounts of elemental sulphur.

Soil Erosion
Goal - To prevent and/or reduce soil erosion through the adoption of appropriate land management practices and techniques.

- Landholders are informed and implement management strategies, which reduce erosion potential. These may include maintenance of surface cover, the utilisation of management options such as forestry, windbreaks and retention and protection of existing vegetation to reduce wind velocity, maintenance of soil fertility to enhance vegetative cover, timing of cultivation, control of vermin, grazing management, and the utilisation of cover crops.

Ecosystem Fragmentation and Degradation
Goal - To reduce the disturbance and destruction of habitats and improve the health and viability of terrestrial native vegetation, wildlife species and ecological communities.

- Protection and enhancement of existing areas of habitat on private and public land.
- Improved diversity and quality of habitat.
- Improved viability of existing animal and plant populations.

Capacity Building
Goal - To ensure that the South East community is motivated, capable and has the capacity to achieve integrated NRM outcomes that benefit the economic, environmental and social wellbeing of the region.

- NRM information being accessed and research needs addressed.

The *South East NRM Plan* community consultative process identified the most highly ranked NRM priority issues for the region as Salinity (Land Resources), and Ecosystem Fragmentation and Degradation (Biodiversity). The focus on salinity is supported by evidence of the region's high risk status identified by the 2001 National Land and Water Audit (NLWA 2001). Barnett (2001) quantifies that 272,000ha of the South East Region is currently affected by secondary salinity (water table induced). The National Land and Water Audit (2000) found that 5.7 million hectares were at risk or affected by dryland salinity in Australia, and that in 50 years time this area could rise to 17 million hectares. Without substantial and immediate changes to agricultural systems to reduce groundwater recharge and impact of dryland salinity Australia's productive capability and wealth from farm exports will diminish (Stirzaker *et al.* 2000, 2002). In the South East Region 87% of the original native vegetation has been cleared, 11 plant and 22 animal species have become regionally extinct, 333 plant species are considered threatened at the State level (63 endangered, 88 vulnerable, 180 rare and 2 not yet listed), and 27 of the 49 pre-European plant communities (55%) are considered rare or threatened (SENRCC 2003).

Many environmental and economic benefits can be achieved from increasing the use of perennial plant species in Australian landscapes (Australian Greenhouse Office & Murray Darling Basin Commission 2001). New plantations of woody perennial species can reduce groundwater recharge, dryland salinity, saline river discharges, wind erosion and drought risk, and increase landscape sustainability, biodiversity, livestock production, economic diversification and stability of financial returns. The losses from salinity affected agricultural land both in terms of productive capability and spatial extent are increasing every year in Australia.

For this study the Upper South East Region is classified as the area (see Figure 1) bounded by the northern edge of the Natural Heritage Trust's South East Region (~35.49°S), the SA/Victorian border (140.96°E), a line between the southern edges of the Hundreds of Mount Benson and Jessie (37.03°S) and the SA coastline (~139.29°E) and covers approximately 1,922,456 hectares. It overlays the Local Government Areas of Naracoorte and Lucindale (northern half), Lacepede, Tatiara, The Coorong (southern two-thirds), and the Southern Mallee (southern quarter). The region supports a number of landuses predominated by cropping/grazing (~74%) and native woodlands, shrublands and wetlands (~24%) and minimal areas of forestry (<1%), urban and human services (<1%) and irrigated perennial crops and horticulture (<1%). The potential area for conversion to agroforestry, fodder shrubs and biomass industries is 1,421,317 hectares or approximately 74% of the region. This statistic is not intended to suggest that we have to displace all of the existing cropping and grazing areas in the region but indicates the scale of opportunity for the region to incorporate alternate or supportive woody biomass industries into these landscapes. The current area of each vegetation/landuse class and sub-division (Hundred) is presented in Table 2.

The neighbouring lower South East Region is already serviced by a substantial forestry industry. Early forestry industry development was mainly based on lumber (starting c.1881 at Mount Gambier) from predominantly softwood *Pinus* species (with other mills at Nangwarry, Mount Burr and Tarpeena) with lumber products still featuring highly in the region. In 1960 the Millicent Pulp Mill was established (KCA 2006) and a second mill developed at Tantanoola in 1992 to produce primarily paper tissue and hygiene products from softwood plantation pines (*Pinus radiata*), although in the late 1990s the Millicent mill also utilised Eucalypt hardwoods. Carter Holt Harvey Panels operates a particleboard mill at Mount Gambier which utilises plantation pine to produce around 277,000m³ of particleboard per year (CHH 2006). In recent times there has been significant investment and area planted with the hardwood Tasmanian Bluegum (*Eucalyptus globulus*) mainly for export pulpwood industries serviced by the deepwater port at Portland. Recently, the development of a new mechanical pulp mill near Penola has been approved (Penola Pulp 2006). The planned pulp mill will produce approximately 350,000 air dry tonnes of pulp per year to supply both the export and domestic paper markets from approximately 700,000 tonnes of plantation eucalypt woodchip.

Table 1 - Proportion of vegetation and land use classes in the Upper South East region.

Vegetation/Landuse Class	Description	Proportion of Area
Annual crops and highly modified pastures	Annual crops (eg. cereals), grazing/pastures explicitly labelled as improved or modified	66.0%
Native grasslands and minimally modified pastures	Native grasslands or vegetation used for grazing/pastures not explicitly labelled as improved or modified	7.6%
Plantation (hardwood)	Hardwood plantation forests	>0.1%
Plantation (softwood/mixed)	Softwood plantation forests or plantations of mixed/unknown composition	0.3%
Perennial crops	Perennial cropping (eg. grapes etc.)	0.4%
Horticultural trees and shrubs	Horticultural trees & shrubs (eg orchards)	>0.1%
Built-up	Urban areas, transport, services etc.	0.6%
Native shrublands and heathlands	Native shrublands, heathlands and open woodlands (non-forest woody vegetation)	11.9%
Native forests and woodlands	Native forests and woodlands	10.8%
Bare	Non-vegetated not elsewhere classified	0.4%
Ephemeral and Permanent Water Features	Lakes, wetlands, water courses and reservoirs	2.0%

Based on national vegetation and landuse mapping by the Bureau of Rural Sciences (2003).

Livestock production is a major existing industry in the South East Region. As of June 30, 2005 there were 4,013,400 sheep and lambs and 665,000 meat cattle in the South East statistical district (ABS 2006). Several feedlots also exist in the region, including substantial feedlots at Meningie and Naracoorte, with smaller lots at Tintinara, Lameroo, Parrakie and Frances. Additionally, a livestock feed manufacturing plant exists in Murray Bridge. The fodder shrubs Tagasaste (*Chamaecytisus* spp.) and Oldman Saltbush (*Atriplex nummularia*) are currently utilised *in situ* for livestock grazing on many farms in the region and potential exists for mechanical harvesting fodder shrubs to supply feedlots and stock feed manufacturing in the region.

There is an increasing interest and awareness of the potential for renewable energy sources to be used to generate electricity, offset the use of fossil fuels, and reduce greenhouse gas emissions and their influences on global climates (Stucley *et al.* 2004, Zorzetto & Chudleigh 1999, Hague *et al.* 2002). Electricity generation from biomass (bioenergy), especially when combined with co products of oil, charcoal, tannins or fodder provides an environmental friendly opportunity in many regions of Australia (Zorzetto & Chudleigh 1999; Bennell, Hobbs & Ellis 2007; Bartle & Shea 2002; Olson *et al.* 2003, Enecon 2001). Stucley *et al.* (2004) have provided a recent review of *Biomass energy production in Australia - Status, costs and opportunities for major* *technologies*. It provides an excellent review of the technologies available of transforming biomass into energy and a variety of fuel types. However, they declare *"There is a general lack of information available on the growth of tree plantations in many parts of Australia."*

The purpose of this study *(Woody Biomass Productivity and Potential Biomass Industries in the Upper South East)* is to:

- provide an evaluation of the annual productivity and product yields of native plant species suited to agroforestry and other woody biomass industries in the region

- map and quantify the landscapes with potential for developing woody biomass industries

- identify natural resource management issues that will benefit from revegetation activities

- determine existing and potential broadscale industries and markets that can utilise woody biomass grown from the region

- undertake economic evaluations of proposed industry types

- convey the results of this research to stakeholders so they may evaluate the potential environmental, agricultural, economic and regional benefits of agroforestry, biomass industries and revegetation in the region.

Table 2 - Extent of average annual rainfall, landuse and vegetation cover types by land subdivision (Hundreds) in the Upper South East region.

Hundred	Rainfall [mm]	Total Area [hectares]	Annual crops and highly modified pastures	Native grasslands and minimally modified pastures	Plantation (hardwood)	Plantation (softwood/mixed)	Perennial crops	Horticultural trees and shrubs	Built-up	Native shrublands and heathlands	Native forests and woodlands	Bare	Water Features
Archibald	443	39612	7320	3005					75	9410	19802		
Beeamma	507	36219	30495	174		59			146	2134	3207		4
Binnum	527	39289	36138	61					320	302	2428		40
Bowaka	645	24911	20826	271	19				232	961	2392		210
Cannawigara	445	38971	35160	80					365	1206	2160		
Carcuma	401	35500	11280	14420						2711	7089		
Colebatch	473	34148	27059	1143						614	5306		26
Coneybeer	427	35451	26939	3847					76	1282	3307		
Coombe	441	45227	31378	11377					129	938	1383		22
Duffield	509	27462	18617	2004					323	2528	1985	558	1447
Field	472	24811	18410	5913						14	347		127
Geegeela	496	35614	27984	369		219		2	308	4029	2690		13
Glen Roy	512	27531	22033	67		50	3357		203	896	766		159
Glyde	477	40806	21950	3398					2	2356	2090	1505	9505
Hynam	532	38602	33176	198	16	10	33	11	139	735	4260		24
Jeffries	440	24631	11199	9790						913	2729		
Jessie	550	24382	22008	44		12	1667		170		315		166
Joyce (North)	568	19044	16495	18	9		133		331	327	1658		73
Kirkpatrick	408	25626	19863	3368						675	1720		
Lacepede	555	26307	17834	744			6		645	2301	1607	79	3091
Laffer	474	45444	37962	1170					201	4190	1594		327
Landseer	525	29825	18746	423					116	4293	5777		470
Lewis	418	42763	16137	14634						4954	7037		1
Livingston	393	34188	24442	5715						864	3167		
Lochaber	534	25978	21916	23	10	16	38		56	497	657		2765
Makin	428	34948	8801	5450					4	16244	4449		
Marcollat	505	39719	35310	4					288	1945	1230		942
McCallum	434	35884	8014	8831						15102	3937		
McNamara	501	39481	26907	1205					97	9005	535		1732
Messent	507	32573	9746	2074					23	13236	6371		1123
Minecrow	560	33863	26670	671	6	86			59	2661	3080		630
Mount Benson	600	25873	17098	810		5195	379		328	805	256		1002
Murrabinna	577	21958	16368	480					249	1000	3187		674
Naracoorte	549	24843	20491	362	6	292	220		1477	96	961	11	927
Neville	493	29679	15018	2807					91	6348	1631	2272	1512
Ngarkat	402	137634	4367	3295						74410	55562		
Parsons	508	24660	19269	23		4	973		198	2497	1666		30
Peacock	519	36954	30759	155					231	2830	2598		381
Pendleton	454	38753	36295	2			97		345	495	1518		1
Petherick	503	43753	32132	473					17	8291	1406		1434
Richards	459	38860	32980	4863					11	240	666		100
Santo	489	28017	10696	1352					69	4497	2711	2400	6292
Senior	438	38471	36840	51					50	493	1037		
Shaugh	437	48180	12606	21979						4101	9494		
Spence (North)	558	21682	19158	66					116	359	1828		155
Stirling	459	39413	36883						1073	417	1037		3
Strawbridge	440	26767	11907	8298						622	5940		
Tatiara	462	52129	48842	29			16		1335	507	1322		78
Townsend	597	31220	26882	255		9			109	594	2922		449
Wells	513	38460	26916	269					24	7393	1240		2618
Willalooka	492	38031	36165						256	636	964		10
Wirrega	481	62024	55455	40		5	1494		551	1048	3289	42	100
Woolumbool	529	36285	30860	272		120			112	2835	1729		357
[Avg.] or Total	*[482]*	*1922456*	*1268802*	*146372*	*66*	*6077*	*8413*	*13*	*10950*	*227837*	*208039*	*6867*	*39020*

2. Biomass Productivity

2.1 Introduction

The lack of productivity and yield data has hindered early attempts to evaluate the potential of biomass industries in the Upper South East (USE) region of South Australia. In the 1990's several small scale trial sites were established by Primary Industries and Resources SA as part of the *Farm Tree Improvement* and *Australian Low Rainfall Tree Improvement Group* projects (Fairlamb & Bulman 1994; Rural Solution SA 2003). Six of these PIRSA sites were established within the USE region (see Figure 3), with a further 5 sites located immediately north of the region and 2 sites located immediately south of the USE region (<650mm rainfall zone). These sites contain a limited number of species and provenances with often poor experimental replication of plots. The publicly reported observations from this study have been limited to height performance data only. The SA Department of Water, Land and Biodiversity Conservation contracted a re-measurement of many of these sites in 2003. This dataset, which we have now analysed, contains information on survival, heights and stem diameters from which we can deduce stemwood productivity per hectare rates. Additionally, Forestry SA has conducted a number of experimental trials in the USE region (predominantly *Hardwood Thinning Trials* focussed on the Bordertown area) and they have kindly allowed us access to that data (Joshua Driscoll, pers. comm.). Fifteen of these sites are within the USE region and a further 5 sites are immediately south of this region. To supplement this current data FloraSearch has conducted several new surveys, focussing on the central, mid-northern and northern edge parts of the USE region.

Most existing assessments of plantation productivity are focussed on assessing height and stem diameters. These measures are suitable for estimating stemwood volumes for classical forestry where the focus is on the recoverable solid timber. For many biomass industries the focus is on the whole plant biomass and the relative proportions of stemwood, bark, twig and leaf fractions. Biomass industry productivity assessments require assessment methodologies that can be used to rapidly and reliably assess both total biomass and yield ratios of each biomass fraction.

Allometrics is a commonly used technique to non-destructively assay plantation productivity from a limited number of measurements (biometrics). In classical forestry industries these allometric models are often based on measurements of tree diameter at breast height or basal area calculations (± tree height) to determine stemwood volumes or biomass, with models often being species specific (Snowdon *et al.* 2000, 2002, Grierson 2000, Kiddle *et al.* 1987). However, allometric models based on high rainfall forestry trees are unlikely to be reliable predictors of productivity for the mallee and shrub lifeforms more suited to lower rainfall regions. New allometric models must be developed to non-destructively and efficiently assess plantations of low rainfall agroforestry species.

New robust and reliable allometric models can then be applied to the results of rapid assessment biometric methodologies to determine the primary productivity of plantations of low rainfall agroforestry species. Reliable assessments of standing biomass of known age plantations are used to determine annual productivity rates, with the most productive species selected for use in new biomass industries or carbon sequestration plantings. Regional predictions of biomass production using geographic information system technologies, observed species productivity rates and regional productivity models (Raupach *et al.* 2001) can then be integrated with spatial data on industrial infrastructure, production systems and economic models to determine the commercial viability of proposed industries in the region (Bennell, Hobbs & Ellis 2007, Ward & Trengove 2004, Hobbs *et al.* 2007).

This study aims to provide reliable and robust methodologies to rapidly assess the primary productivity of low rainfall species using simple plant observations and allometric models, and to quantify production rates for a range of species grown on dryland sites in the USE region. Further, existing measurements from other studies will be analysed and biometric relationships use to determine plantation productivity and yield of biomass components. Finally, for a selected range of species, spatial models of regional productivities and yields will be constructed so that we can evaluate the capability of native species to provide plantation feedstock to biomass industries or sequester carbon in the region.

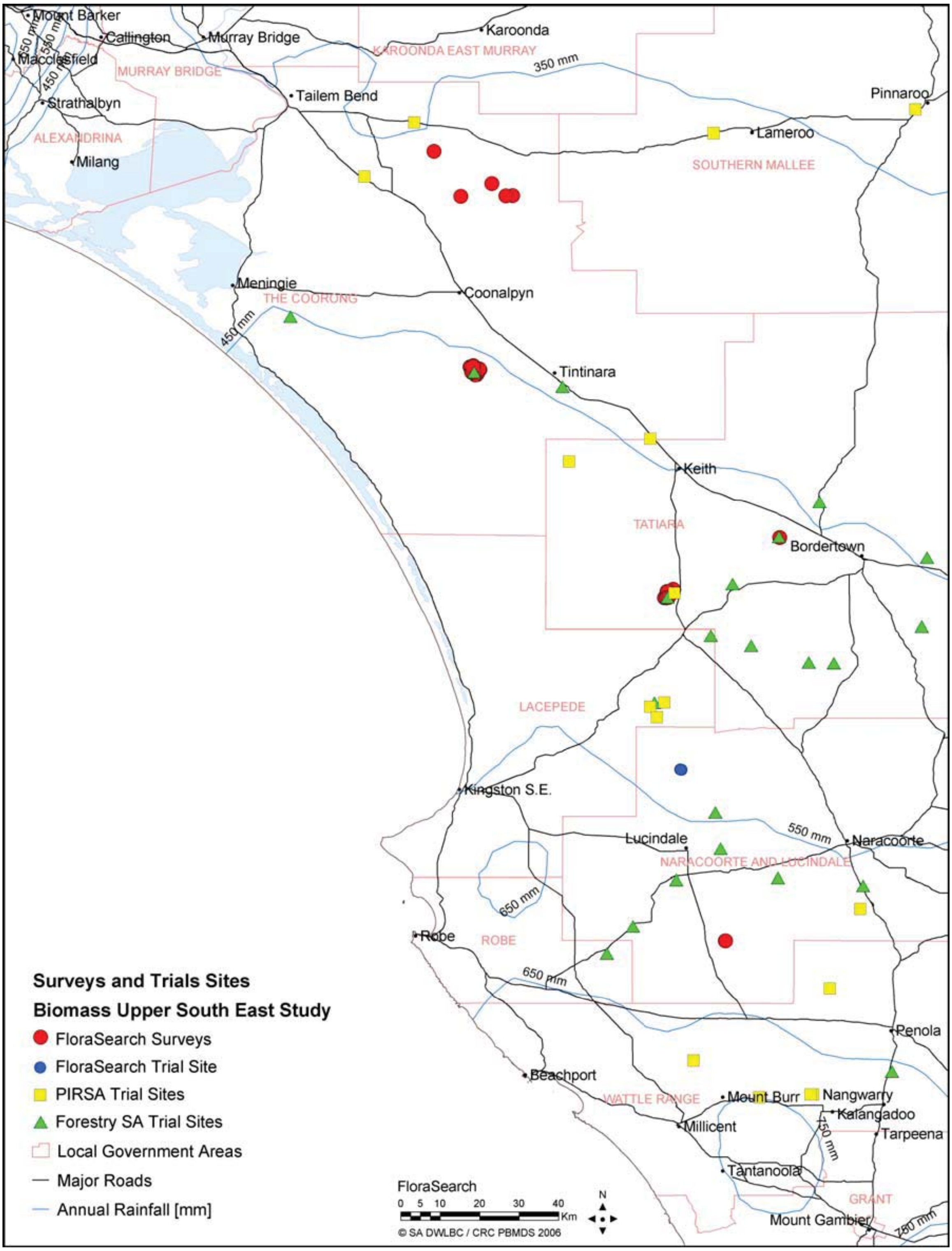
2.2 Plant Biometrics and Allometric Relationships

Plants were sampled from dryland environments in the Upper South East (USE) region from forestry and revegetation sites of known age. The plant species were chosen to represent those species most highly ranked for agroforestry development for the region (Hobbs *et al.* 2007). The species selected were predominately forestry tree species but included representative samples of small trees, mallees and fodder shrubs. Our previous study *Plant Biometrics and Biomass Productivity in the River Murray Dryland Corridor* (Hobbs & Bennell 2005) provides a more detailed study of allometric relationships for mallee and shrub species. Results from that study, for species also suited to the USE region have been incorporated into this current study. Three individuals of each species and location were chosen for detailed biometric measurements of plant morphology and biomass sampling.

Individual plant measurements included height, crown width, distance to neighbouring plants, stem count and circumference at two lower section heights (basal and intermediate: 0.5m and 1.3m for trees and mallees; and 0.2m and 0.8m for shrubs), and visual ranking of leaf density using reference photographs (8 classes). The stemwood volume (outer bark) of each plant was calculated from stem height and circumferences using standard forestry formulas for tree volumes of each stemwood section (1. lower section – cylinder volume; 2. mid section - Smalian's frustrum of a paraboloid volume, and 3. upper section - paraboloid volume).

Samples of wood and bark were taken from each basal and intermediate height for each plant with an additional sample taken half way between the intermediate height and the top of the plant. The diameter of the wood (minus bark) and bark thicknesses were measured across the north-south axis of the sample, and used to determine the bark proportion of the outer bark stemwood volume. The green weight of the wood only and bark only samples were measured immediately. The green volume of the wood only samples was determined by displacement in water, and the separate wood and bark samples were oven dried to a steady dry-weight to determine wood basic density and the moisture content of each sample component.

Figure 3 – Location of FloraSearch survey sites and farm forestry trial sites in the Upper South East region and neighbouring area (Forestry SA, Primary Industries and Resources SA, FloraSearch Field Trial of Woody Germplasm).



The whole of each plant was destructively sampled and sorted into three biomass fractions: 1. stemwood and bark (>20mm diameter); 2. twig and bark (2-20mm diameter); and 3. leaf, fine twig and bark (<2mm diameter) and each fraction weighed immediately. Samples (>200g) from each green biomass fraction was weighed immediately, oven dried to a steady dry-weight and reweighed to determine their moisture content. The total dry biomass of each plant was determined from the green weight of each biomass fraction and the observed moisture content of oven-dried subsamples. Whole plant carbon contents were calculated from the sum of dry biomass fractions and the commonly accepted generic conversion factor of 0.5 (Snowdon *et al.* 2002).

Allometric relationships between simple measurements of height, crown area, basal stem area, leaf density, stemwood volumes and observations of total green biomass (including stemwood and bark; twig and bark; and leaf, fine twig and bark) were plotted, explored visually and tested using linear regressions. Interactions between these simple measurements and lifeform or plant genera groupings were also evaluated.

Upper South East Biometrics and Allometric Relationships

Fifty-one individual plants were measured and destructively sampled for the biometrics study. These represent 17 plantations (15 species, see Table 3), and include 3 generic groupings (11 Eucalypts, 4 non-Eucalypts) and 3 lifeform types (9 trees, 4 mallees and 2 shrubs). Two important agroforestry species were sampled twice (Sugargum *Eucalyptus cladocalyx* & Swamp Yate *Eucalyptus occidentalis*) from both block and windbreak plantations. The age of plantations sampled for this study ranged from 3 year old fodder shrubs to 12.7 year old mallees (average 9.5 years for trees and mallees). Table 3 and Table 4 provide summaries of a number of key plant characteristics for species and locations used in the biometrics study. Relationships between green biomass, dry biomass and carbon content are presented in Table 5. The average proportion of dry biomass to green biomass by weight (incorporating different moisture contents of each fraction) for all species ranges between 0.386 for Oldman Saltbush *Atriplex nummularia* fodder shrubs and 0.587 for Drooping Sheoak *Allocasuarina verticillata* (mean=0.498). The carbon content expressed as a proportion of green biomass by weight ranges between 0.193 for Oldman Saltbush and 0.293 for Drooping Sheoak (mean=0.249).

Individual plant morphological measurements were converted into a range of biometric parameters commonly used to predict above ground plant biomass (see Table 6). These include plant height, basal stem area (outer bark), crown area (from crown widths), stemwood volume (outer bark; from plant height and 2 stemwood area observations), and foliage density. Foliage density classes were expressed as a percent of maximum density (i.e. very dense 100%, dense 86%, moderately dense 71%, moderate 57%, moderately sparse 43%, sparse 29%, very sparse 14%, no leaves 0%)

Allometric relationships between these morphological parameters and individual plant green biomass were explored. Separate analyses were conducted for total green biomass and green biomass fractions: 1. wood (>20mm diameter) and bark; 2. twig (2-20mm diameter) and bark; and 3/ leaf, fine twig (<2mm diameter) and bark. The biomass from fractions 1 and 2 were combined to create a fourth class (i.e. wood & bark + twig & bark) and tested against the morphological parameters. Preliminary plots and results illustrate a linear relationship between many parameters (and their interactions) and green biomass values. The small tree lifeform class was not modelled due to the limited number of observations (n=9). Due to non-normal distributions of data the biometric parameters and biomass values were transformed using natural logarithms prior to testing the strength of allometric relationships (see Figure 4 - Figure 12, Table 7). Green biomass and biomass fraction model equations take the form:

$$\boldsymbol{y} = \mathbf{e}^{\boldsymbol{a}\mathbf{.ln(}\boldsymbol{x}\mathbf{ + 1) + }\boldsymbol{c}} \mathbf{- 1}$$

where ***y*** **=** green biomass [kg plant^{-1}], ***x*** = predictor morphological variables, ***a*** = predictor factor and ***c*** = intercept of the linear regression (see Table 7 for details).

Table 7 contains a summary of analyses using the most logical selection of variables to predict total biomass and biomass fractions. The interaction of species groups and lifeform classes on biomass predictions from morphological measurements are often significant (see Table 7, Figure 4 - Figure 12). The best single variable generalised model (r^2=0.88) of total green biomass (kg plant^{-1}) is from basal area (outer bark) measurements (with no species group or lifeform interactions) and is represented by the formula:

Total Green Biomass [kg plant^{-1}] (r^2=0.88)

$$\text{Total Green Biomass} = e^{1.1317 \times \ln((\text{Basal Area [cm}^2]) + 1) - 1.2327} - 1$$

However, by including 2 broad lifeform classes (1. Trees, 2. Mallees & Shrubs) as model interactions significantly stronger predictions can be made (r^2=0.92) of total green biomass (kg plant^{-1}) from stemwood volume (outer bark) calculations these are represented by the formulas:

Tree Total Green Biomass [kg plant^{-1}] (r^2=0.93)

$$\text{Tree Total Green Biomass} = e^{0.8955 \times \ln((\text{Stemwood Volume} \times 1000\ [\text{m}^3]) + 1) + 0.9197} - 1$$

Mallee/Shrub Total Green Biomass [kg plant^{-1}] (r^2=0.88)

$$\text{Mallee/Shrub Total Green Biomass} = e^{1.0290 \times \ln((\text{Stemwood Volume} \times 1000\ [\text{m}^3]) + 1) + 1.2590} - 1$$

Allometric models developed for the USE region were compared against two other published allometric equations: 1. green stem weight by Kiddle *et al.* (1987, pg 34), developed for low rainfall woodland species in South Australia; and 2. dry biomass by Snowdon *et al.* (2000, pg 12), developed for separate woodland and shrubland species and used by the Australian Greenhouse Office for assessments of carbon sequestration (see Table 10). These models were applied to measurements from 51 plants observed in the USE region and the mean difference between modelled and observed biomass (expressed as a percent of the observed biomass) for each model was calculated. The trend of these differences indicates the degree to which models generally overestimate or underestimate plantation biomass productivity in the region.

Kiddle *et al.*'s allometric model is a moderately poor predictor of green stemwood biomass in this region with a mean difference of 35% from the observed biomass and overestimates trees by 18% and underestimates mallees by 11%. Snowdon *et al.*'s woodland (mallees and trees) model of dry biomass has a mean difference of 56% and overestimates by 38%. Allometric equations of Kiddle *et al.* and Snowdon *et al.* are especially poor predictors of shrub biomass. Generalised models developed for River Murray Corridor plantations (Hobbs & Bennell 2005) provide better overall estimates of plantation biomass than Kiddle *et al.* or Snowdon *et al.* but can significantly mispredict biomass for lifeform groups in the USE region. Allometric models developed for the USE study provide much more accurate predictions of plant biomass, with mean differences of 17-18% and they generally overestimate biomass by only 2.5%.

Combined Upper South East and River Murray Corridor Allometric Relationships

Combined biometric measurements from *Upper South East* and *Murray Corridor* studies were analysed to develop more generic allometric models. The analysis conducted is identical to that described above but utilises 104 observations. Table 11 contains a summary of these analyses. The resulting generalised model (r^2=0.86) of total green biomass (kg plant^{-1}) from stemwood volume (outer bark) measurements (with no species group or lifeform interactions) is represented by the formula:

Total Green Biomass [kg plant^{-1}] (r^2=0.86)

$$= e^{0.8460 \times \ln((\text{Stemwood Volume} \times 1000\ [m^3]) + 1) - 1.2475} - 1$$

However, by including 4 lifeform by species group classes (1. Tree Eucalypt, 2. Tree Non-Eucalypt, 3/ Mallee Eucalypt, 4/ Shrub Non-Eucalypt) as model interactions stronger predictions can be made (r^2=0.90) of total green biomass (kg plant^{-1}) from stemwood volume (outer bark) calculations, these are represented by the formulas:

Tree (Eucalypt) Total Green Biomass [kg plant^{-1}] (r^2=0.94)

$$= e^{0.8276 \times \ln((\text{Stemwood Volume} \times 1000\ [m^3]) + 1) + 1.1711} - 1$$

Tree (Non-Eucalypt) Total Green Biomass [kg plant^{-1}] (r^2=0.97)

$$= e^{1.1120 \times \ln((\text{Stemwood Volume} \times 1000\ [m^3]) + 1)} - 1$$

Mallee (Eucalypt) Total Green Biomass [kg plant^{-1}] (r^2=0.83)

$$= e^{0.8704 \times \ln((\text{Stemwood Volume} \times 1000\ [m^3]) + 1) + 1.4332} - 1$$

Shrub (Non-Eucalypt) Total Green Biomass [kg plant^{-1}] (r^2=0.79)

$$= e^{1.3086 \times \ln((\text{Stemwood Volume} \times 1000\ [m^3]) + 1)} - 1$$

Table 3 - Plant species measured and destructively sampled for biometrics study, including some key plant characteristics (mean values, n=3).

Species (plantation type)	Rainfall [mm]	Age [years]	Height [m]	Crown Width [m]	Lifeform [Tree/Mallee/Shrub]	Foliage Density [%]	Total Green Biomass [kg plant^{-1}]	Proportion Green Biomass by Weight		
								Wood & Bark	Twig & Bark	Leaf, Fine Twig & Bark
Acacia mearnsii (block)	492	12.5	9.9	3.3	T	57	128.2	0.79	0.12	0.09
Acacia pycnantha (block)	387	7.0	3.4	3.2	S	86	68.0	0.37	0.22	0.41
Allocasuarina verticillata (block)	492	10.9	9.6	4.9	T	38	344.6	0.81	0.07	0.12
Atriplex nummularia (block)	466	3.0	1.8	2.5	S	86	19.7	0.30	0.31	0.40
Corymbia maculata (block)	492	10.8	8.0	3.2	T	52	50.9	0.74	0.12	0.14
Eucalyptus camaldulensis (windbreak)	460	10.7	11.2	4.9	T	57	232.6	0.79	0.09	0.12
Eucalyptus cladocalyx (block)	460	6.7	7.1	2.7	T	71	59.9	0.58	0.21	0.22
Eucalyptus cladocalyx (windbreak)	460	6.7	5.8	2.4	T	86	67.0	0.60	0.17	0.24
Eucalyptus diversifolia (mixed block)	460	12.7	5.5	4.3	M	66	175.5	0.41	0.39	0.20
Eucalyptus dumosa (block)	387	12.0	3.3	2.7	M	62	35.8	0.43	0.32	0.25
Euca*lyptus globulus* (block)	460	10.7	13.8	3.5	T	57	194.9	0.75	0.09	0.16
Eucalyptus incrassata (mixed block)	460	12.7	3.6	4.3	M	71	92.2	0.40	0.31	0.29
Eucalyptus leucoxylon (block)	492	10.7	9.7	2.9	T	43	81.4	0.81	0.08	0.12
Eucalyptus occidentalis (block)	460	5.7	10.0	3.3	T	57	137.1	0.74	0.09	0.17
Eucalyptus occidentalis (windbreak)	460	6.7	8.6	2.3	T	57	78.9	0.67	0.12	0.21
Eucalyptus porosa (block)	387	6.7	3.9	3.8	M	71	50.3	0.34	0.23	0.43
Eucalyptus viminalis (block)	460	5.7	11.1	3.9	T	52	177.4	0.74	0.08	0.18

Table 4 – Mean wood properties, bark proportions and moisture contents of biomass fractions for plant species sampled for biometrics study.

Species (plantation type)	Basic Density [kg/m³]	Proportion Bark to Stemwood		Proportion Moisture by Weight			
		By Volume	By Weight	Wood & Bark	Wood Only	Twig & Bark	Leaf, Fine Twig & Bark
	(n=9)#	(n=9)	(n=9)	(n=9)	(n=9)	(n=3)	(n=3)
Acacia mearnsii (block)	650	0.15	0.18	0.39	0.38	0.47	0.54
Acacia pycnantha (block)	675	0.21	0.23	0.38	0.36	0.47	0.57
Allocas*uarina verticillata* (block)	724	0.20	0.20	0.39	0.38	0.45	0.54
Atriplex nummularia (block)	626	0.00		0.49	0.49	0.53	0.76
Corymbia maculata (block)	601	0.44	0.42	0.54	0.46	0.50	0.47
Eucalyptus camaldulensis (windbreak)	483	0.26	0.24	0.60	0.60	0.57	0.58
Eucalyptus cladocalyx (block)	634	0.30	0.30	0.49	0.46	0.47	0.46
Eucalyptus cladocalyx (windbreak)	600	0.27	0.26	0.52	0.47	0.47	0.46
Eucalyptus diversifolia (mixed block)	581	0.15	0.16	0.49	0.49	0.46	0.48
Eucalyptus dumosa (block)	767	0.24	0.25	0.36	0.35	0.40	0.49
Eucalyptus globulus (block)	530	0.16	0.14	0.54	0.53	0.53	0.50
Eucalyptus incrassata (mixed block)	726	0.27	0.27	0.40	0.39	0.48	0.47
Eucalyptus leucoxylon (block)	657	0.33	0.33	0.46	0.43	0.49	0.47
Eucalyptus occidentalis (block)	538	0.16	0.13	0.51	0.50	0.50	0.51
Eucalyptus occidentalis (windbreak)	604	0.16	0.14	0.48	0.48	0.50	0.48
Eucalyptus porosa (block)	577	0.20	0.21	0.48	0.48	0.48	0.58
Eucalyptus viminalis (block)	487	0.25	0.21	0.59	0.57	0.53	0.49

(# number of samples per species and location)

Table 5 – Relationships between total green biomass, dry biomass and carbon content of plant species measured and destructively sampled for biometrics study (mean values, n=3).

Species (plantation type)	Total Green Biomass [kg plant^{-1}]	Dry Biomass [kg plant^{-1}]				Proportion Dry Biomass to Green Biomass by Weight	Proportion Carbon to Green Biomass by Weight
		Wood & Bark	Twig & Bark	Leaf, Fine Twig & Bark	Total		
Acacia mearnsii (block)	128.2	60.0	8.3	5.2	73.5	0.573	0.287
Acacia pycnantha (block)	68.0	15.3	7.9	12.0	35.2	0.517	0.259
Allocasuarina verticillata (block)	344.6	169.3	13.6	19.3	202.3	0.587	0.293
Atriplex nummularia (block)	19.7	2.9	2.8	1.9	7.6	0.386	0.193
Corymbia maculata (block)	50.9	16.8	3.1	3.9	23.8	0.468	0.234
Eucalyptus camaldulensis (windbreak)	232.6	71.7	9.3	11.3	92.3	0.397	0.198
Eucalyptus cladocalyx (block)	59.9	17.4	6.5	7.1	31.0	0.517	0.259
Eucalyptus cladocalyx (windbreak)	67.0	19.1	5.9	8.7	33.6	0.502	0.251
Eucalyptus diversifolia (mixed block)	175.5	35.8	37.5	18.4	91.7	0.522	0.261
Eucalyptus dumosa (block)	35.8	9.6	6.8	4.0	20.4	0.569	0.284
Eucalyptus globulus (block)	194.9	66.8	8.2	15.8	90.8	0.466	0.233
Eucalyptus incrassata (mixed block)	92.2	21.7	14.9	14.3	50.9	0.552	0.276
Eucalyptus leucoxylon (block)	81.4	34.6	3.1	5.0	42.7	0.525	0.262
Euc*alyptus occidentalis* (block)	137.1	50.2	6.2	11.7	68.1	0.497	0.248
Eucalyptus occidentalis (windbreak)	78.9	26.7	4.7	8.4	39.8	0.505	0.252
Eucalyptus porosa (block)	50.3	8.6	6.1	8.6	23.3	0.464	0.232
Eucalyptus viminalis (block)	177.4	52.9	6.9	15.6	75.4	0.425	0.212

Table 6 – Summary of key plant attributes tested for developing allometric models of total green biomass and biomass fractions (mean values, n=3).

Species (plantation type)	Height [m]	Basal Area [cm²] at 0.5m height	Crown Area [m²]	Foliage Density [%]	Stemwood Volume x 1000 [m³]	Green Biomass [kg plant^{-1}]				
						Total	Wood & Bark	Twig & Bark	*Wood & Bark + Twig & Bark*	Leaf, Fine Twig & Bark
Acacia mearnsii (block)	9.9	180	9.7	57	82.4	128.2	99.9	15.6	115.5	11.5
Acacia pycnantha (block)	3.4	97	8.3	86	14.5	68.0	24.7	15.0	39.7	27.8
Allocasuarina verticillata (block)	9.6	484	19.1	38	173.9	344.6	275.8	24.7	300.5	41.8
Atriplex nummularia (block)	1.8	68#	4.8	86	6.3	19.7	5.7	6.1	11.7	7.8
Cor*ymbia maculata* (block)	8.0	114	7.8	52	32.0	50.9	36.7	6.2	42.9	7.2
Eucalyptus camaldulensis (windbreak)	11.2	450	19.1	57	172.4	232.6	181.7	21.4	203.1	26.9
Eucalyptus cladocalyx (block)	7.1	119	5.7	71	30.2	59.9	33.4	12.3	45.7	13.1
Eucalyptus cladocalyx (windbreak)	5.8	142	4.5	86	28.5	67.0	39.4	11.1	50.4	15.9
Eucalyptus diversifolia (mixed block)	5.5	209	15.6	66	51.6	175.5	70.5	69.0	139.5	35.2
Eucalyptus dumosa (block)	3.3	63	6.5	62	7.8	35.8	14.9	11.6	26.5	8.8
Eucalyptus globulus (block)	13.8	224	10.1	57	126.1	194.9	144.4	17.3	161.7	31.8
Eucalyptus incrassata (mixed block)	3.6	132	14.8	71	19.0	92.2	36.2	28.5	64.7	26.9
Eucalyptus leucoxylon (block)	9.7	172	6.6	43	61.1	81.4	64.9	6.1	71.0	9.5
Eucalyptus occidentalis (block)	10.0	238	8.7	57	95.9	137.1	101.3	11.9	113.2	23.2
Eucalyptus occidentalis (windbreak)	8.6	134	4.5	57	49.7	78.9	51.5	9.4	60.8	16.9
Eucalyptus porosa (block)	3.9	93	11.7	71	11.6	50.3	16.7	11.7	28.4	21.5
Eucalyptus viminalis (block)	11.1	313	12.6	52	129.9	177.4	129.3	14.8	144.1	31.7

(# basal area at 0.2m height)

Table 7 – Correlations between plant morphological measures and above ground green biomass (kg plant^{-1}), including allometric model parameter values (n=51).

Variable (y)	Predictor (x)	r^2	Allometric Model Parameters[#] Factor (a)	Intercept (c)
Total Green Biomass	Basal Area [cm²]	0.88	1.1317	-1.2327
	Height [m] x Crown Area [m²]	0.82	0.8256	1.1488
	Height [m] x Crown Area [m²] x Foliage Density [%]	0.81	0.9017	-2.8422
	Stemwood Volume x 1000 [m³]	0.83	0.6999	1.8843
	Stemwood Volume x 1000 [m³] x Foliage Density [%]	0.84	0.7542	-1.3849
Wood & Bark	Basal Area [cm²]	0.87	1.4543	-3.4290
	Stemwood Volume x 1000 [m³]	0.93	0.9583	0.3596
Twig & Bark	Basal Area [cm²]	0.33	0.5271	ns
	Stemwood Volume x 1000 [m³]	0.19	0.2703**	1.6536
Wood & Bark + Twig & Bark	Basal Area [cm²]	0.89	1.2601	-2.1480
	Stemwood Volume x 1000 [m³]	0.88	0.8002	1.2459
Leaf, Fine Twig & Bark	Foliage Density [%]	0.00	ns	ns
	Height [m] x Crown Area [m²]	0.45	0.4776	0.9828
	Height [m] x Crown Area [m²] x Foliage Density [%]	0.56	0.5860	-1.8473
	Stemwood Volume x 1000 [m³]	0.34	0.3538	1.5961
	Stemwood Volume x 1000 [m³] x Foliage Density [%]	0.42	0.3195	ns
	Basal Area [cm²]	0.50	0.5779	ns
	Basal Area [cm²] x Foliage Density [%]	0.42	0.3747	ns

(# at p<0.001 significance levels unless indicated: * p<0.05; ** p<0.01; ns=not significant)

Table 8 – Correlations between plant morphological measures and above ground green biomass (kg plant^{-1}) and the influence of lifeform categories (n=51).

Variable (*y*)	**Predictor (*x*)$^{\#}$**	**Initial $r^{2\#}$**	**Lifeform Group (2 class) $r^{2\#}$**	**Lifeform Sub-group (4 class) $r^{2\#}$**
Total Green Biomass	Basal Area [cm²]	0.88***	0.88^{ns}	0.90*
	Height [m] x Crown Area [m²]	0.82***	0.82^{ns}	0.83^{ns}
	Height [m] x Crown Area [m²] x Foliage Density [%]	0.81***	0.82^{ns}	0.84*
	Stemwood Volume x 1000 [m³]	0.83***	0.92***	0.93***
	Stemwood Volume x 1000 [m³] x Foliage Density [%]	0.84***	0.79^{ns}	0.86***
Wood & Bark	Basal Area [cm²]	0.87***	0.90**	0.92***
	Stemwood Volume x 1000 [m³]	0.93***	0.94*	0.95**
Twig & Bark	Basal Area [cm²]	0.33***	0.67***	0.72***
	Stemwood Volume x 1000 [m³]	0.19**	0.68***	0.71***
Wood & Bark + Twig & Bark	Basal Area [cm²]	0.89***	0.89^{ns}	0.91**
	Stemwood Volume x 1000 [m³]	0.88***	0.94***	0.95***
Leaf, Fine Twig & Bark	Height [m] x Crown Area [m²]	0.45***	0.57***	0.60**
	Height [m] x Crown Area [m²] x Foliage Density [%]	0.56***	0.65**	0.66**
	Basal Area [cm²]	0.50***	0.68***	0.69***
	Basal Area [cm²] x Foliage Density [%]	0.42***	0.73***	0.74***
	Stemwood Volume x 1000 [m³]	0.34***	0.66***	0.68***
	Stemwood Volume x 1000 [m³] x Foliage Density [%]	0.42***	0.70***	0.71***

(# correlation coefficients & significance levels: * p<0.05; ** p<0.01; *** p<0.001. ns=not significant; Lifeform Groups= Tree [n=33], Mallee+Shrub [n=18]; Lifeform Sub-groups = Tree Eucalypts [n=27], Tree Non-Eucalypts [n=6], Mallee Eucalypts [n=12], Shrub Non-Eucalypts [n=6])

Table 9 – Selection of highly ranked allometric models to predict and above ground green biomass (kg plant^{-1}) from plant morphological measurements and lifeform observations (Upper South East sites).

Variable (*y*)	Lifeform Group x Stemwood Volume x 1000 [m^3] Predictor (*x*)	n	r^2	Allometric Model Parameters[#]	
				Factor (*a*)	Intercept (*c*)
Total Green Biomass	Total	51	0.92	-	-
	Tree	33	0.93	0.8955	0.9197
	Mallee/Shrub	18	0.88	1.0290	1.2590
Wood & Bark	Total	51	0.94	-	-
	Tree	33	0.96	1.0312	ns
	Mallee/Shrub	18	0.84	1.1252	ns
Twig & Bark	Total	51	0.68	-	-
	Tree	33	0.55	0.5997	ns
	Mallee/Shrub	18	0.90	1.0642	ns
Wood & Bark + Twig & Bark	Total	51	0.94	-	-
	Tree	33	0.94	0.9447	0.5197
	Mallee/Shrub	18	0.89	1.1101	0.6324
Leaf, Fine Twig & Bark	Total	51	0.66	-	-
	Tree	33	0.63	0.6439	0.1746
	Mallee/Shrub	18	0.71	0.7985	0.7674

(# at $p<0.001$ significance levels unless indicated: * $p<0.05$; ** $p<0.01$; ns=not significant)

Figure 4 – Relationships between total green biomass and plant height by crown area by foliage density for species groups and lifeforms.

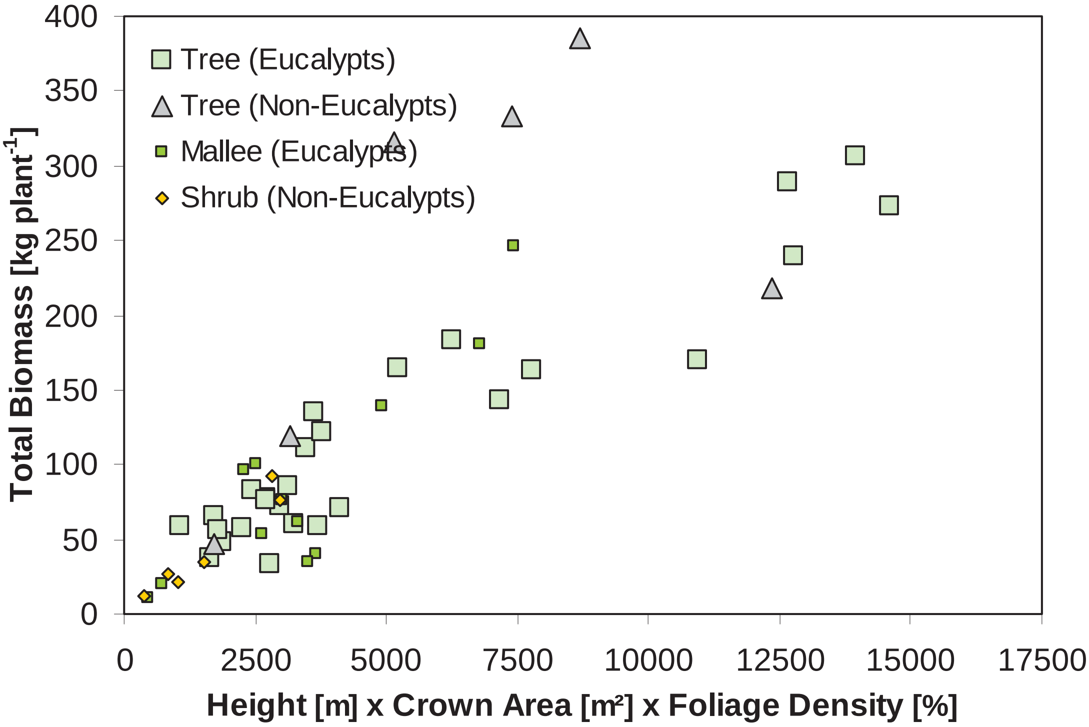


Figure 5 – Relationships between total green biomass and plant basal area for species groups and lifeforms.

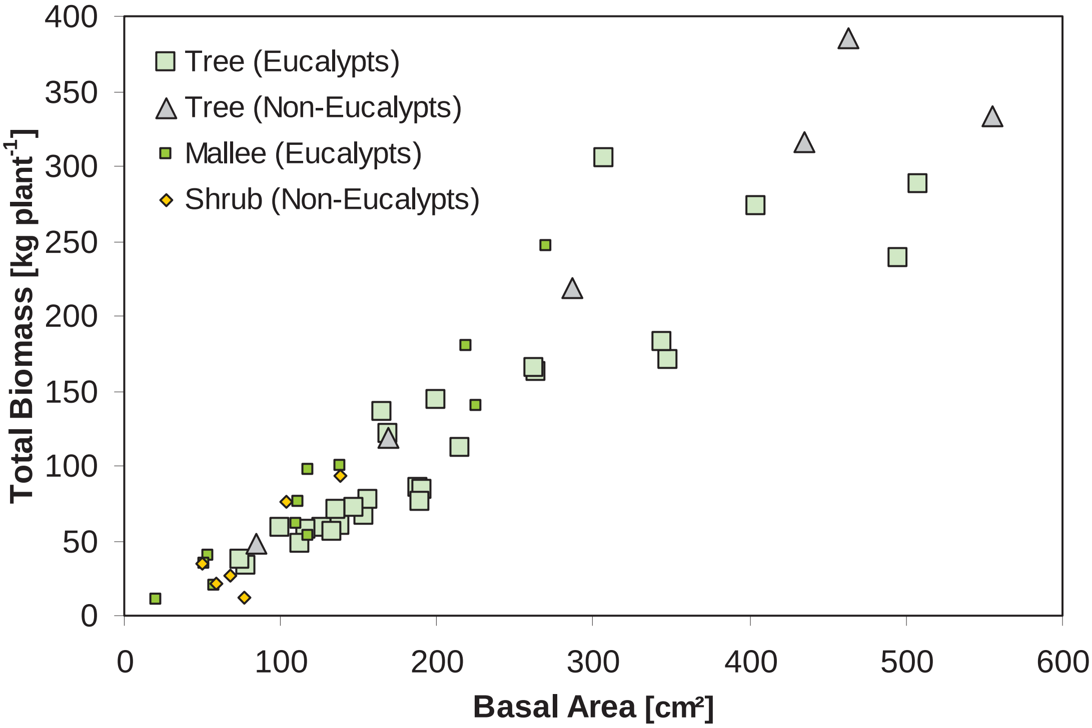


Figure 6 – Relationships between total green biomass and stemwood volume for species groups and lifeforms.

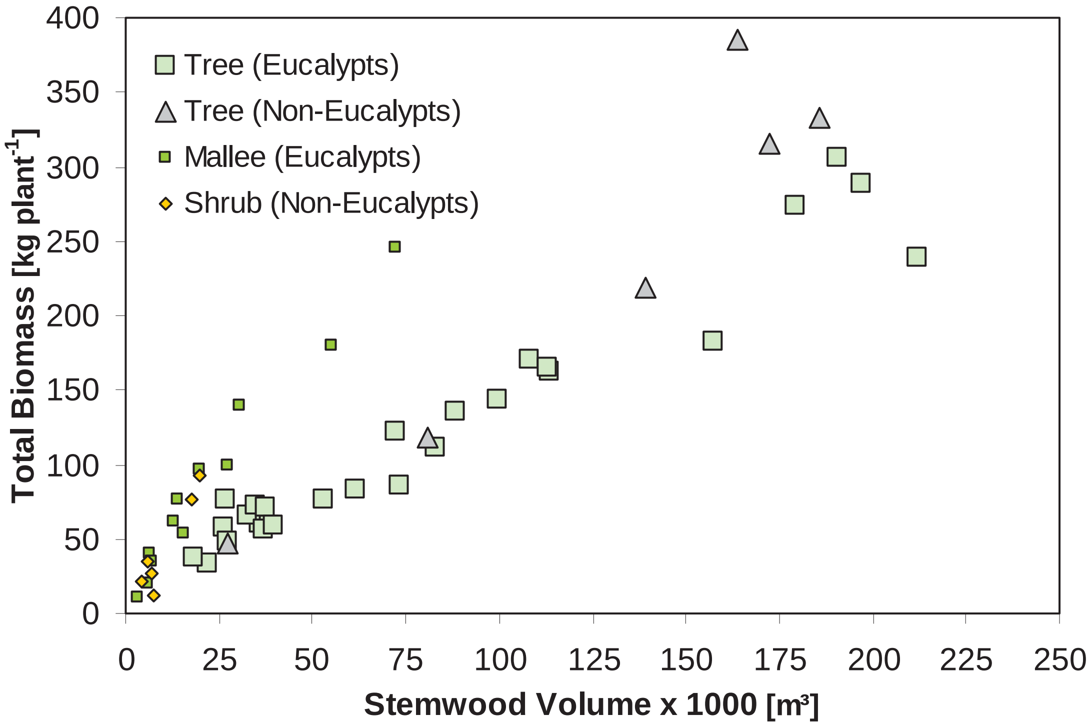


Figure 7 – Relationships between wood and bark green biomass fraction, and stemwood volume for species groups and lifeforms.

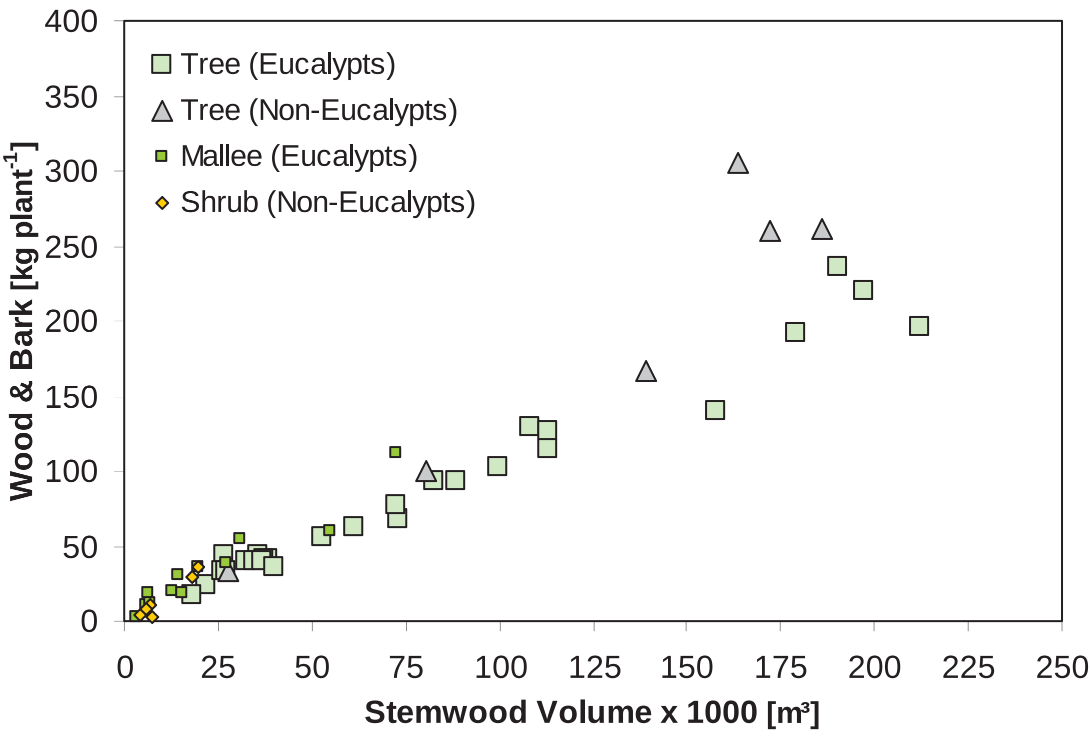


Figure 8 – Relationships between twig and bark green biomass fraction, and stemwood volume for species groups and lifeforms.

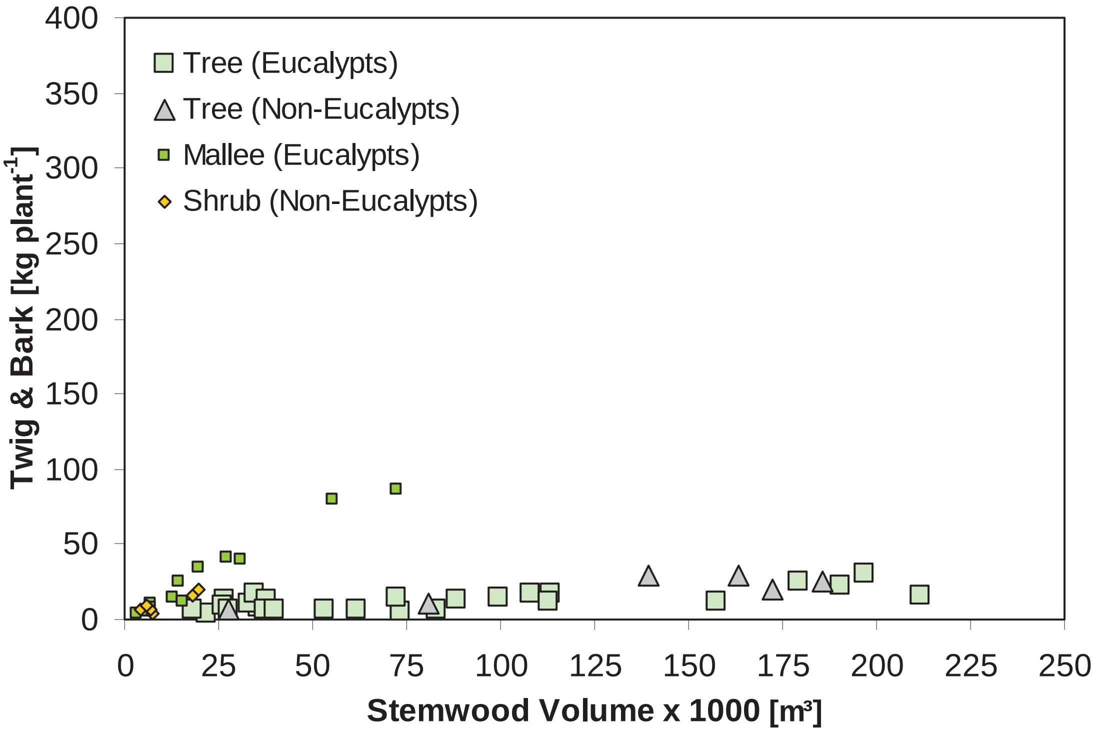


Figure 9 – Relationships between wood and bark plus twig and bark green biomass fraction, and stemwood volume for species groups and lifeforms.

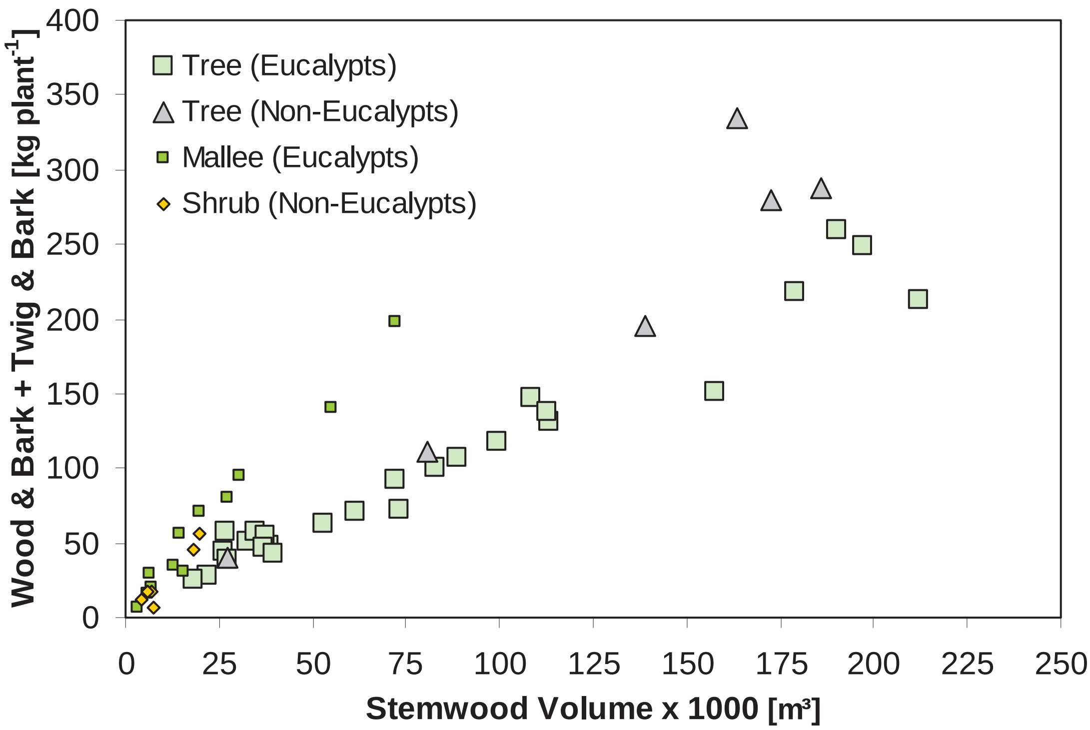


Figure 10 – Relationships between leaf, fine twig and bark green biomass fraction, and stemwood volume for species groups and lifeforms.

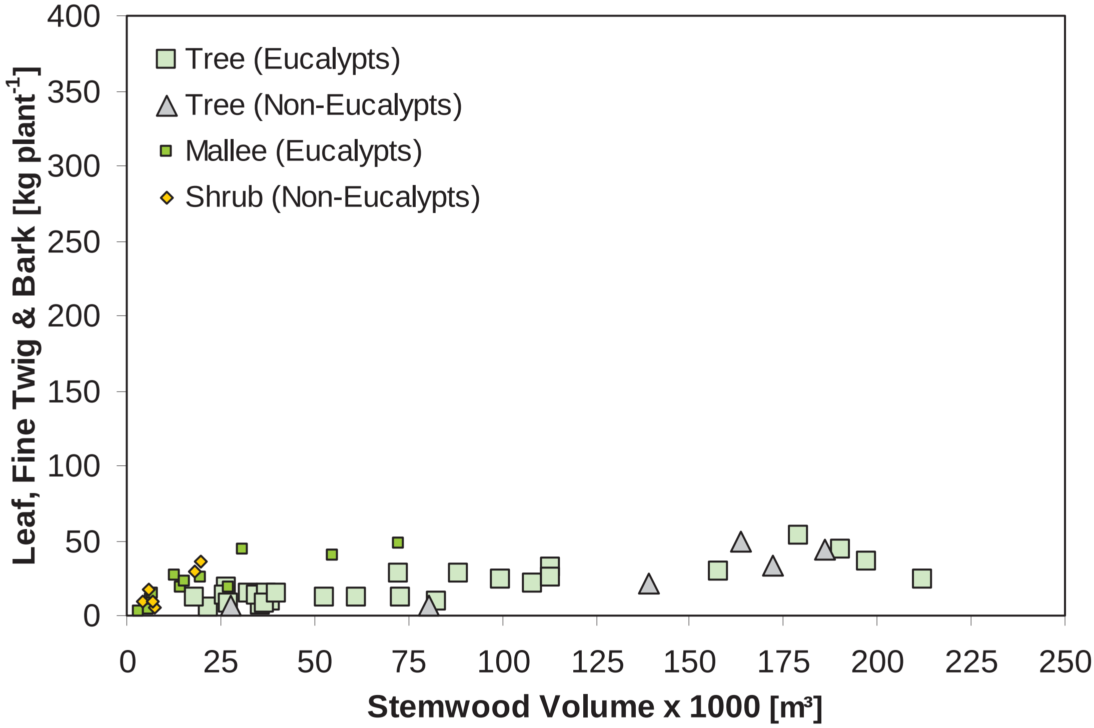


Figure 11 – Relationships between leaf, fine twig and bark green biomass fraction, and stemwood volume by foliage density for species groups and lifeforms.

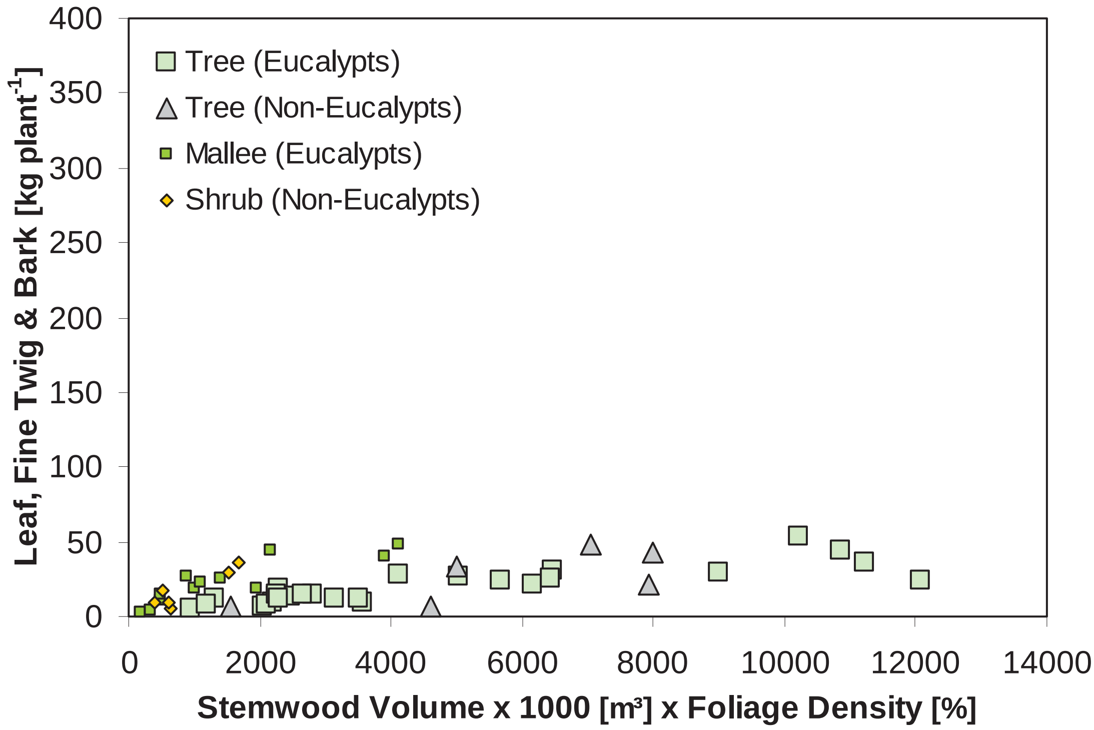


Figure 12 – Relationships between leaf, fine twig and bark green biomass fraction, and plant height by crown area by foliage density for species groups and lifeforms.

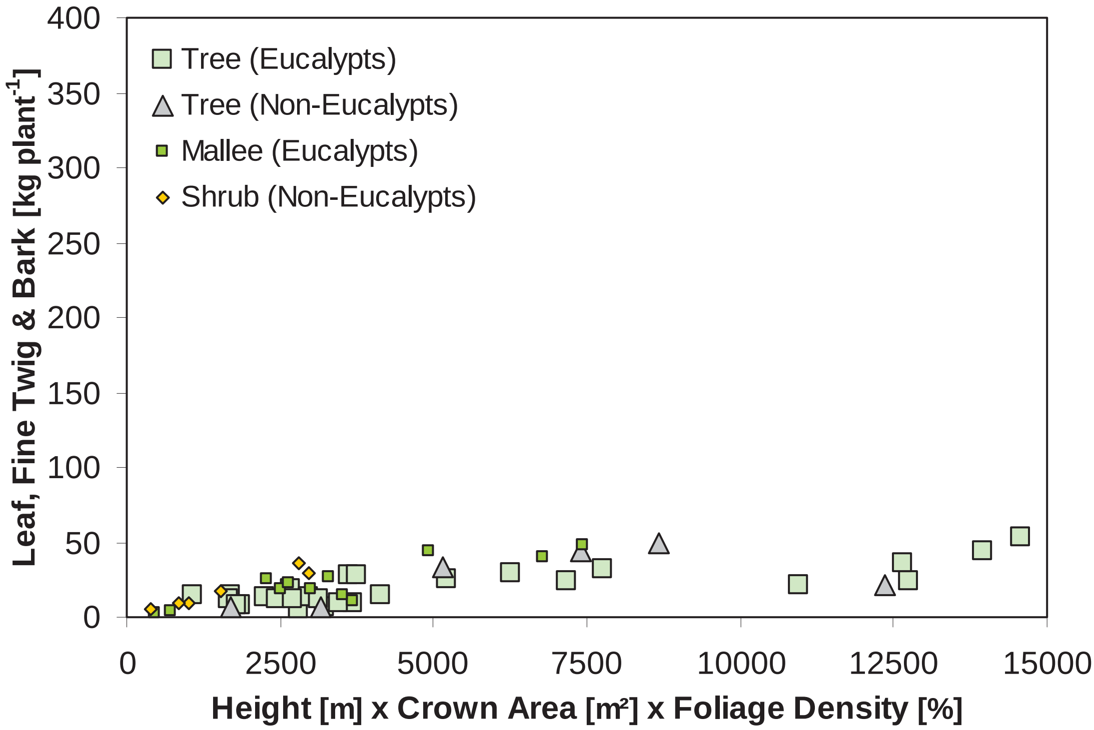


Table 10 – Mean percent difference and mean trend (+ overestimate, - underestimate) of predicted plant biomass from allometric models and observed plant biomass.

	Green Wood & Bark + Twig & Bark Biomass [kg plant-1]						Total Dry Biomass [kg plant-1]					
	Kiddle *et al.* 1987		Hobbs & Bennell 2005		Hobbs *et al.* 2007		Snowdon *et al.* 2000		Hobbs & Bennell 2005		Hobbs *et al.* 2007	
Lifeforms	Diff. [%]	Trend [%]	Diff. [%]	Trend [%]	Diff. [%]	Trend [%]	Diff. [%]	Trend [%]	Diff. [%]	Trend [%]	Diff. [%]	Trend [%]
All (n=51)	35	+18	27	-12	17	+2	56	+38	32	-3	18	+3
Trees (n=33)	26	+18	14	+4	13	0	65	+65	23	+19	14	+2
Mallees (n=12)	38	-11	50	-50	18	-7	24	+16	46	-46	20	-2
Shrubs (n=6)	81	+71	49	-26	36	+29	69	-69	49	-33	38	+18

Table 11 – Combined biomass studies (Upper South East and Murray Corridor) selection of highly ranked allometric models to predict the above ground green biomass (kg plant^{-1}) from plant morphological measurements and lifeform/species observations.

Variable (*y*)	Predictor (*x*)	n	r²	Allometric Model Parameters#	
				Factor (*a*)	Intercept (*c*)
Total Green Biomass	**Stemwood Volume x 1000 [m³]**	104	0.86	0.8460	1.2475
	By Lifeform Group	104	0.90	-	-
	Tree (Eucalypt)	27	0.94	0.8276	1.1711
	Tree (Non-Eucalypt)	9	0.97	1.1120	ns
	Mallee (Eucalypt)	36	0.83	0.8704	1.4332
	Shrub (Non-Eucalypt)	32	0.79	1.3086	ns
Wood & Bark	**Stemwood Volume x 1000 [m³]**	104	0.86	1.2106	-0.8178
	By Lifeform Group	104	0.90	-	-
	Tree (Eucalypt)	27	0.97	0.9419	0.3344*
	Tree (Non-Eucalypt)	9	0.96	1.0460	ns
	Mallee (Eucalypt)	36	0.86	1.0192	ns
	Shrub (Non-Eucalypt)	32	0.53	1.1258	-0.9761*
Twig & Bark	**Stemwood Volume x 1000 [m³]**	104	0.39	0.3757	1.3111
	By Lifeform Group	104	0.67	-	-
	Tree (Eucalypt)	27	0.46	0.5921	ns
	Tree (Non-Eucalypt)	9	0.74	0.6417**	ns
	Mallee (Eucalypt)	36	0.66	0.7503	0.5578*
	Shrub (Non-Eucalypt)	32	0.81	0.9689	ns
Wood & Bark + Twig & Bark	**Stemwood Volume x 1000 [m³]**	104	0.90	0.9475	0.5816
	By Lifeform Group	104	0.92	-	-
	Tree (Eucalypt)	27	0.95	0.8743	0.7717
	Tree (Non-Eucalypt)	9	0.97	1.0799	ns
	Mallee (Eucalypt)	36	0.85	0.9946	0.6464**
	Shrub (Non-Eucalypt)	32	0.78	1.1427	ns
Leaf, Fine Twig & Bark	**Stemwood Volume x 1000 [m³]**	104	0.53	0.4993	1.0384
	By Lifeform Group	104	0.71	-	-
	Tree (Eucalypt)	27	0.63	0.6903	ns
	Tree (Non-Eucalypt)	9	0.77	0.6604**	ns
	Mallee (Eucalypt)	36	0.64	0.6174	1.0856
	Shrub (Non-Eucalypt)	32	0.70	0.9070	ns

(# at $p<0.001$ significance levels unless indicated: * $p<0.05$; ** $p<0.01$; ns=not significant)

2.3 Plantation Productivity

To bolster existing trial site information from PIRSA and Forestry SA, and to provide information on species not grown in PIRSA/Forestry SA trials, FloraSearch targeted 35 new plantations in the region. These surveys represented 19 species (see Table 12), with multiple measurements (either by provenance, location, planting design or combined) for Swamp Yate (*Eucalyptus occidentalis*), Sugargum (*E. cladocalyx*), Tasmanian Bluegum (*E. globulus*), River Redgum (*E. camaldulensis*), Rough-barked Manna Gum (*E. viminalis ssp. cygnetensis*), Spotted Gum (*Corymbia maculata*), and Ridge-fruited Mallee (*E. incrassata*). The height, crown width, stem count and circumferences at basal and intermediate heights, leaf density and plant spacing were measured for typically 30 individuals for most species and sites. Additional data from the biometrics study (3 to 6 plants) were also included in this dataset.

All PIRSA, Forestry SA and FloraSearch trial site and survey productivity data was combined from sites within, and immediately neighbouring, the Upper South East (USE) region. Conversion of this data to stemwood productivity rates and application of allometric relationships were used to determine estimates of total plant productivity and yields of biomass components and totals for each species and site. Observed and estimated plant biomass productivity values for each species and location from the biometrics and productivity studies were standardised to an annual biomass accumulation rate to account for the different ages of the plant studied. The average annual rainfall for each sampled locality was extracted from spatial coverages of annual rainfall (CSIRO Land & Water 2001) using ArcGIS (ESRI 2005). Observed and modelled annual biomass accumulation rates for each species and locality was then standardised to an annual rainfall of 500mm using a simple linear relationship to permit a simple comparison of each species' relative biomass productivity. Summaries of the FloraSearch productivity surveys and observations are presented in Table 12 and Table 13.

Productivity data from the top 10% best performing plots for each species and trial/survey site location were extracted from the combined productivity dataset. These selections were aimed at identifying the best performing plant species, provenances and genetic choices suited to the local soil and climatic conditions and excluded plant germplasm that was either poorly suited to that site or plots which had suffered from poor management or a significant environmental event. Appendix A contains summaries of plot and survey data from the 74 sites, 46 species, and 1,731 plots determined from measurement on over 13,872 individual plants.

From the array of species contained within this combined productivity dataset FloraSearch has previously identified which species are suitable for each biomass industry class based on product testing results and published literature (Hobbs *et al.* 2007). The four major *Biomass Industry* product groups and species suited to the Upper South East region are listed in Table 14. We have created bioclimatic distribution models for these species from climatic GIS data and natural and plantation location data; these are presented in Figure 13. A fifth group (*Habitat Species*) comprises native species which naturally occur within a given region. Fifteen species were selected to represent different lifeforms which are both productive and common to the region. These *USE Habitat Species* include Black Wattle (*Acacia mearnsii*), Blackwood (*Ac. melanoxylon*), Golden Wattle (*Ac. pycnantha*), Drooping Sheoak (*Allocasuarina verticillata*), River Redgum (*Eucalyptus camaldulensis*), Coastal White Mallee (*E. diversifolia*), White

Mallee (*E. dumosa*), Pink or Hill Gum (*E. fasciculosa*), Ridge-fruited Mallee (*E. incrassata*), SA Bluegum (*E. leucoxylon*), Peppermint Box (*E. odorata*), Red Morrell Mallee (*E. oleosa*), Swamp Gum (*E. ovata*), SA Mallee Box (*E. porosa*), Red Mallee (*E. socialis*) and Rough-barked Manna Gum (*E. viminalis ssp. cygnetensis*). Productivity data for species within each of these five "*Biomass Industry Groups*" was extracted from the "*Top 10% Species Plots*" productivity dataset.

For developing productivity models the productivity of plots planted at a density of greater than 1000 trees or plants per hectare (tph) were proportionally reduced to the equivalent of 1000tph so not to bias per hectare productivity rates (1500tph rate for saltbush fodder species). The productivity of plots with less than 1000tph were not increased proportionally to their plant density. These rules were designed to create conservation models and estimates of plantation productivity.

Increased productivity rates per hectare could be expected for many, if not all, species observed in our study using higher planting densities. For species and plots with a crown area of less than $10m^2$ it is likely that higher planting densities than 1000tph are possible. An indicative optimum planting rate per hectare for each species may be deduced from dividing the hectare area (i.e. $10,000m^2$) by the crown area of the species. This 'crown' density of plants per hectare may be appropriate for short-cycle plantings but the optimum density to maximise biomass productivity per hectare will depend on the degree of plant competition for light, water and other nutrients.

Planting at rates higher than the 'crown' density rate may potentially increase productivity per hectare, however, this can only be accurately determined from more detailed trials and research. Where the observed planting density is lower than the calculated 'crown' density for a plantation it is likely that the productivity per hectare can be increased by planting at a higher rate than the observed rate. The 'crown' density data suggests that the minimum planting density for the short cycle biomass crops in the region is 1200 plants per hectare for trees and mallees and 1800 plants per hectare for saltbush fodder. A range of factors, including species selection, rainfall, topography, water table depth, soil types and fertility and crop management will influence the optimal planting rate in each paddock.

Table 12 – Surveyed growth observations, stemwood volumes and biomass productivity of plant species in the Upper South East region.

Species #	Annual Rainfall [mm]	Age [years]	Observations	Height [m]	Basal Area [cm²]	Crown Area [m²]	Foliage Density [%]	Stemwood Volume x 1000 [m³ plant⁻¹]	Total Green Biomass [kg plant⁻¹]
Acacia mearnsii	492	12.5	32	9.89	186	10.56	57	80.48	136.99
Acacia pycnantha	387	7.0	3	3.37	97	8.32	86	14.47	68.03
Allocasuarina verticillata	492	10.9	30	8.58	477	28.43	38	195.37	365.29
Atriplex nummularia (ungrazed)	466	3.0	30	1.62	76	5.45	86	5.60	11.72
Corymbia maculata	492	10.8	25	9.01	273	9.68	52	99.40	134.84
Corymbia maculata	492	6.9	28	10.23	224	6.85	57	86.93	127.55
Eucalyptus camaldulensis	362	7.6	30	5.70	156	7.45	57	30.92	54.19
Eucalyptus camaldulensis	492	9.9	30	8.20	165	4.19	43	45.37	73.78
Eucalyptus camaldulensis [windbreak]	376	7.7	30	9.64	206	6.35	43	73.33	108.21
Eucalyptus camaldulensis [windbreak]	460	10.7	33	11.39	565	17.78	57	222.40	275.93
Eucalyptus cladocalyx [1]	460	10.7	30	14.92	520	22.02	57	327.72	382.40
Eucalyptus cladocalyx [2]	460	6.7	33	5.63	103	5.84	71	23.87	43.83
Eucalyptus cladocalyx [windbreak 1]	460	6.7	30	4.97	148	4.08	86	28.54	52.26
Eucalyptus cladocalyx [windbreak 2]	460	6.7	30	6.39	145	5.22	86	34.12	59.24
Eucalyptus diversifolia	460	12.7	3	5.50	209	15.58	66	51.55	175.49
Eucalyptus dumosa	387	12.0	31	3.80	74	8.14	62	12.83	39.75
Eucalyptus globulus	460	10.7	33	12.53	238	9.32	57	131.71	176.20
Eucalyptus globulus	492	6.8	30	11.13	250	7.21	57	100.30	144.45
Eucalyptus globulus ssp. globulus [1]	606	4.9	12	18.00	280	12.96	57	210.89	268.87
Eucalyptus globulus ssp. globulus [2]	606	4.9	12	19.20	267	9.91	57	212.12	270.63
Eucalyptus gomphocephala [windbreak]	460	12.0	6	12.35	1493	24.99	74	730.19	727.52
Eucalyptus grandis	492	6.8	30	10.57	236	8.65	57	90.41	133.11
Eucalyptus incrassata	374	8.0	30	3.73	95	6.13	71	13.41	41.35
Eucalyptus incrassata	460	12.7	3	3.55	132	14.79	71	18.97	92.23
Eucalyptus leucoxylon	492	10.7	33	8.60	233	7.65	43	72.43	107.66
Eucalyptus occidentalis	460	5.7	34	9.75	274	9.10	57	109.12	155.19
Eucalyptus occidentalis	492	9.9	30	10.46	207	6.30	57	89.50	129.83
Eucalyptus occidentalis [windbreak 1]	460	6.7	32	8.15	142	4.80	57	48.95	79.66
Eucalyptus occidentalis [windbreak 2]	460	6.7	30	10.23	191	5.28	57	89.15	129.96
Eucalyptus occidentalis [windbreak 3]	460	6.5	6	12.12	235	6.83	57	123.03	171.87
Eucalyptus oleosa	387	6.8	30	2.97	63	6.59	86	9.21	30.14
Eucalyptus porosa	387	6.7	33	3.86	134	12.85	71	23.02	65.60
Eucalyptus saligna	492	6.8	30	9.09	193	8.77	43	68.46	105.46
Eucalyptus viminalis	460	5.7	33	9.95	312	10.68	52	117.50	161.21
Eucalyptus viminalis ssp. cygnetensis	492	9.9	30	11.13	368	11.32	43	148.40	200.64

observations from block plantings except where indicated [windbreak], numbers represent repeated samples at a site.

Table 13 – Observed mean annual increments (MAI) of stemwood volume, total green biomass and carbon dioxide sequestration equivalents, and rainfall-standardised values in the Upper South East region.

Species #	Annual Rainfall [mm]	Age [years]	Observed Plant Density [plants ha^{-1}]	MAI Stemwood Volume [m³ ha^{-1} yr^{-1}]	Green Biomass [t ha^{-1} yr^{-1}]	CO_2 Sequestration equiv. [t ha^{-1} yr^{-1}]	MAI Stemwood Volume @ 500mm rainfall [m³ ha^{-1} yr^{-1}]	Green Biomass @ 500mm rainfall [t ha^{-1} yr^{-1}]	CO_2 Sequestration equiv. @ 500mm rainfall [t ha^{-1} yr^{-1}]
Acacia mearnsii	492	12.5	3017	19.41	33.04	34.96	19.73	33.58	35.53
Acacia pycnantha	387	7.0	528	1.09	5.14	4.83	1.41	6.64	6.24
Allocasuarina verticillata	492	10.9	395	7.10	13.27	14.28	7.21	13.48	14.51
Atriplex nummularia (ungrazed)	466	3.0	966	1.83	3.83	2.71	1.96	4.11	2.91
Corymbia maculata	492	10.8	432	3.99	5.41	4.61	4.05	5.50	4.69
Corymbia maculata	492	6.9	685	8.69	12.75	10.86	8.83	12.96	11.04
Eucalyptus camaldulensis	362	7.6	142	0.58	1.02	0.74	0.80	1.40	1.02
Eucalyptus camaldulensis	492	9.9	1103	5.07	8.24	6.01	5.15	8.37	6.10
Eucalyptus camaldulensis [windbreak]	376	7.7	1027	9.78	14.43	10.52	13.01	19.19	13.99
Eucalyptus camaldulensis [windbreak]	460	10.7	793	16.42	20.37	14.85	17.85	22.14	16.14
Eucalyptus cladocalyx [1]	460	6.7	793	2.82	5.18	4.90	3.07	5.63	5.32
Eucalyptus cladocalyx [2]	460	10.7	440	13.44	15.69	14.58	14.61	17.05	15.85
Eucalyptus cladocalyx [windbreak 1]	460	6.7	939	4.00	7.33	6.70	4.35	7.97	7.28
Eucalyptus cladocalyx [windbreak 2]	460	6.7	1024	5.22	9.06	8.42	5.67	9.85	9.15
Eucalyptus diversifolia	460	12.7	1279	5.17	17.60	16.82	5.62	19.13	18.29
Eucalyptus dumosa	387	12.0	836	0.90	2.78	2.93	1.16	3.59	3.79
Eucalyptus globulus	460	10.7	898	11.01	14.73	12.53	11.97	16.01	13.62
Eucalyptus globulus	492	6.8	1010	14.79	21.30	18.12	15.03	21.64	18.41
Eucalyptus globulus ssp. globulus [1]	606	4.9	1143	48.91	62.35	53.05	40.35	51.44	43.77
Eucalyptus globulus ssp. globulus [2]	606	4.9	1136	48.89	62.38	53.07	40.34	51.47	43.79
Eucalyptus gomphocephala [windbreak]	460	12.0	500	30.42	30.31	27.21	33.07	32.95	29.58
Eucalyptus grandis	492	6.8	945	12.47	18.37	16.49	12.68	18.66	16.76
Eucalyptus incrassata	374	8.0	1120	1.89	5.81	5.82	2.52	7.77	7.78
Eucalyptus incrassata	460	12.7	712	1.06	5.16	5.16	1.15	5.60	5.61
Eucalyptus leucoxylon	492	10.7	1088	7.34	10.91	10.53	7.46	11.09	10.71
Eucalyptus occidentalis	460	5.7	708	13.54	19.26	17.34	14.72	20.93	18.85
Eucalyptus occidentalis	492	9.9	1198	10.85	15.74	14.42	11.03	16.00	14.66
Eucalyptus occidentalis [windbreak 1]	460	6.7	828	6.06	9.86	9.18	6.58	10.71	9.98
Eucalyptus occidentalis [windbreak 2]	460	6.7	1133	15.10	22.01	20.16	16.41	23.93	21.92
Eucalyptus occidentalis [windbreak 3]	460	6.5	1111	21.03	29.38	26.91	22.86	31.93	29.25
Eucalyptus oleosa	387	6.8	1585	2.15	7.04	7.99	2.78	9.10	10.33
Eucalyptus porosa	387	6.7	1522	5.23	14.89	12.88	6.75	19.24	16.64
Eucalyptus saligna	492	6.8	880	8.80	13.56	12.17	8.94	13.78	12.37
Eucalyptus viminalis	460	5.7	526	10.82	14.85	11.72	11.77	16.14	12.74
Eucalyptus viminalis ssp. cygnetensis	492	9.9	855	12.85	17.37	13.71	13.06	17.65	13.93

observations from block plantings except where indicated [windbreak], numbers represent repeated samples at a site.

Table 14 – Species suited to the four major biomass industry classes and climatic zones of the Upper South East region.

Species	Common Name	Biomass Industry Group			
		Pulp-wood	Bio-energy	Oil Mallee	Fodder
Acacia mearnsii	Black Wattle	✓	✓		
Acacia retinodes	Wirilda or Swamp Wattle	✓	✓		
Atriplex nummularia	Oldman Saltbush				✓
Eucalyptus aromaphloia	Scent Bark	✓	✓		
Eucalyptus camaldulensis	River Redgum		✓		
Eucalyptus cladocalyx	Sugargum		✓		
Eucalyptus globulus	Tasmanian Bluegum	✓	✓		
Eucalyptus gomphocephala	Tuart		✓		
Eucalyptus horistes	WA Oil Mallee			✓	
Eucalyptus leucoxylon	SA Bluegum		✓		
Eucalyptus occidentalis	Swamp Yate	✓	✓		
Eucalyptus odorata	Peppermint Box			✓	
Eucalyptus oleosa	Red Morrell Mallee			✓	
Eucalyptus ovata	Swamp Gum	✓	✓		
Eucalyptus petiolaris	Eyre Peninsula Bluegum	✓	✓		
Eucalyptus polybractea	Blue Mallee	✓		✓	
Eucalyptus porosa	SA Mallee Box	✓		✓	
Eucalyptus viminalis ssp. cygnetensis	Rough-barked Manna Gum	✓	✓		

Figure 13 – Climatic suitability map of biomass industry species for the Upper South East region.

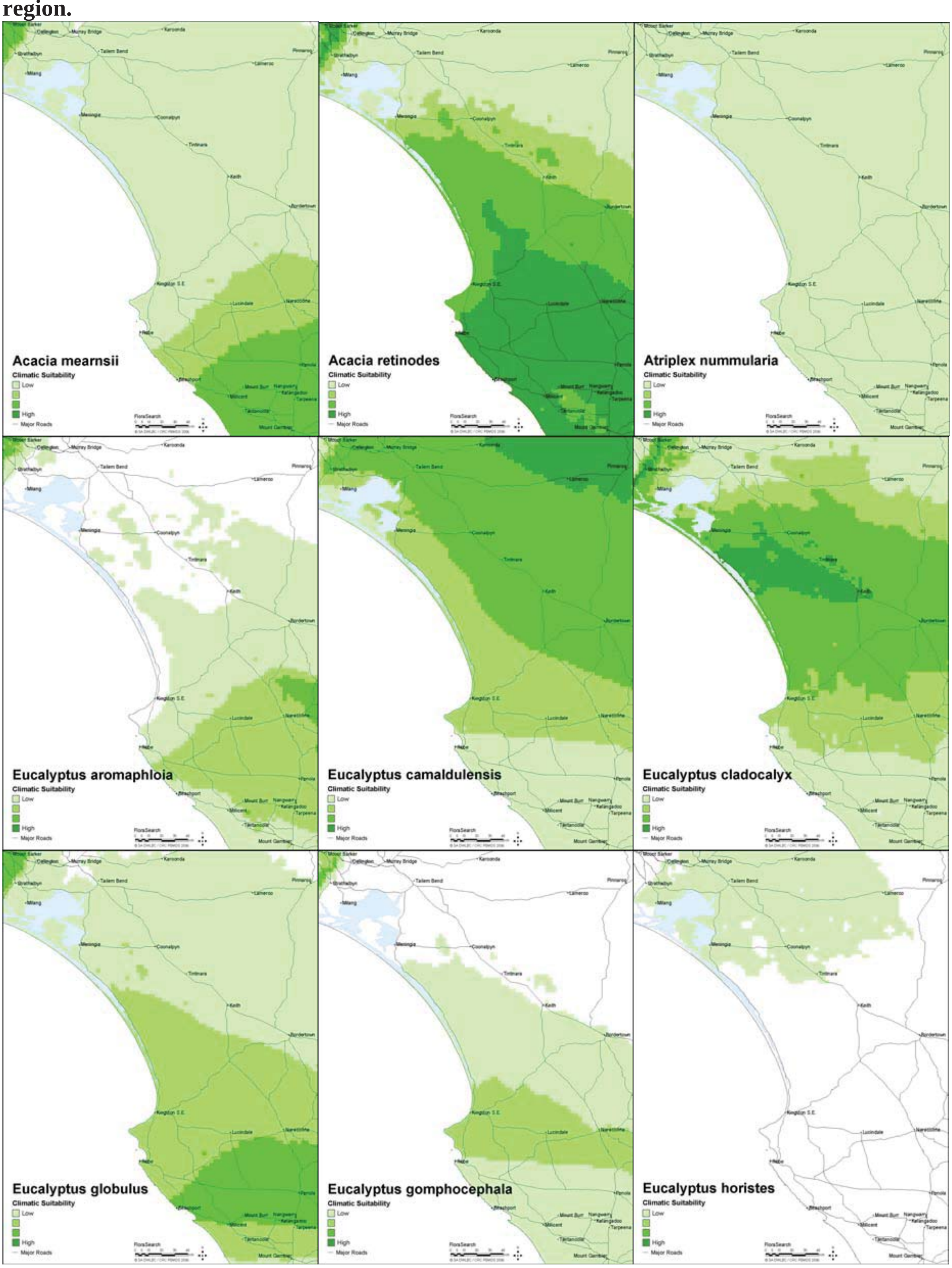


Figure 13 (continued)

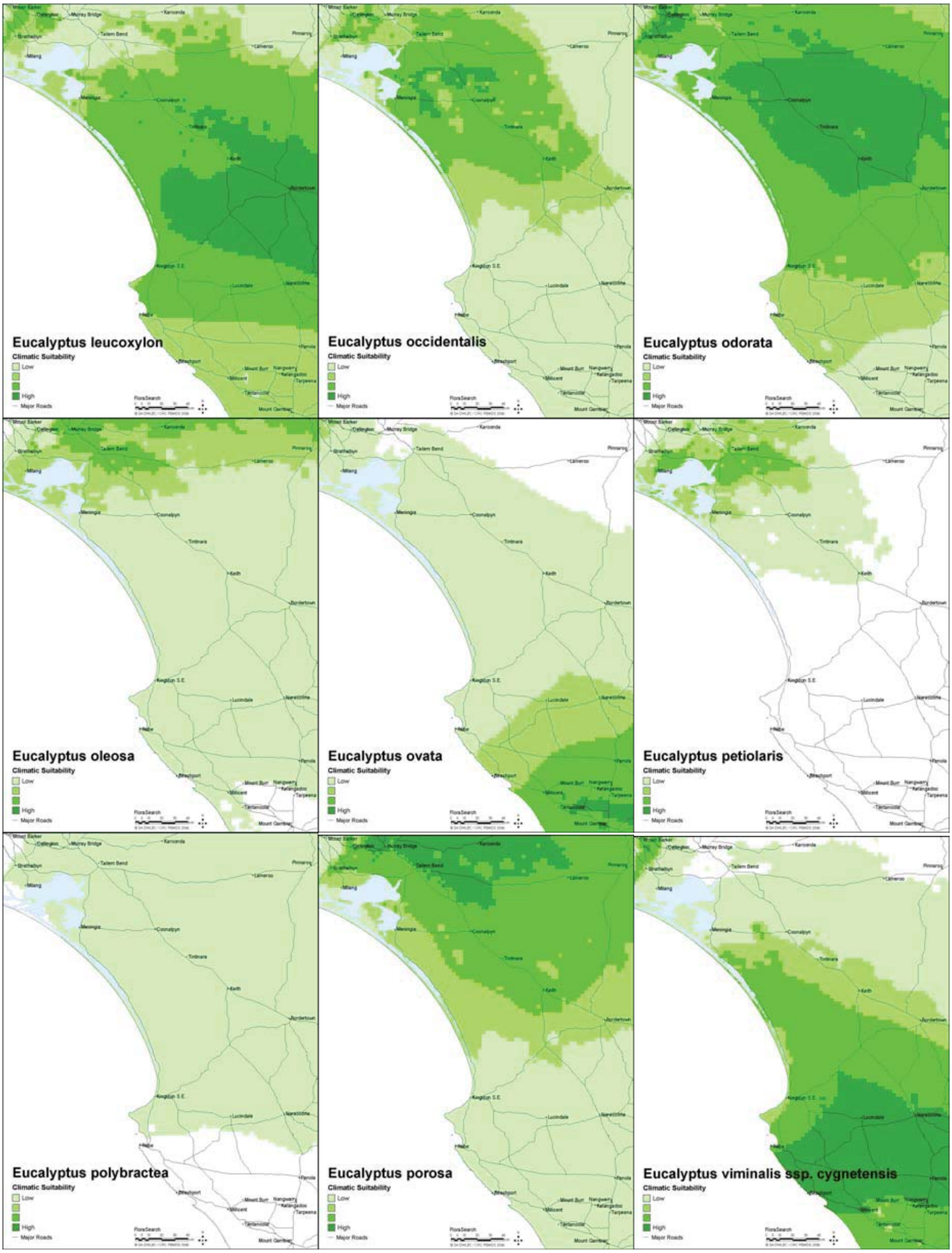
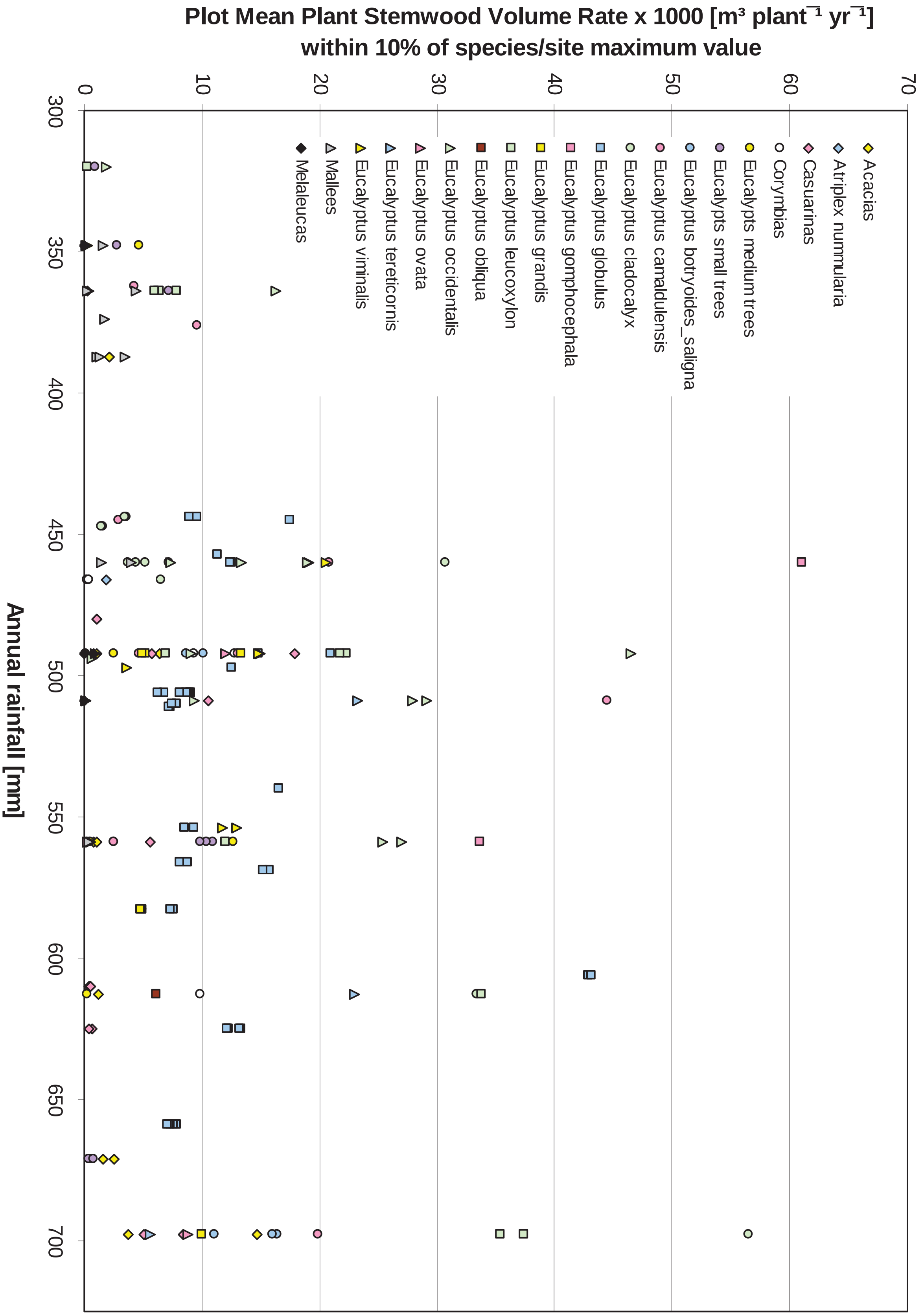


Figure 14 – Plot average annual plant stemwood production rates by annual rainfall for sites and species observations within 10% of each species by site maximum value.

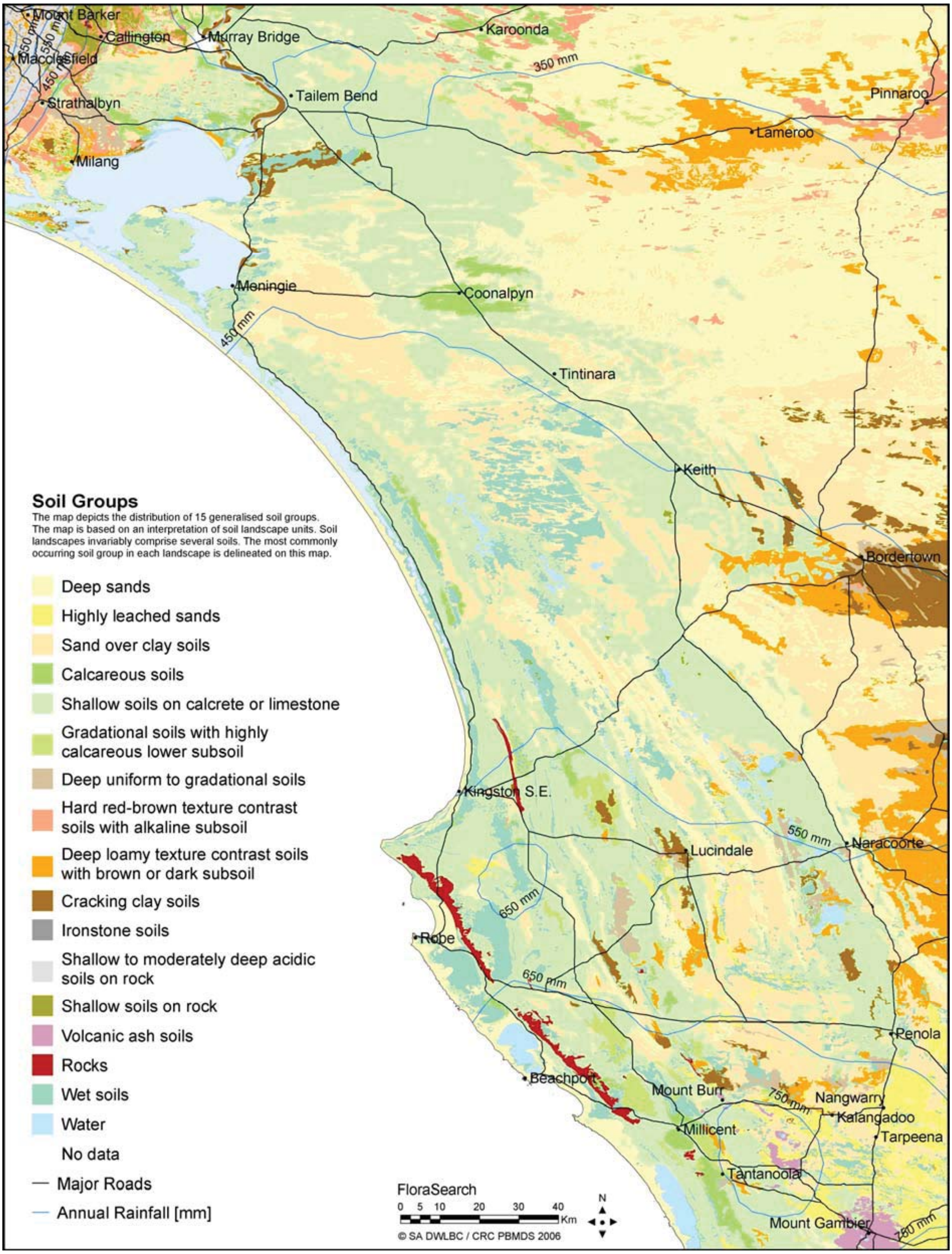


2.4 Regional Productivity

The development of regional productivity models has been focussed on each of the *Biomass Industry Group* of species (ie. *Pulpwood Species*, *Bioenergy Species*, *Oil Mallee Species*, *Saltbush Fodder Species* & *Habitat Species*). The models have been based on relationships between our observations of plantation productivity in the region and soil-climate models. Raupach *et al.* (2001) developed the "*BiosEquil Model*" and created a national productivity surface coverage suitable for computer-based Geographic Information Systems (GIS). The *BiosEquil Model* coverage provides coarse resolution (~1km²) data for Australia. The high quality of soil mapping in South Australia (SA DWLBC Soil and Land Program 2006, Figure 15) allows us to spatially refine the *BiosEquil Model* to a resolution less than one hectare (ie.100x100metres resolution). Relationships between BiosEquil Model data and SA maps of inherent fertility in the Upper South East (USE) region (see Figure 16) and average annual rainfall were identified. From these relationships and high quality soil and rainfall maps we have created a high resolution (1 ha scale) equivalent of the *BiosEquil Model*, which we will refer to as the "*USE Productivity Index*" GIS coverage.

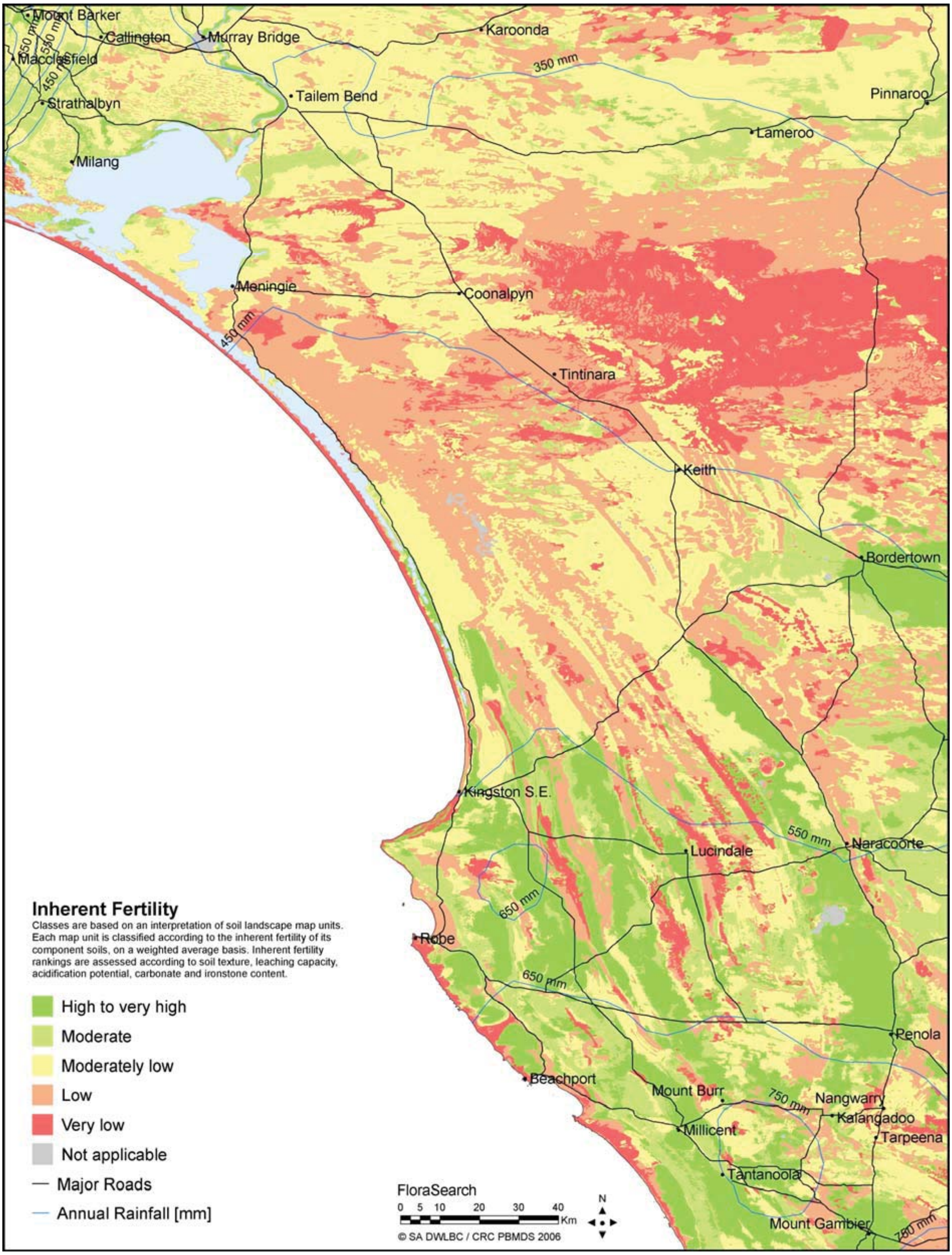
ArcGIS software was used to extract the corresponding *USE Productivity Index* value for each field trial or survey site location used for our plantation productivity study. Site and species productivity data was restricted to those species within the *Biomass Industry Species Groups* and the *Top 10% Species Plots* dataset. Strong linear regressions between *USE Productivity Index* values and restricted productivity data for each of the *Biomass Industry Species Groups* has allowed us to predict industry specific plantation productivities and yields across the USE region. A selection of model outputs for annual rates of stemwood production and green biomass production are presented in Figure 17 to Figure 25. Summaries of estimated plantation productivity for each of the *Biomass Industry Species Groups* for each sub-division (Hundred) of the USE region are presented in Table 15.

Figure 15 – Generalised soil groups of the Upper South East region.



(Source: SA DWLBC Soil and Land Program 2006)

Figure 16 – Inherent fertility of soils in the Upper South East region.



(Source: SA DWLBC Soil and Land Program 2006)

Figure 17 – Estimated annual stemwood production of Pulp and Fibre Species.

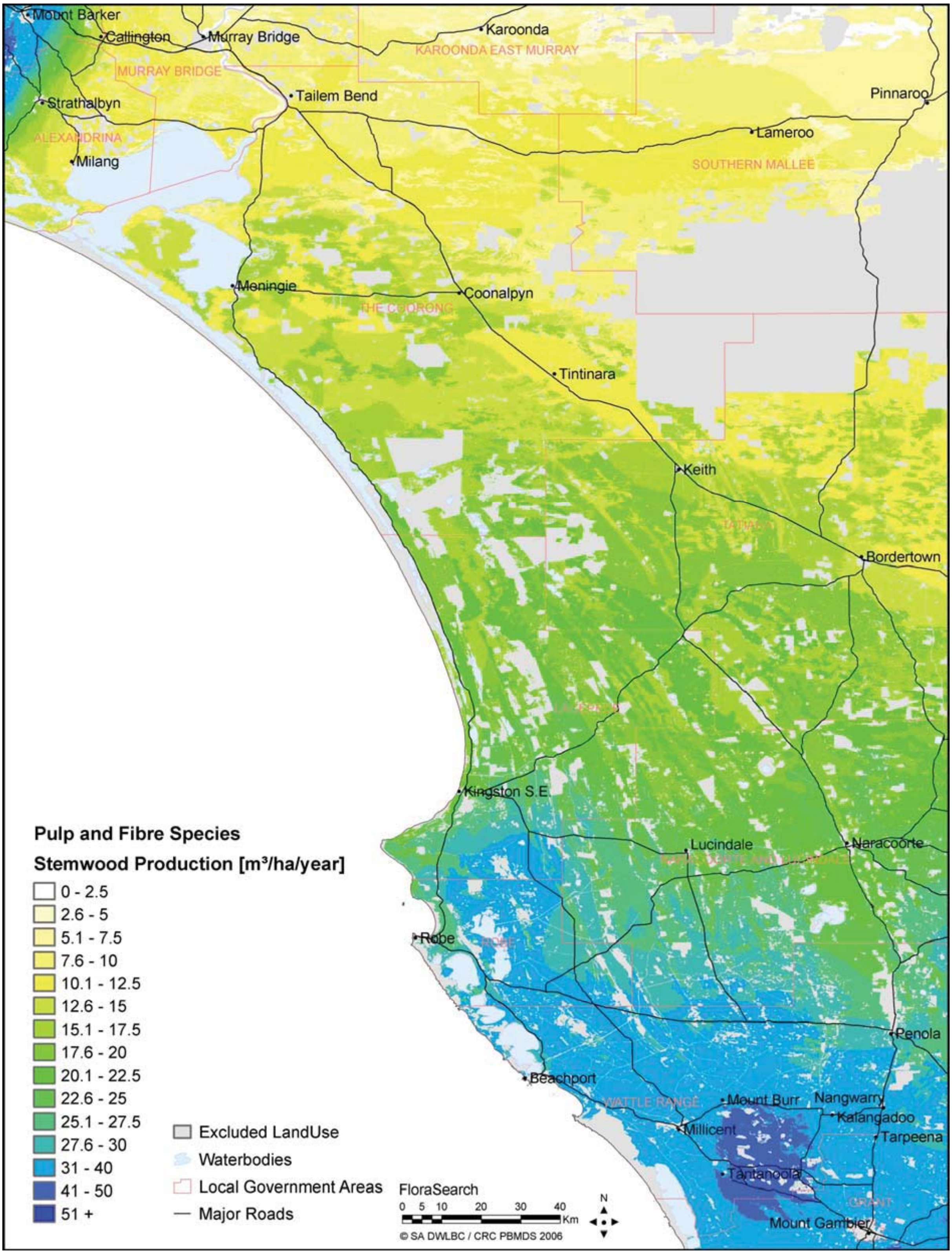


Figure 18 – Estimated annual stemwood production of Bioenergy Species.

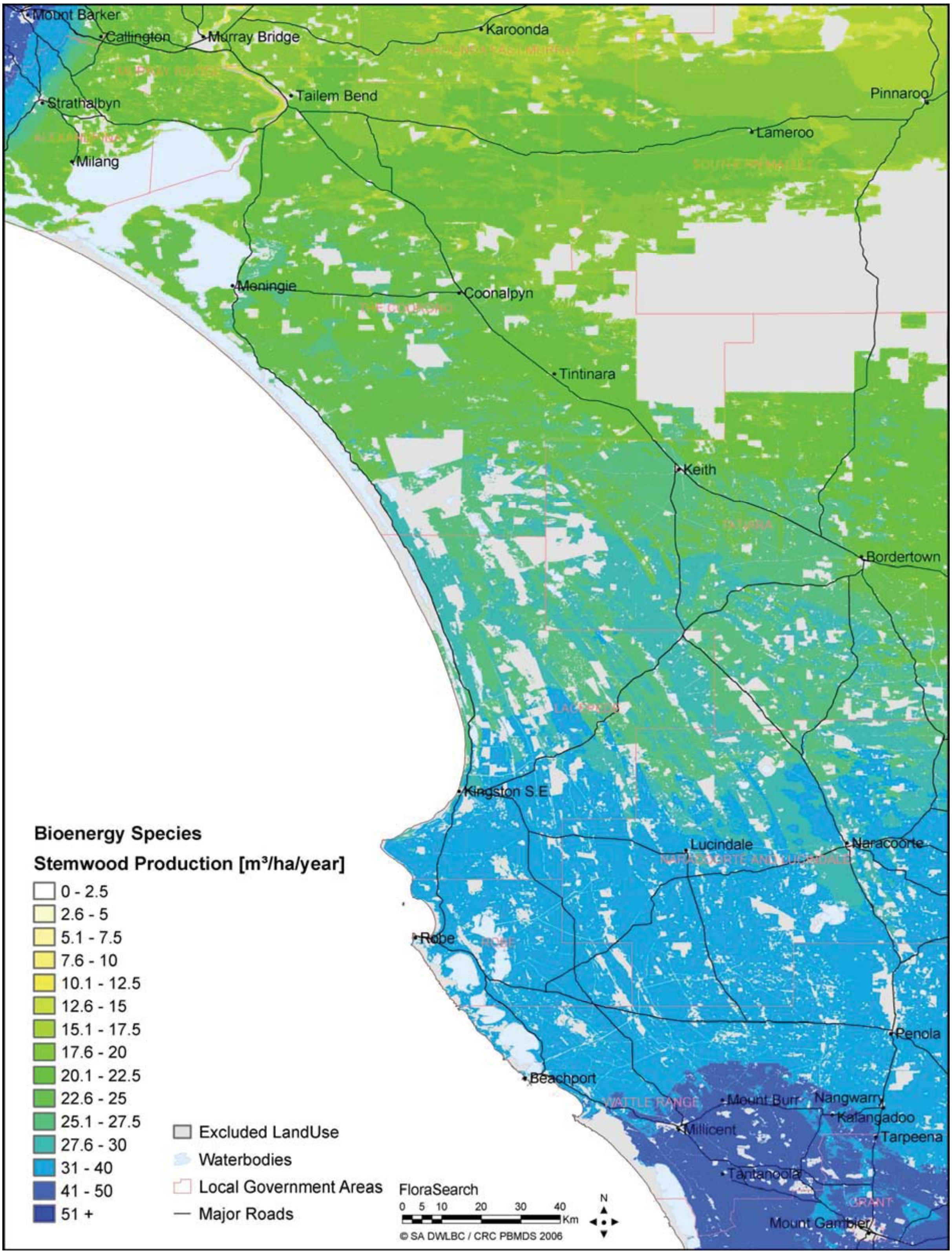


Figure 19 – Estimated annual stemwood production of Oil Mallee Species.

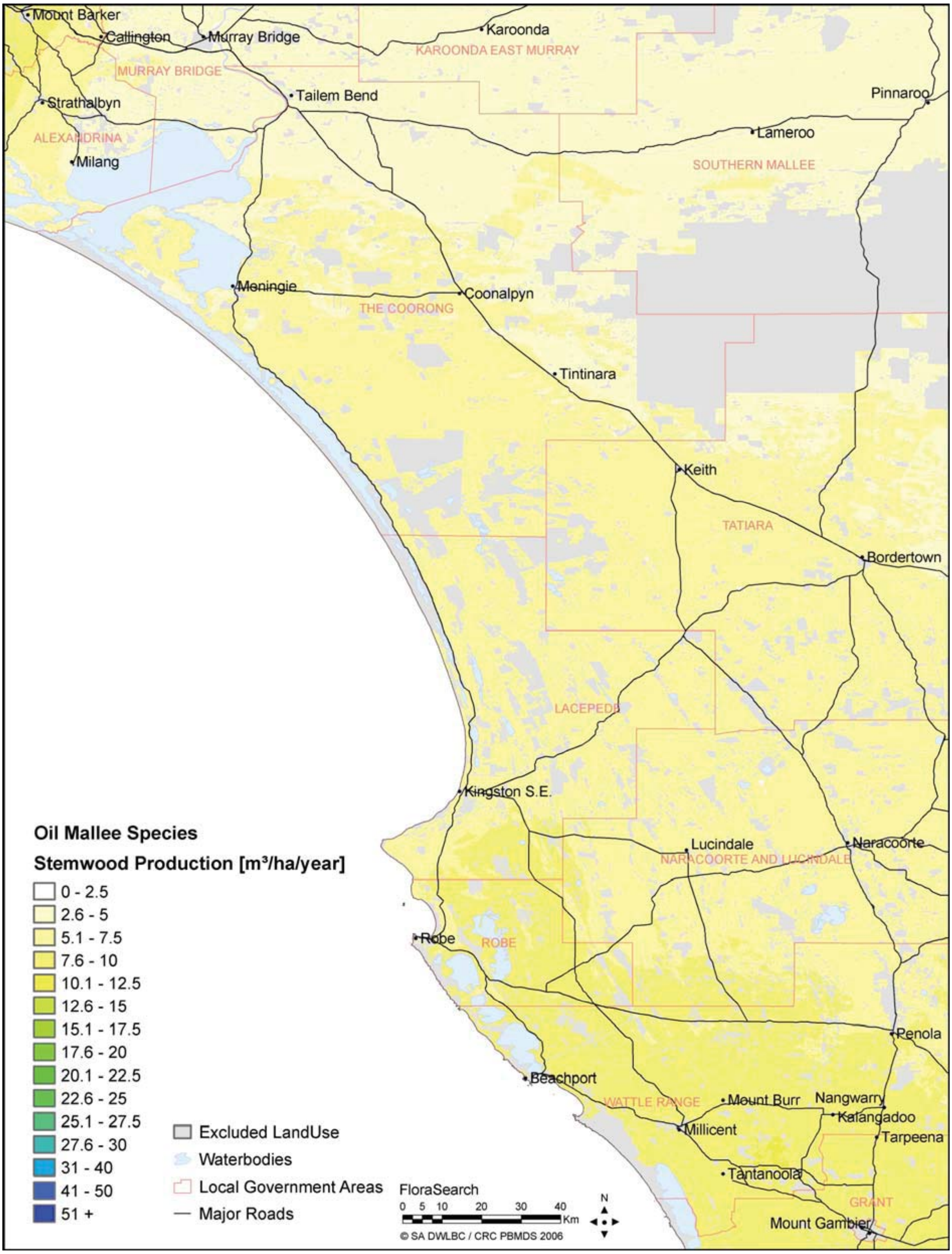


Figure 20 – Estimated annual stemwood production of Habitat Species.

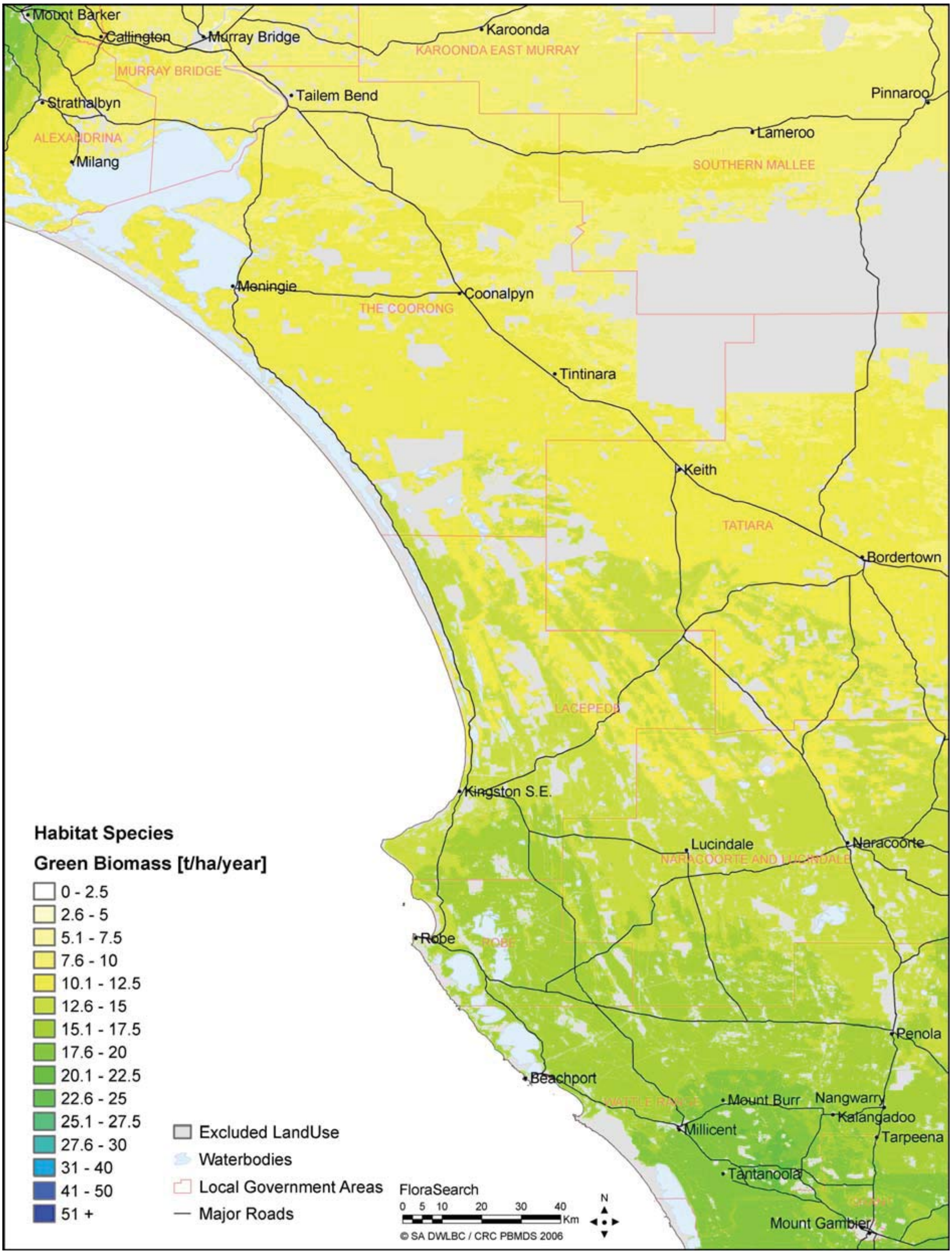


Figure 21 – Estimated annual above-ground green biomass production of Pulp and Fibre Species.

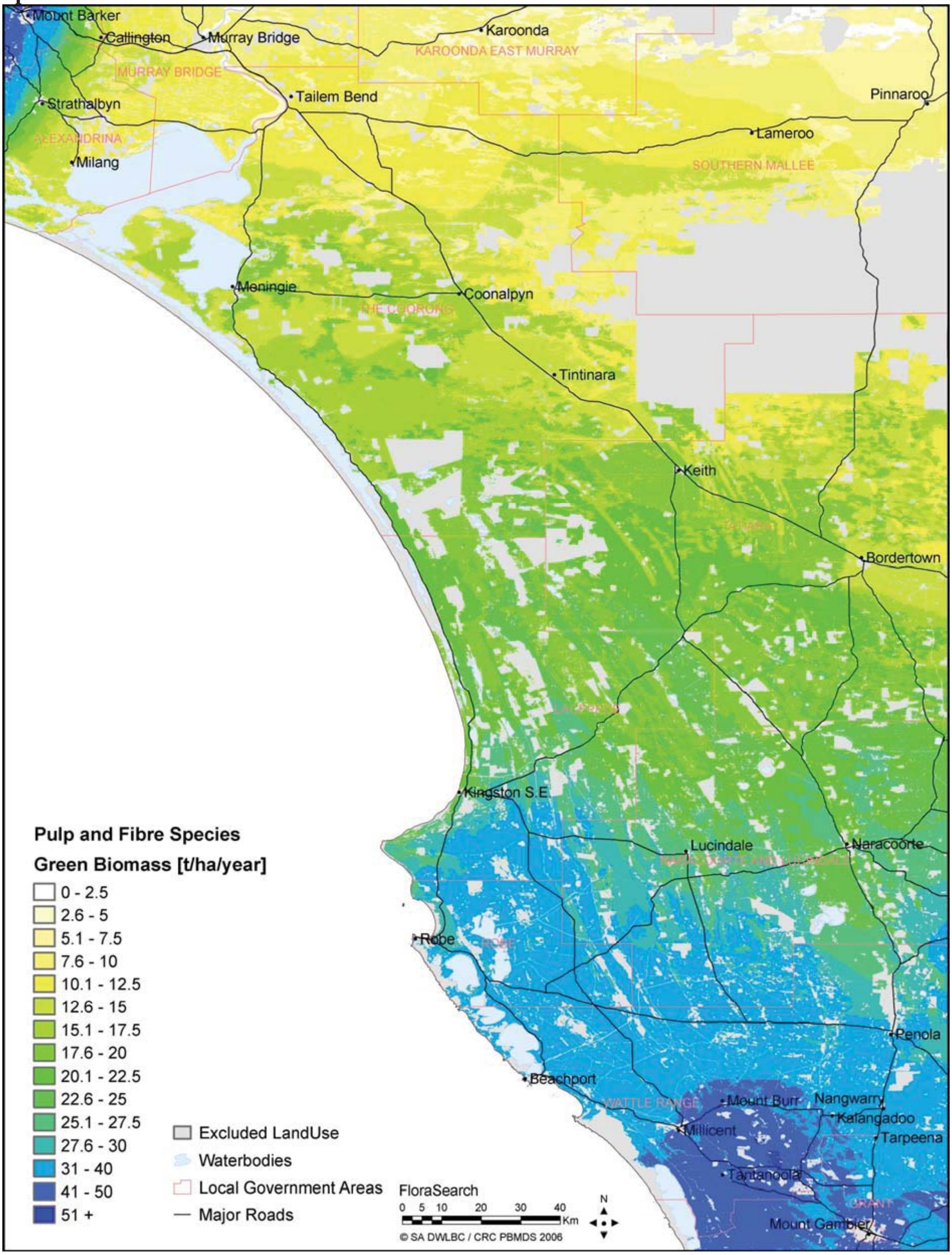


Figure 22 – Estimated annual above-ground green biomass production of Bioenergy Species.

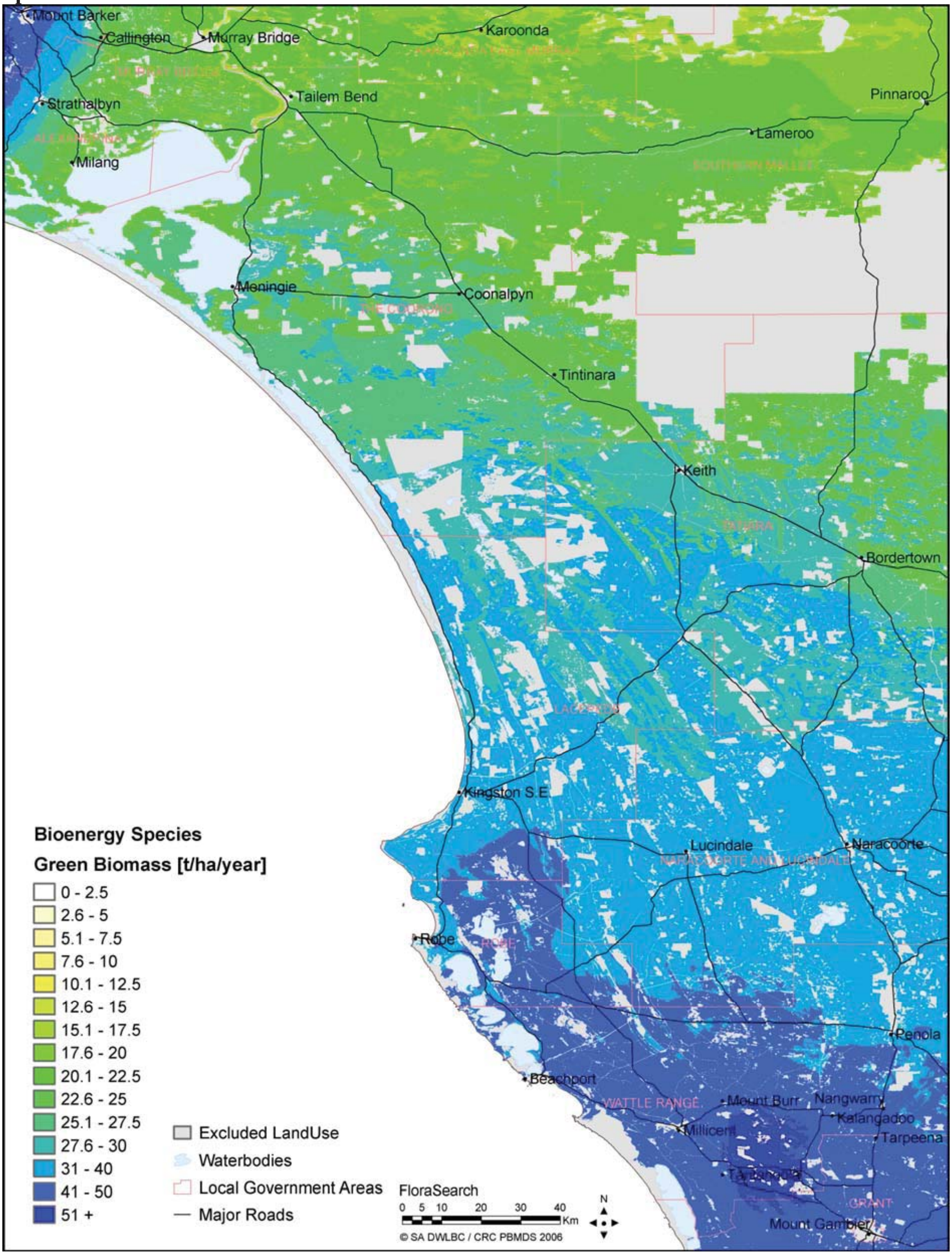


Figure 23 – Estimated annual above-ground green biomass production of Oil Mallee Species.

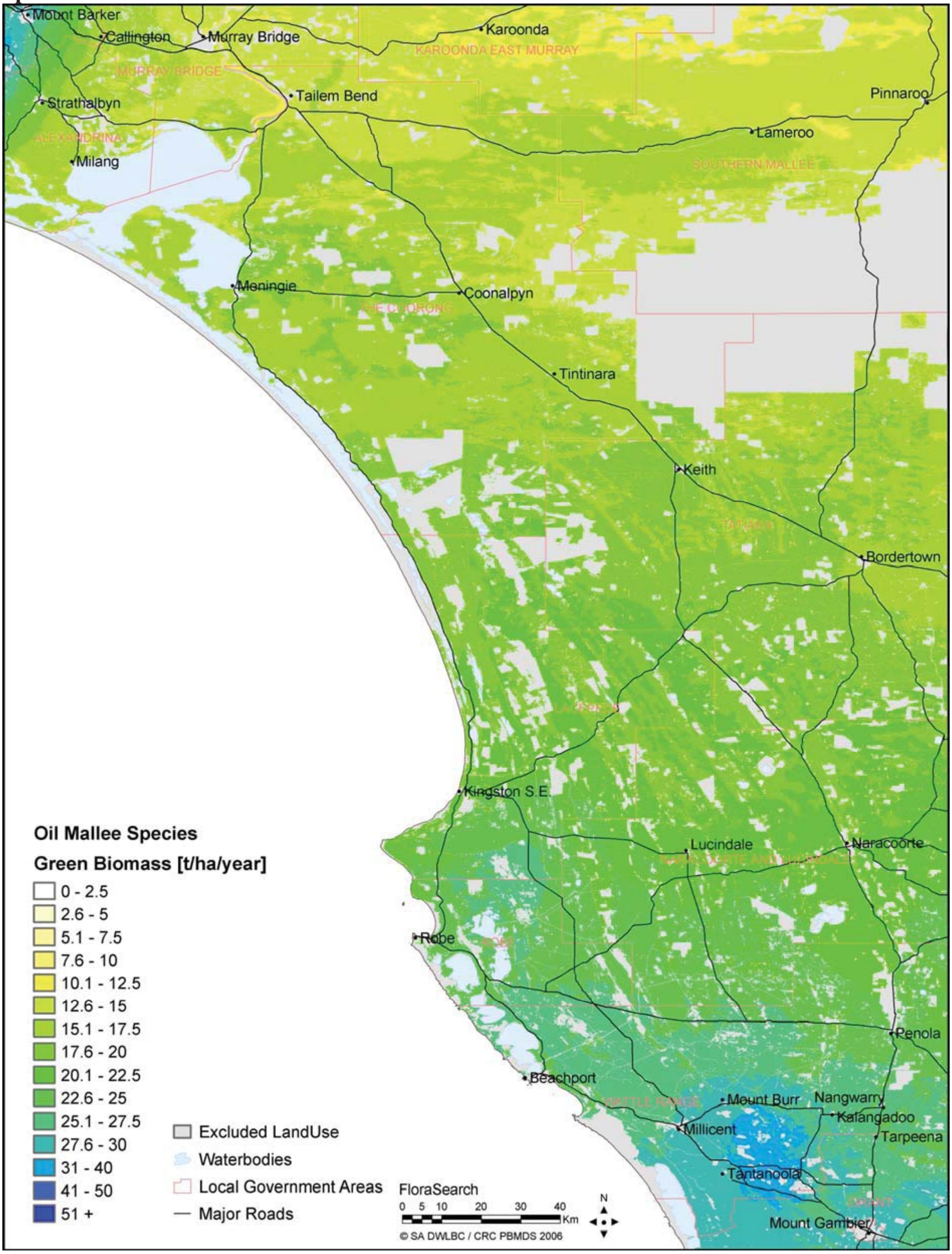


Figure 24 – Estimated annual above-ground green biomass production of Habitat Species.

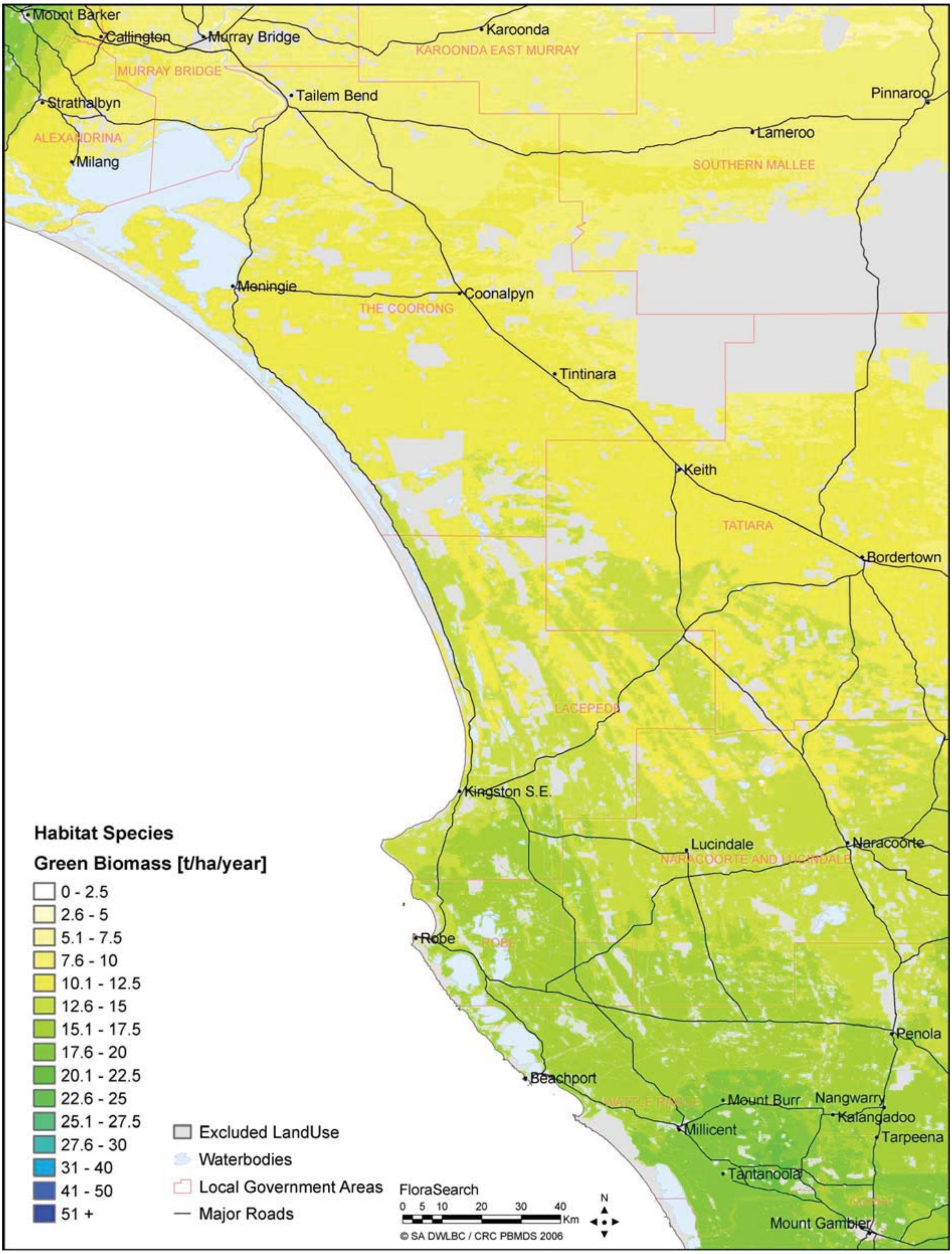


Figure 25 – Estimated annual above-ground green biomass production of Saltbush Fodder Species.

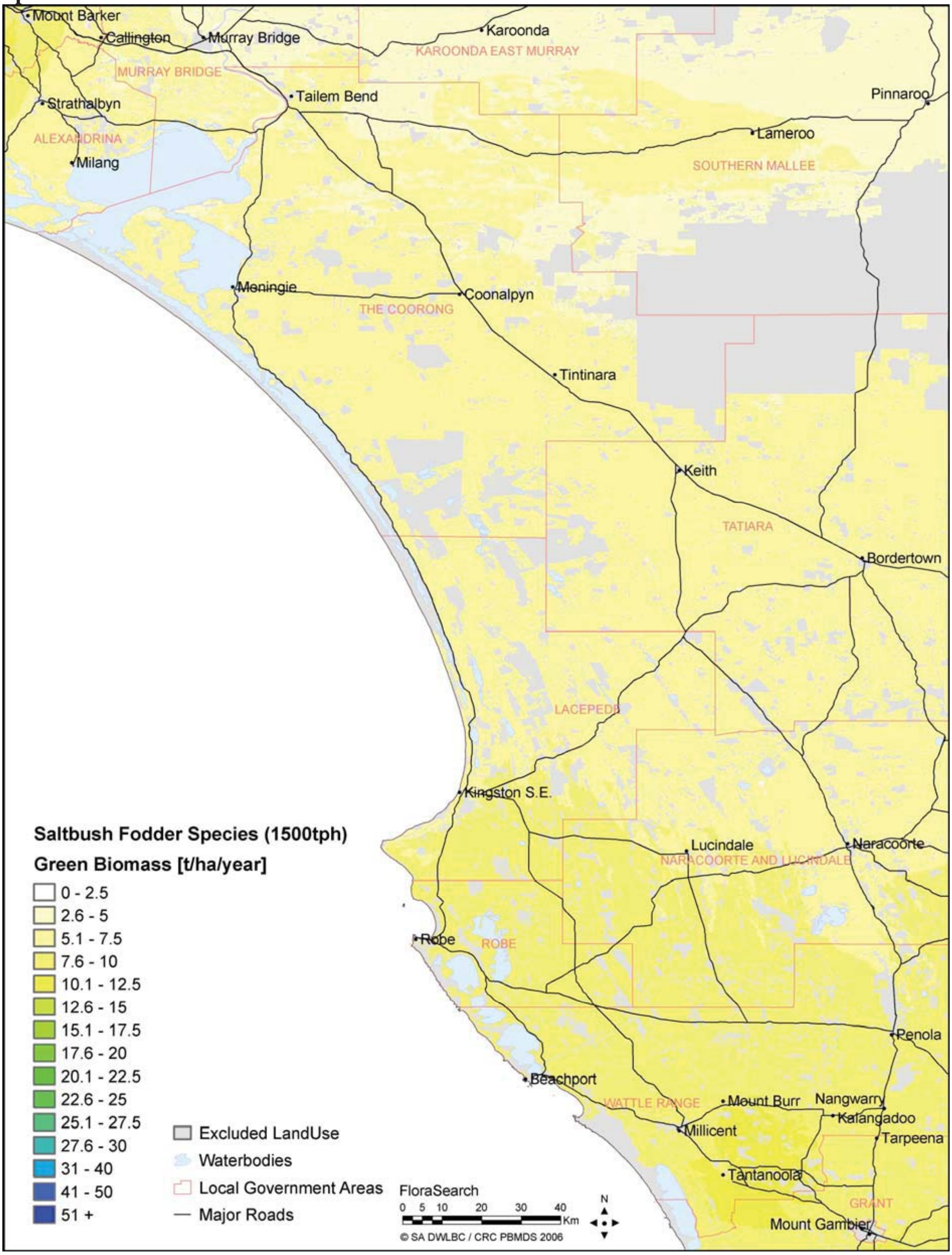


Table 15 - Estimated average annual primary productivity in potential agroforestry areas by land subdivision (Hundreds) in the Upper South East focus area.

Hundred	Rainfall [mm]	Potential Agroforestry Area [ha]	Stemwood Productivity [m³/ha/year] by species group					Green Biomass Productivity [t/ha/year] by species group				
			Pulpwood	Bioenergy	Oil Mallee	Saltbush Fodder	Habitat	Pulpwood	Bioenergy	Oil Mallee	Saltbush Fodder	Habitat
Archibald	443	9850	14.25	23.63	5.35	2.78	5.08	15.65	26.37	16.96	5.82	10.88
Beeamma	507	30388	18.59	27.08	6.01	3.12	5.7	20.4	30.22	19.06	6.54	12.22
Binnum	527	35965	21.02	29.02	6.38	3.32	6.05	23.08	32.39	20.23	6.95	12.98
Bowaka	644	20717	30.06	36.21	7.76	4.03	7.36	33	40.4	24.59	8.44	15.77
Cannawigara	445	34640	14.25	23.62	5.35	2.78	5.07	15.64	26.36	16.96	5.82	10.88
Carcuma	400	25433	8.79	19.29	4.52	2.35	4.29	9.65	21.53	14.33	4.92	9.19
Colebatch	473	28081	15.08	24.29	5.48	2.85	5.2	16.56	27.11	17.37	5.96	11.14
Coneybeer	427	30525	13.48	23.02	5.23	2.72	4.96	14.8	25.69	16.59	5.7	10.64
Coombe	441	42515	12.42	22.18	5.07	2.64	4.81	13.64	24.75	16.08	5.52	10.32
Duffield	509	19462	19.01	27.42	6.07	3.16	5.76	20.87	30.6	19.26	6.61	12.35
Field	472	24233	15.08	24.29	5.48	2.85	5.2	16.56	27.11	17.37	5.96	11.14
Geegeela	496	27963	17.75	26.42	5.88	3.06	5.58	19.49	29.48	18.65	6.4	11.97
Glen Roy	512	21780	19.01	27.4	6.07	3.16	5.76	20.87	30.58	19.25	6.61	12.35
Glyde	478	24433	15.05	24.26	5.47	2.84	5.19	16.52	27.07	17.34	5.95	11.12
Hynam	532	33077	21.09	29.07	6.39	3.32	6.06	23.15	32.45	20.27	6.96	13
Jeffries	440	20796	13.59	23.11	5.25	2.73	4.98	14.92	25.79	16.65	5.71	10.68
Jessie	549	21516	23.35	30.87	6.73	3.5	6.39	25.63	34.45	21.35	7.33	13.7
Joyce (North)	567	16378	23.54	31.02	6.76	3.52	6.42	25.84	34.62	21.45	7.36	13.76
Kirkpatrick	408	23036	12.42	22.18	5.07	2.64	4.81	13.64	24.75	16.08	5.52	10.32
Lacepede	557	17272	23.69	31.14	6.79	3.53	6.44	26	34.75	21.52	7.39	13.8
Laffer	473	38493	16.95	25.78	5.76	2.99	5.47	18.61	28.77	18.27	6.27	11.72
Landseer	524	18924	20.32	28.46	6.27	3.26	5.95	22.31	31.76	19.89	6.83	12.76
Lewis	418	30160	10.62	20.74	4.8	2.49	4.55	11.66	23.15	15.21	5.22	9.76
Livingston	393	29982	11.13	21.15	4.87	2.53	4.63	12.22	23.6	15.46	5.31	9.92
Lochaber	534	21317	20.54	28.54	6.28	3.27	5.96	22.55	31.85	19.92	6.84	12.78
Makin	428	14153	11.17	21.18	4.88	2.54	4.63	12.26	23.63	15.48	5.31	9.93
Marcollat	505	34748	19.34	27.68	6.12	3.18	5.81	21.23	30.89	19.42	6.67	12.46
McCallum	434	16811	12.2	22	5.04	2.62	4.78	13.4	24.55	15.97	5.48	10.25
McNamara	500	26875	17.85	26.48	5.89	3.06	5.59	19.59	29.56	18.69	6.42	11.99
Messent	507	9421	17.08	25.8	5.76	2.99	5.46	18.75	28.79	18.26	6.27	11.71
Minecrow	561	26887	22.77	30.41	6.65	3.46	6.31	25	33.94	21.08	7.24	13.52
Mount Benson	601	22305	26.75	33.57	7.25	3.77	6.88	29.37	37.47	23	7.89	14.75
Murrabinna	578	16142	24.5	31.78	6.91	3.59	6.56	26.89	35.47	21.91	7.52	14.05
Naracoorte	549	20284	22.08	29.84	6.54	3.4	6.2	24.24	33.31	20.73	7.12	13.3
Neville	493	15517	19.18	27.55	6.1	3.17	5.79	21.06	30.75	19.34	6.64	12.41
Ngarkat	401	7551	9.12	19.55	4.57	2.38	4.33	10.01	21.82	14.49	4.97	9.29
Parsons	508	19066	18.22	26.79	5.95	3.1	5.65	20	29.89	18.88	6.48	12.11
Peacock	519	30706	19.59	27.88	6.16	3.2	5.85	21.51	31.12	19.54	6.71	12.54
Pendleton	454	36069	14.83	24.09	5.44	2.83	5.16	16.28	26.89	17.24	5.92	11.06
Petherick	503	31951	19.44	27.76	6.14	3.19	5.83	21.34	30.98	19.47	6.68	12.49
Richards	459	37753	13.62	23.13	5.25	2.73	4.98	14.95	25.81	16.66	5.72	10.69
Santo	489	10064	17.31	26.06	5.81	3.02	5.52	19	29.08	18.44	6.33	11.83
Senior	438	36751	13.06	22.68	5.17	2.69	4.9	14.34	25.31	16.39	5.63	10.51
Shaugh	437	34322	12.38	22.14	5.06	2.63	4.81	13.59	24.71	16.06	5.51	10.3
Spence (North)	558	19019	23.35	30.87	6.73	3.5	6.39	25.64	34.45	21.36	7.33	13.7
Stirling	459	36320	16.44	25.37	5.68	2.95	5.39	18.05	28.32	18.02	6.19	11.56
Strawbridge	440	19887	14.17	23.56	5.34	2.77	5.06	15.55	26.3	16.92	5.81	10.85
Tatiara	462	48028	13.96	23.39	5.3	2.76	5.03	15.33	26.1	16.81	5.77	10.78
Townsend	597	26681	25.91	32.9	7.12	3.7	6.76	28.44	36.72	22.59	7.75	14.49
Wells	512	26543	19.12	27.44	6.07	3.16	5.76	20.99	30.62	19.26	6.61	12.35
Willalooka	492	35928	18.56	27.02	5.99	3.12	5.69	20.37	30.15	19.01	6.53	12.19
Wirrega	481	54898	17.96	26.54	5.9	3.07	5.6	19.72	29.61	18.71	6.42	12
Woolumbool	528	30838	20.32	28.46	6.27	3.26	5.95	22.31	31.76	19.89	6.83	12.76
Avg. or [Total]	*482*	*[1392454]*	*17.57*	*26.27*	*5.85*	*3.04*	*5.55*	*19.29*	*29.31*	*18.56*	*6.37*	*11.91*

3. Natural Resource Management Issues and Benefits of Revegetation

3.1 Introduction

The natural environment and history of landuse in the Upper South East (USE) region has shaped many of the natural resource management issues that we currently face in the region. The natural environment has inherited, and commonly features, low topography, poor water drainage, high water tables, saline and low fertility soils and salty groundwater (see Figure 16, Figure 26 - Figure 28). The clearance of approximately 75% of the native perennial vegetation in the USE region (see Figure 32) for predominately annual-based crops and pastures has substantially changed the hydrology of the area. Changes in the hydrology has generally accentuated soil salinity through the release of salt once stored in soil profiles and rising water tables in many areas (Figure 29). Poor drainage and rising watertables result in unproductive waterlogged soils. The removal of native vegetation cover also exposes light sandy soils to a greater risk of wind erosion (Figure 30). Salinity, waterlogging and wind erosion reduces the productivity and sustainability of agricultural lands.

The natural resource management issues of dryland salinity, ecosystem fragmentation and degradation feature highly (and to a lesser extent, wind erosion, waterlogging & soil acidification) in the current *South East Natural Resource Management Plan* (SENRCC 2003) and will undoubtedly be core issues in the new *South East Regional Natural Resource Management Plan* (SENRMB 2006). It is well recognised that perennial revegetation, including commercial agroforestry, perennial farming systems and habitat re-creation can provide environmental and ecosystem services that may alleviate some of these NRM problems faced in the region (Australian Greenhouse Office & Murray Darling Basin Commission 2001, SENRCC 2003). New plantations of woody perennial species can reduce groundwater recharge, dryland salinity, saline river discharges, wind erosion and drought risk, and increase landscape sustainability, biodiversity, livestock production, economic diversification and stability of financial returns.

In the broader context of environmental services and climate change we have also conducted a series of analyses on the potential of five perennial revegetation types to sequester carbon dioxide from the atmosphere.

3.2 Soil Salinity and Wind Erosion Risk

To evaluate the extent and severity of soil salinity and wind erosion risk in the Upper South East (USE) region we have conducted spatial analyses of DWLBC Land and Soil Program's (2006) mapping of dry saline land, dryland salinity induced by water table and wind erosion risk (see Figure 26, Figure 29, Figure 30). This analysis is focussed on the annual cropping and grazing areas only. An index of extent and severity has been created by scaling the classes of dry saline land, salinity induced by water table and wind erosion risk between 0 and 1, where a value of 1 represents the most widespread and severely affected location. Then for each Hundred subdivision we have determined the average index value of each hectare under annual cropping and grazing. A high average index value highlights subdivisions which are most affected by salinity or erosion risk (see Table 16).

The main driver of dryland salinity in the Upper South East (USE) region is the leakage of water from the root zone of predominately annual crops and pastures. The resulting deep drainage contributes to the recharge of water tables in the region and increases the risk of dryland salinity. Every 1mm of deep drainage per hectare contributes 10,000 litres of water towards recharging the water table. Smettem (1998) predicts that deep drainage under annual crops and pastures in the 375 to 600mm rainfall zone is approximately 40 times that of native perennial vegetation. Smettem's work was conducted on similar landscapes to those found in the USE region. Using Smettem's models of deep drainage:

$$\textbf{Deep Drainage (Native Systems) [mm]} = \mathbf{0.0336e^{0.0059 * Rainfall\ [mm]}}\textbf{; and}$$

$$\textbf{Deep Drainage (Agricultural Systems) [mm]} = \mathbf{7.8619e^{0.0025 * Rainfall\ [mm]}}$$

and spatial coverages of rainfall and landuse we have mapped the spatial distribution of deep drainage for the USE region (Figure 31). The spatial variation in deep drainage resulting from different landuses is tremendous. Average annual rates and volumes of deep drainage under annual crops and pastures for each local subdivision are presented in Table 16.

For every 1% of the annual cropping and grazing land revegetated with woody perennial crops or habitat will reduce the region's recharge by approximately 3.6 Gigalitres per year. Revegetation can contribute significantly to reducing one of the drivers of dryland salinity in the region. Conversely, in agricultural areas reliant on unconfined low salt aquifers careful planning of revegetation activities and water extraction will be required to ensure the persistence of the groundwater resource.

3.3 Ecosystem Fragmentation and Degradation

Approximately 75% of the Upper South East (USE) region has been cleared of native vegetation for the development of agricultural industries. Most of this clearance has been undertaken on the most fertile landscapes. Much of the remaining low fertility, saline and waterlogged soils, and wetlands are now formally conserved in our national estates. Other low productivity lands remain unused or opportunistically grazed by livestock. Government-managed National parks and reserves formally conserve 13.9% of the native landscapes of region. A further 3.9% of the region is conserved on private lands under formal Native Heritage Agreements with the state government with strong restriction on landuse and livestock grazing. Other native forests, woodlands, shrublands and heathlands (6.7% of the region) lie outside of formal conservation areas and are protected by legislation from any further clearing, however, these predominately privately owned lands are usually part of agricultural enterprises and still may be subject to the pressures of livestock grazing and other management that may degrade these relatively natural systems.

The coarse degree of ecosystem fragmentation is mapped in Figure 32. The formally conserved areas are focussed on the low fertility landscapes of the Ngarkat area in the northeast of the region and saline or waterlogging landscapes in the Coorong and adjacent wetland areas. Conservation areas or unconserved remnant native vegetation in other areas are highly dispersed and relatively unconnected vegetation structures and habitats. These areas have the greatest risk of biodiversity loss from the influence of high edge effects and isolation, particularly on small ground-based mammals and reptiles. In the greater South East Region 11 plant and 22 animal species have become regionally extinct, 333 plant species are considered threatened at the State level (63 endangered, 88 vulnerable, 180 rare and 2 not yet listed), and 27 of the 49 pre-European plant communities (55%) are considered rare or threatened (SENRCC 2003).

As an estimate of habitat loss and degradation in each Hundred subdivision we have combined the “Habitat Areas” of formal conservation on government and private lands with the currently remnant native vegetation which is not formally conserved. The total remaining “non-Habitat Areas” are then expressed as a proportion of the total subdivision area or a simplified index of ecosystem fragmentation and degradation; higher index values (~1) represent highly fragmented or degraded landscapes. Table 16 presents summaries of each regional conservation landuse type by Hundred for the USE region.

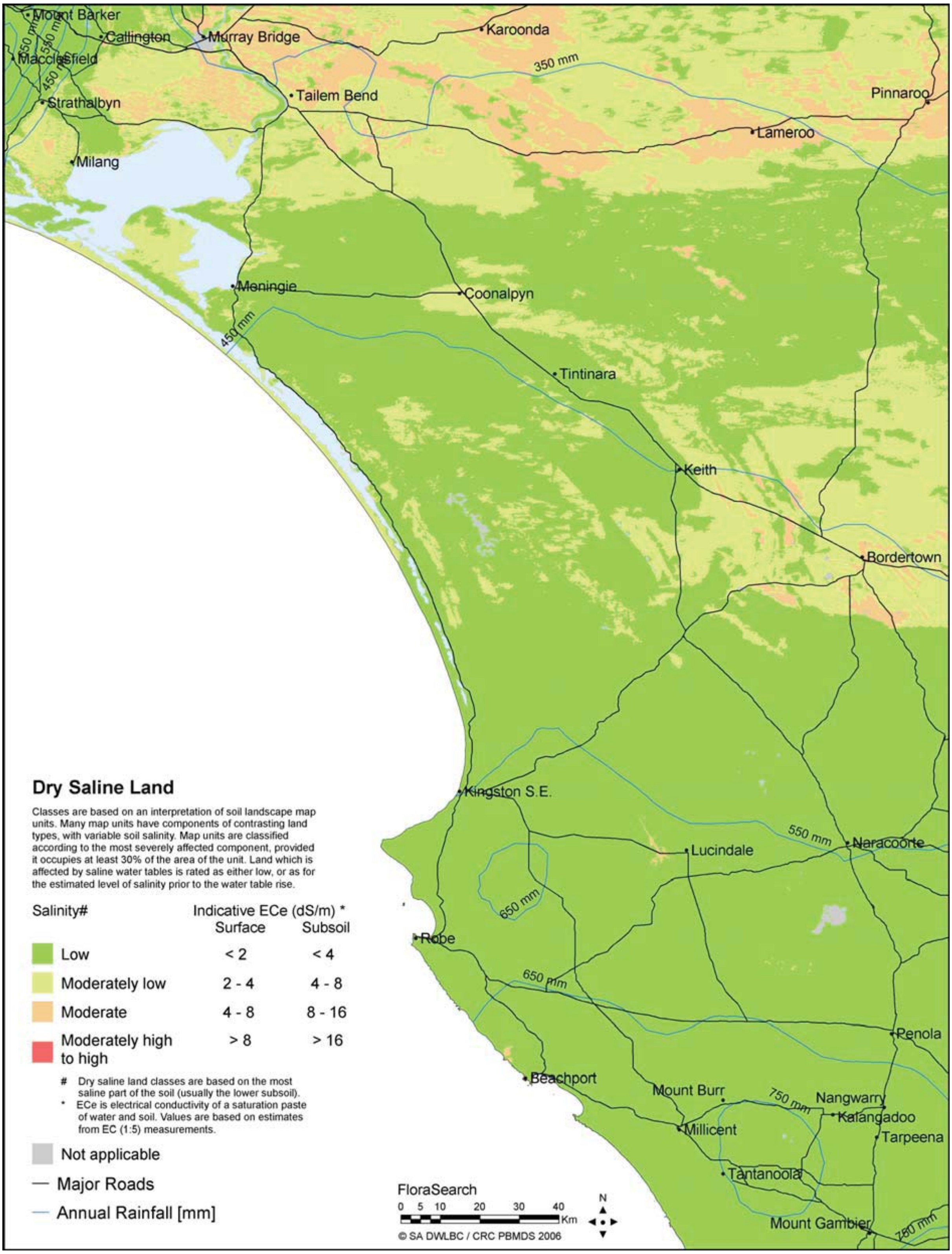
3.4 Overall Environmental Risk

To prioritise the Hundred subdivisions which will receive the most benefit from revegetation with woody perennial plants we have used the unweighted averaged of each Hundred’s dryland salinity, habitat loss and wind erosion risk indices. These results are presented in Table 16 and graphically in Figure 33. These results highlight the need for revegetation in many areas, but especially the Hundreds of Richards, McNamara, Coombe and Laffer of the Tintinara district with their substantial vegetation clearance, high water tables and light sandy soils.

3.5 Carbon Sequestration Potential

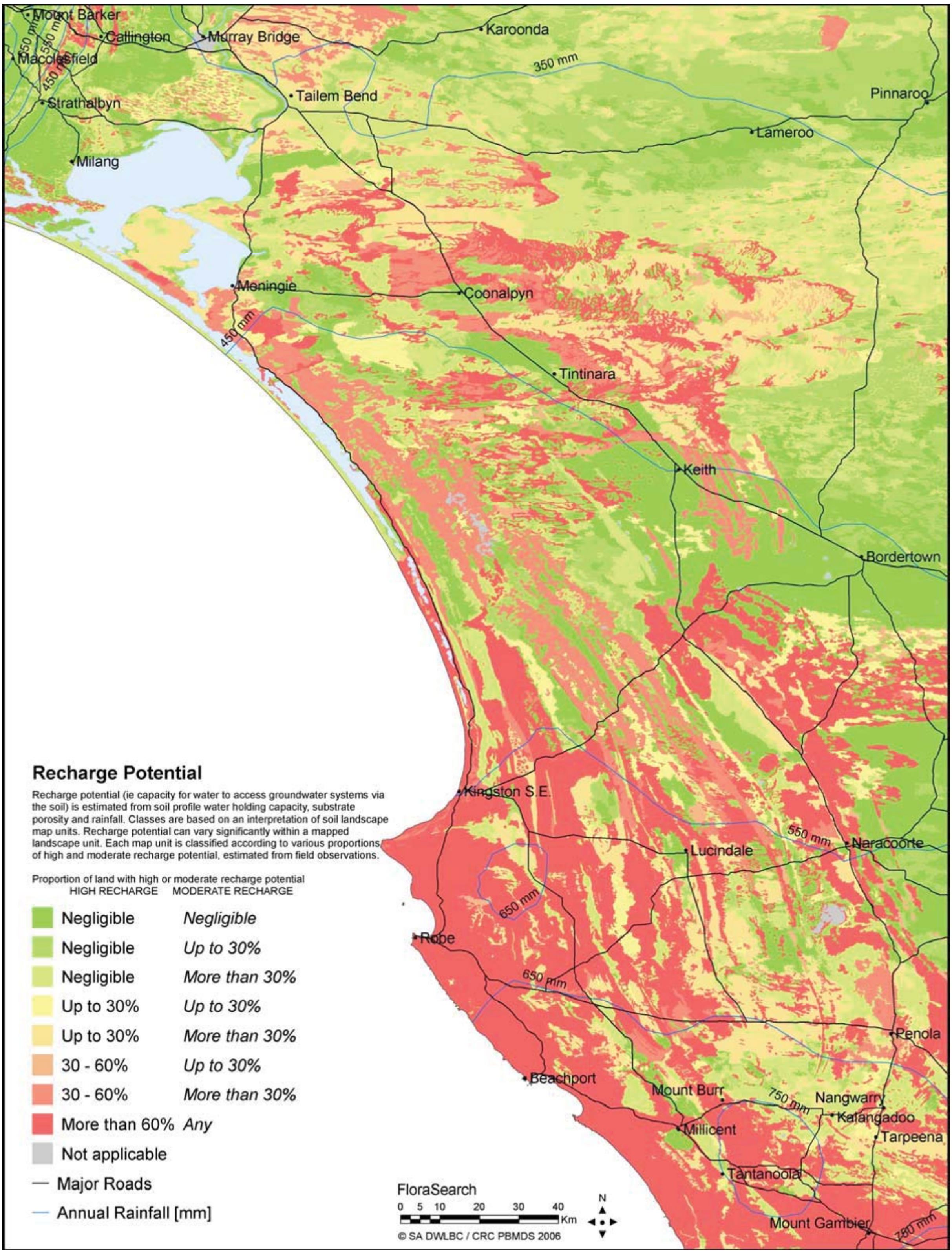
Revegetation using woody perennial vegetation can also provide additional environmental services by sequestering atmospheric carbon dioxide and reducing greenhouse gases that contribute to climate change. We have constructed spatial models of above-ground carbon sequestration based on the plantation productivity data of the five perennial *Biomass Industry Species Groups* outlined in the previous section on *Biomass Productivity* (see Figure 37 - Figure 38). These figures represent the unharvested 20 year average carbon sequestration rates for each species group. Summaries presented in Table 17 show the expected rates of carbon sequestration of revegetation on the annual cropping and grazing land within each Hundred subdivision in the USE region.

Figure 26 – Naturally dry saline land in the Upper South East region.



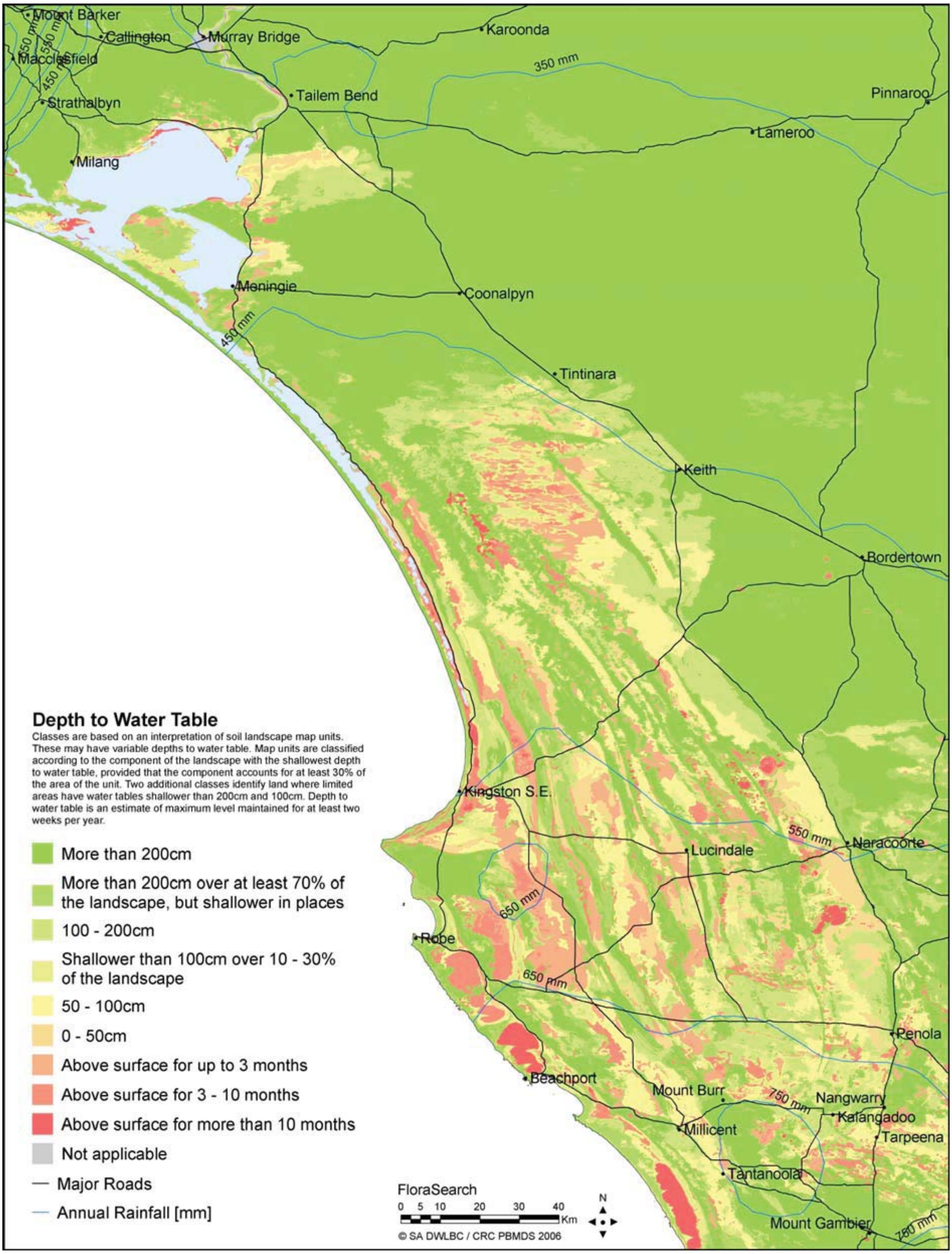
(Source: SA DWLBC Soil and Land Program 2006)

Figure 27 – Recharge potential of soils in the Upper South East region.



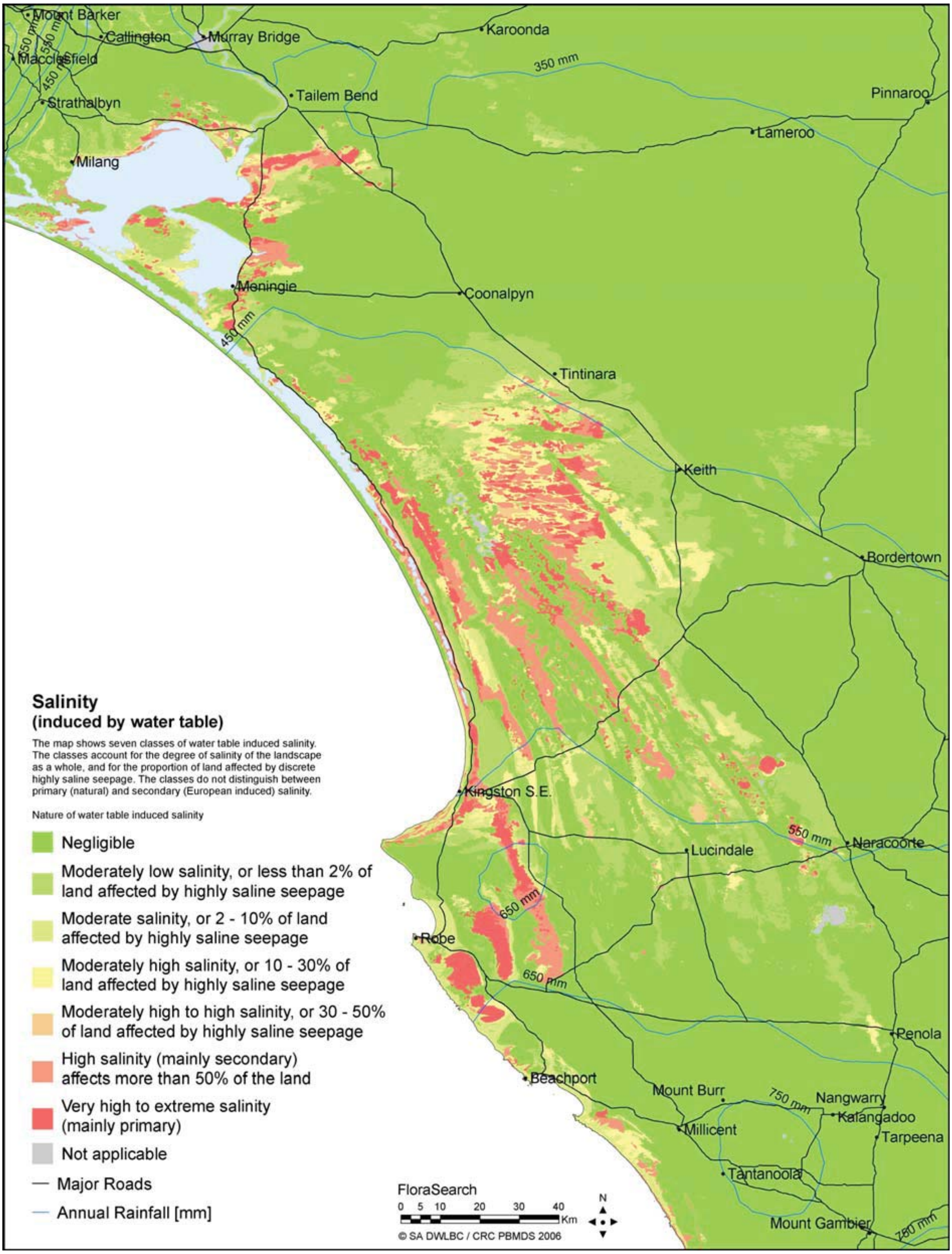
(Source: SA DWLBC Soil and Land Program 2006)

Figure 28 – Depth to the water table in the Upper South East region.



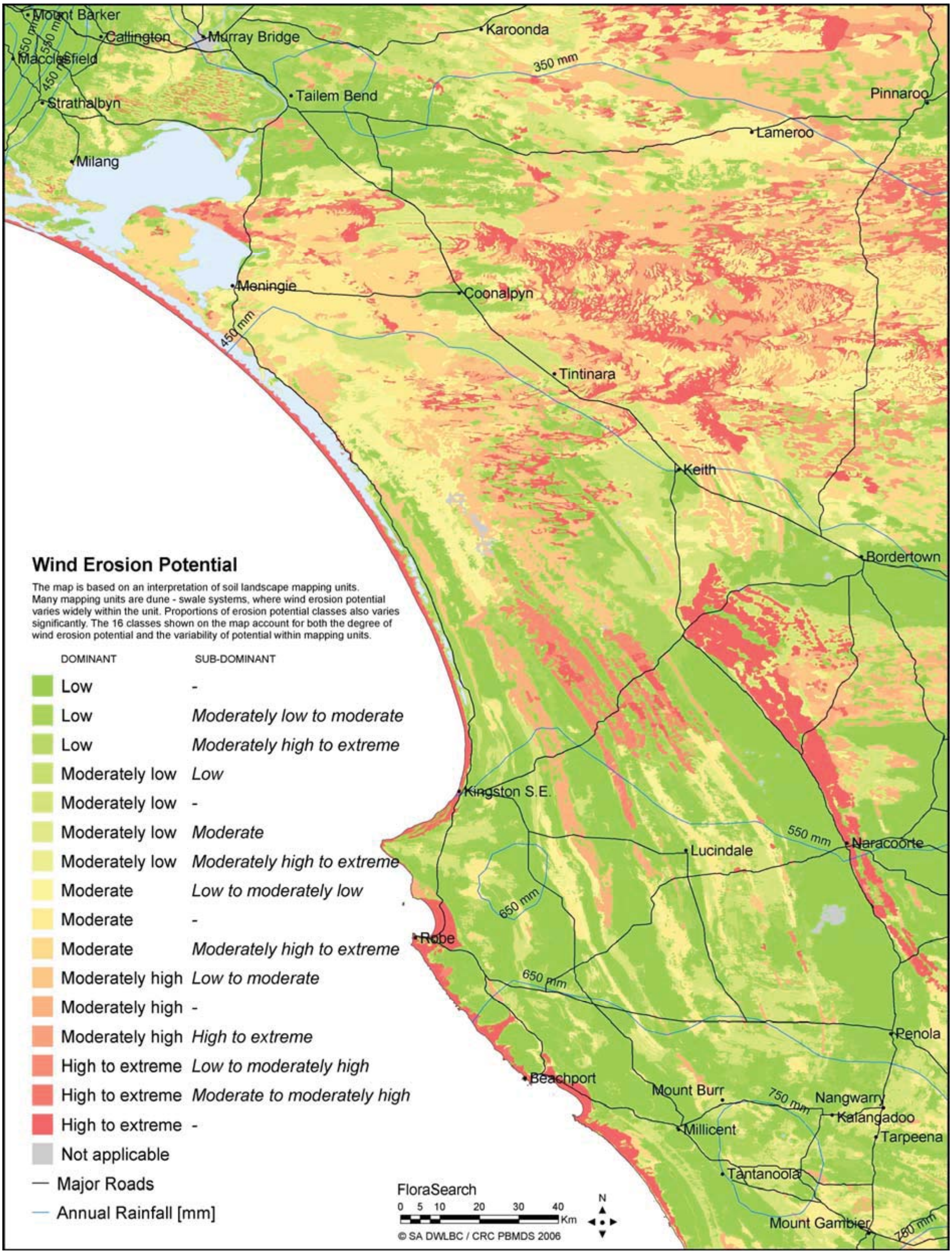
(Source: SA DWLBC Soil and Land Program 2006)

Figure 29 – Salinity induced by water table in the Upper South East region.



(Source: SA DWLBC Soil and Land Program 2006)

Figure 30 – Wind erosion potential in the Upper South East region.



(Source: SA DWLBC Soil and Land Program 2006)

Figure 31 – Annual deep drainage rates under agricultural and native vegetation in the Upper South East region.

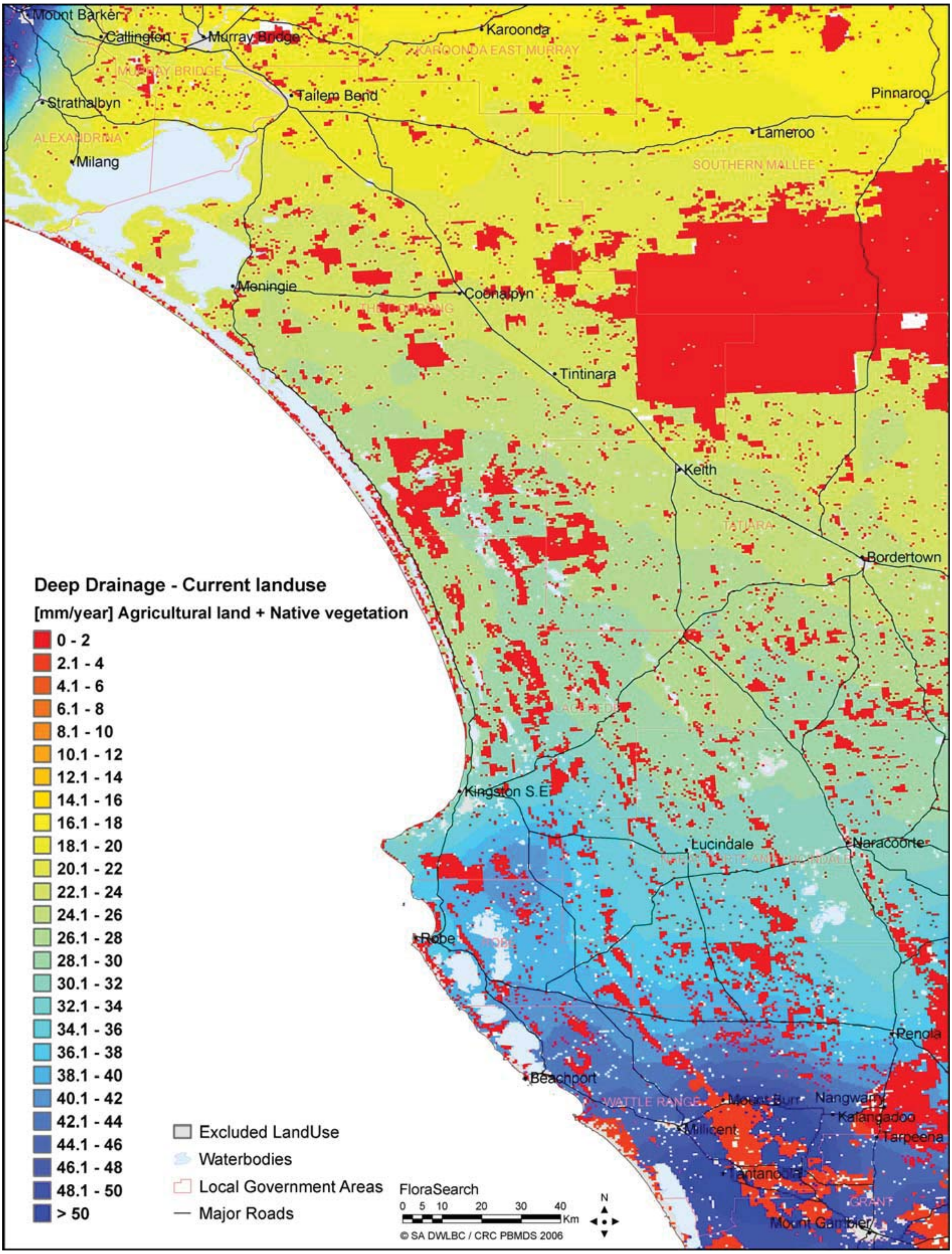


Figure 32 – Conservation areas and remnant native vegetation on private lands in the Upper South East region.

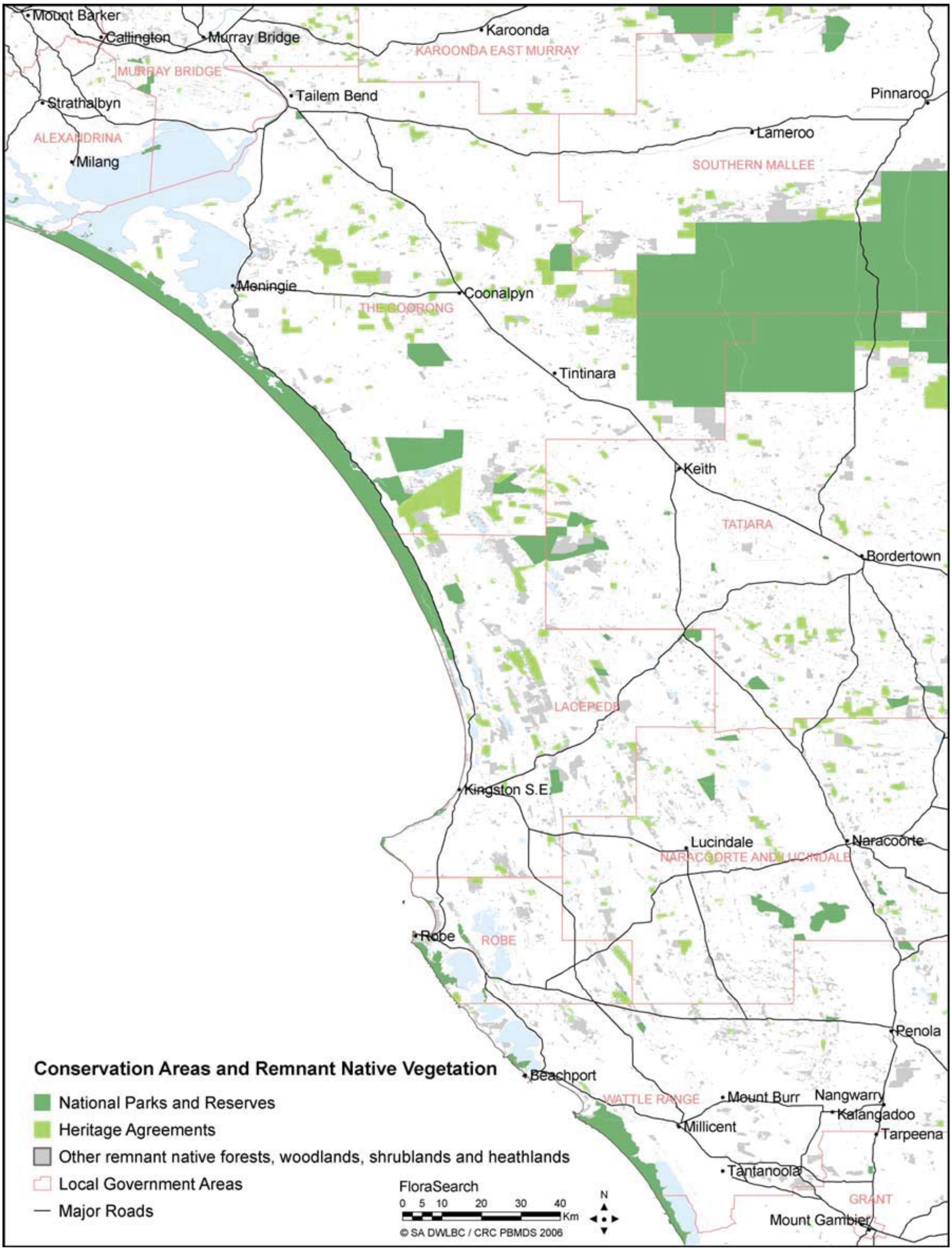


Table 16 - Regional conservation and dryland agricultural lands (potential agroforestry) affected by deep drainage, salinity and wind erosion risk by land subdivision (Hundreds).

Hundred	Parks and Reserves [ha]	Heritage Agreements [ha]	Native but Not Formally Conserved [ha]	*All Habitat Areas [ha]*	Index Habitat Areas #1	Dryland Agriculture [ha]	Rainfall [mm]	Deep Drainage [mm/ha/year]	Total Deep Drainage [GL/year]	Index Dry Saline Land	Index Salinity #2 - water table induced	Index Wind Erosion Risk #3	Index Overall (avg. #1, #2, #3)
Archibald	25096	558	3641	*29295*	0.260	9850	443	22.1	2.2	0.136	0.052	0.520	0.278
Beeamma		2737	2808	*5545*	0.847	30388	507	26.6	8.1	0.000	0.000	0.554	0.467
Binnum	13	755	2031	*2799*	0.929	35965	527	28.6	10.3	0.000	0.000	0.101	0.343
Bowaka		691	2686	*3377*	0.864	20717	644	37.8	7.8	0.000	0.290	0.118	0.424
Cannawigara	5	1036	2705	*3746*	0.904	34640	445	23.0	8.0	0.191	0.015	0.409	0.443
Carcuma	2908	2487	4564	*9959*	0.719	25433	400	20.5	5.2	0.009	0.000	0.672	0.464
Colebatch	4948	5	1007	*5960*	0.825	28081	473	25.3	7.1	0.043	0.152	0.601	0.526
Coneybeer	2	2881	1877	*4760*	0.866	30525	427	22.1	6.7	0.103	0.012	0.351	0.410
Coombe		182	2157	*2339*	0.948	42515	441	23.3	9.9	0.048	0.189	0.552	0.563
Duffield	958	985	3505	*5448*	0.802	19462	509	26.2	5.1	0.000	0.318	0.209	0.443
Field		118	263	*381*	0.985	24233	472	25.4	6.2	0.021	0.045	0.441	0.490
Geegeela	1645	1502	3888	*7035*	0.802	27963	496	25.3	7.1	0.000	0.000	0.425	0.409
Glen Roy	494	347	978	*1819*	0.934	21780	512	27.2	5.9	0.000	0.072	0.318	0.441
Glyde	12525	146	2220	*14891*	0.635	24433	478	25.2	6.2	0.010	0.098	0.517	0.417
Hynam	16	2149	2993	*5158*	0.866	33077	532	28.8	9.5	0.000	0.032	0.409	0.436
Jeffries		3267	568	*3835*	0.844	20796	440	23.2	4.8	0.000	0.008	0.511	0.454
Jessie	21		306	*327*	0.987	21516	549	30.7	6.6	0.000	0.000	0.018	0.335
Joyce (North)		339	1667	*2006*	0.895	16378	567	31.1	5.1	0.003	0.112	0.228	0.412
Kirkpatrick		1291	1260	*2551*	0.900	23036	408	21.1	4.9	0.000	0.000	0.495	0.465
Lacepede	184	812	3070	*4066*	0.845	17272	557	30.1	5.2	0.000	0.350	0.202	0.466
Laffer	2274	1559	2172	*6005*	0.868	38493	473	25.0	9.6	0.048	0.453	0.341	0.554
Landseer		3604	6587	*10191*	0.658	18924	524	26.9	5.1	0.000	0.328	0.363	0.450
Lewis	13	8241	4300	*12554*	0.706	30160	418	21.2	6.4	0.077	0.003	0.654	0.454
Livingston		2246	1886	*4132*	0.879	29982	393	20.4	6.1	0.053	0.000	0.431	0.437
Lochaber	11	89	1075	*1175*	0.955	21317	534	29.1	6.2	0.000	0.180	0.129	0.421
Makin	18595	310	1886	*20791*	0.405	14153	428	21.8	3.1	0.133	0.008	0.593	0.335
Marcollat	937	123	2185	*3245*	0.918	34748	505	27.1	9.4	0.005	0.143	0.326	0.462
McCallum	18461		607	*19068*	0.469	16811	434	22.8	3.8	0.192	0.039	0.532	0.347
McNamara	1952	3283	5222	*10457*	0.735	26875	500	26.2	7.0	0.048	0.515	0.606	0.619
Messent	10873	8731	2571	*22175*	0.319	9421	507	25.6	2.4	0.008	0.136	0.479	0.311
Minecrow	3	846	4996	*5845*	0.827	26887	561	30.1	8.1	0.000	0.157	0.212	0.399
Mount Benson	268		835	*1103*	0.957	22305	601	26.7	6.0	0.000	0.137	0.212	0.435
Murrabinna	1269	722	2330	*4321*	0.803	16142	578	32.0	5.2	0.000	0.217	0.181	0.400
Naracoorte		4	1055	*1059*	0.957	20284	549	30.0	6.1	0.000	0.110	0.135	0.401
Neville	9447	807	2830	*13084*	0.559	15517	493	25.7	4.0	0.034	0.346	0.296	0.400
Ngarkat	127276	1214	1530	*130020*	0.055	7551	401	20.8	1.6	0.056	0.000	0.646	0.234
Parsons	982	1003	2296	*4281*	0.826	19066	508	26.5	5.1	0.020	0.000	0.659	0.495
Peacock	541	997	3921	*5459*	0.852	30706	519	27.2	8.4	0.003	0.222	0.480	0.518
Pendleton		479	1580	*2059*	0.947	36069	454	23.6	8.5	0.218	0.017	0.464	0.476
Petherick	3396	440	6163	*9999*	0.771	31951	503	26.8	8.6	0.034	0.406	0.294	0.491
Richards			906	*906*	0.977	37753	459	24.5	9.2	0.016	0.302	0.524	0.601
Santo	14239	1927	654	*16820*	0.400	10064	489	25.4	2.6	0.031	0.219	0.386	0.335
Senior		127	1422	*1549*	0.960	36751	438	23.1	8.5	0.237	0.000	0.415	0.458
Shaugh	3478	6444	3761	*13683*	0.716	34322	437	22.7	7.8	0.210	0.003	0.490	0.403
Spence (North)		1124	1100	*2224*	0.897	19019	558	30.6	5.8	0.000	0.108	0.235	0.413
Stirling	100	32	1350	*1482*	0.962	36320	459	24.3	8.8	0.082	0.106	0.336	0.468
Strawbridge		4722	2158	*6880*	0.743	19887	440	22.5	4.5	0.010	0.001	0.543	0.429
Tatiara	25	112	1747	*1884*	0.964	48028	462	24.4	11.7	0.278	0.000	0.066	0.343
Townsend		793	2824	*3617*	0.884	26681	597	33.5	8.9	0.013	0.105	0.194	0.394
Wells	3189	1383	4291	*8863*	0.770	26543	512	27.1	7.2	0.022	0.333	0.450	0.518
Willalooka	144	75	1411	*1630*	0.957	35928	492	26.4	9.5	0.100	0.233	0.389	0.526
Wirrega	76	1112	3292	*4480*	0.928	54898	481	25.4	13.9	0.156	0.005	0.265	0.399
Woolumbool	1384	607	2798	*4789*	0.868	30838	528	28.0	8.6	0.000	0.217	0.264	0.450
[Avg.] or Total	*267748*	*75444*	*127935*	*471127*	*[0.755]*	*1392454*	*[482]*	*[26.0]*	*359.5*	*[0.050]*	*[0.128]*	*[0.382]*	*[0.435]*

Figure 33 – Overall environmental risk from dryland salinity, habitat loss and wind erosion risks in the Upper South East region.

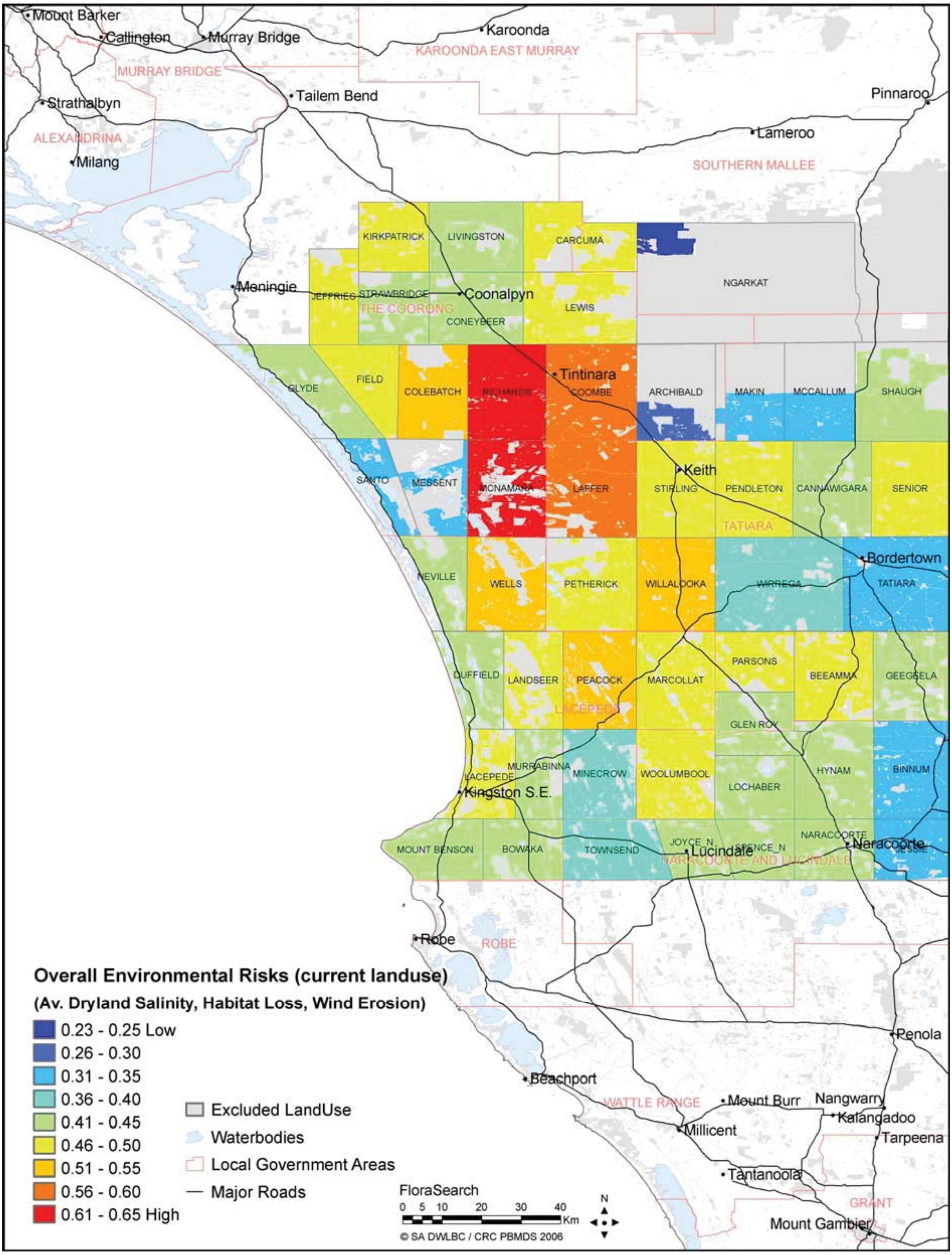


Table 17 - Estimated unharvested above-ground carbon dioxide sequestration rates and district totals by land subdivision (Hundreds) and agroforestry species group.

Hundred	Rainfall [mm]	Potential Agroforestry Area [ha]	Carbon Dioxide Sequestration [t CO2 equiv./ha/year] by species group					Carbon Dioxide Sequestration [Kt CO2 equiv./Hundred/year] by species group				
			Pulpwood	Bioenergy	Oil Mallee	Saltbush Fodder	Habitat	Pulpwood	Bioenergy	Oil Mallee	Saltbush Fodder	Habitat
Archibald	443	9850	13.43	23.48	15.37	4.12	9.59	132	231	151	41	94
Beeamma	507	30388	17.51	26.90	17.27	4.62	10.77	532	818	525	141	327
Binnum	527	35965	19.81	28.83	18.34	4.91	11.43	713	1037	659	177	411
Bowaka	644	20717	28.32	35.97	22.29	5.97	13.90	587	745	462	124	288
Cannawigara	445	34640	13.43	23.47	15.37	4.12	9.58	465	813	532	143	332
Carcuma	400	25433	8.29	19.16	12.99	3.48	8.10	211	487	330	88	206
Colebatch	473	28081	14.21	24.14	15.74	4.21	9.81	399	678	442	118	276
Coneybeer	427	30525	12.70	22.87	15.03	4.03	9.38	388	698	459	123	286
Coombe	441	42515	11.71	22.03	14.57	3.90	9.09	498	937	620	166	386
Duffield	509	19462	17.91	27.24	17.46	4.67	10.88	349	530	340	91	212
Field	472	24233	14.21	24.14	15.74	4.21	9.81	344	585	381	102	238
Geegeela	496	27963	16.73	26.25	16.91	4.53	10.54	468	734	473	127	295
Glen Roy	512	21780	17.91	27.22	17.44	4.67	10.88	390	593	380	102	237
Glyde	478	24433	14.18	24.10	15.71	4.21	9.80	346	589	384	103	239
Hynam	532	33077	19.87	28.88	18.37	4.92	11.45	657	955	607	163	379
Jeffries	440	20796	12.81	22.96	15.09	4.04	9.41	266	477	314	84	196
Jessie	549	21516	22.00	30.67	19.35	5.18	12.07	473	660	416	111	260
Joyce (North)	567	16378	22.18	30.82	19.44	5.20	12.12	363	505	318	85	198
Kirkpatrick	408	23036	11.71	22.03	14.57	3.90	9.09	270	508	336	90	209
Lacepede	557	17272	22.32	30.93	19.50	5.22	12.16	385	534	337	90	210
Laffer	473	38493	15.98	25.61	16.55	4.43	10.32	615	986	637	171	397
Landseer	524	18924	19.15	28.28	18.03	4.83	11.24	362	535	341	91	213
Lewis	418	30160	10.01	20.61	13.79	3.69	8.60	302	622	416	111	259
Livingston	393	29982	10.49	21.01	14.01	3.75	8.74	315	630	420	112	262
Lochaber	534	21317	19.35	28.35	18.05	4.83	11.26	413	604	385	103	240
Makin	428	14153	10.52	21.04	14.02	3.76	8.75	149	298	198	53	124
Marcollat	505	34748	18.22	27.50	17.60	4.71	10.97	633	955	611	164	381
McCallum	434	16811	11.50	21.86	14.48	3.88	9.03	193	367	243	65	152
McNamara	500	26875	16.82	26.31	16.94	4.54	10.56	452	707	455	122	284
Messent	507	9421	16.10	25.63	16.55	4.43	10.32	152	241	156	42	97
Minecrow	561	26887	21.46	30.21	19.10	5.11	11.91	577	812	514	138	320
Mount Benson	601	22305	25.21	33.36	20.84	5.58	13.00	562	744	465	124	290
Murrabinna	578	16142	23.08	31.58	19.86	5.32	12.38	373	510	320	86	200
Naracoorte	549	20284	20.80	29.65	18.79	5.03	11.71	422	601	381	102	238
Neville	493	15517	18.07	27.37	17.53	4.69	10.93	280	425	272	73	170
Ngarkat	401	7551	8.59	19.42	13.13	3.52	8.19	65	147	99	27	62
Parsons	508	19066	17.17	26.61	17.11	4.58	10.67	327	507	326	87	203
Peacock	519	30706	18.46	27.70	17.71	4.74	11.04	567	851	544	146	339
Pendleton	454	36069	13.98	23.94	15.63	4.18	9.74	504	863	564	151	351
Petherick	503	31951	18.32	27.58	17.64	4.72	11.00	585	881	564	151	351
Richards	459	37753	12.83	22.98	15.10	4.04	9.41	485	868	570	153	355
Santo	489	10064	16.31	25.89	16.71	4.47	10.42	164	261	168	45	105
Senior	438	36751	12.31	22.53	14.85	3.98	9.26	452	828	546	146	340
Shaugh	437	34322	11.66	22.00	14.55	3.90	9.08	400	755	500	134	311
Spence (North)	558	19019	22.01	30.67	19.35	5.18	12.07	419	583	368	99	230
Stirling	459	36320	15.49	25.21	16.33	4.37	10.18	563	916	593	159	370
Strawbridge	440	19887	13.35	23.41	15.34	4.11	9.56	265	466	305	82	190
Tatiara	462	48028	13.16	23.23	15.24	4.08	9.50	632	1116	732	196	456
Townsend	597	26681	24.41	32.69	20.47	5.48	12.77	651	872	546	146	341
Wells	512	26543	18.01	27.26	17.46	4.67	10.88	478	724	463	124	289
Willalooka	492	35928	17.49	26.84	17.23	4.61	10.74	628	964	619	166	386
Wirrega	481	54898	16.93	26.36	16.96	4.54	10.58	929	1447	931	249	581
Woolumbool	528	30838	19.15	28.27	18.03	4.83	11.24	591	872	556	149	347
[Avg.] or Total	*[482]*	*1392454*	*[16.56]*	*[26.10]*	*[16.82]*	*[4.50]*	*[10.49]*	*22743*	*36072*	*23275*	*6233*	*14514*

Figure 34 – Estimated annual above-ground carbon dioxide sequestration of Habitat Species (unharvested).

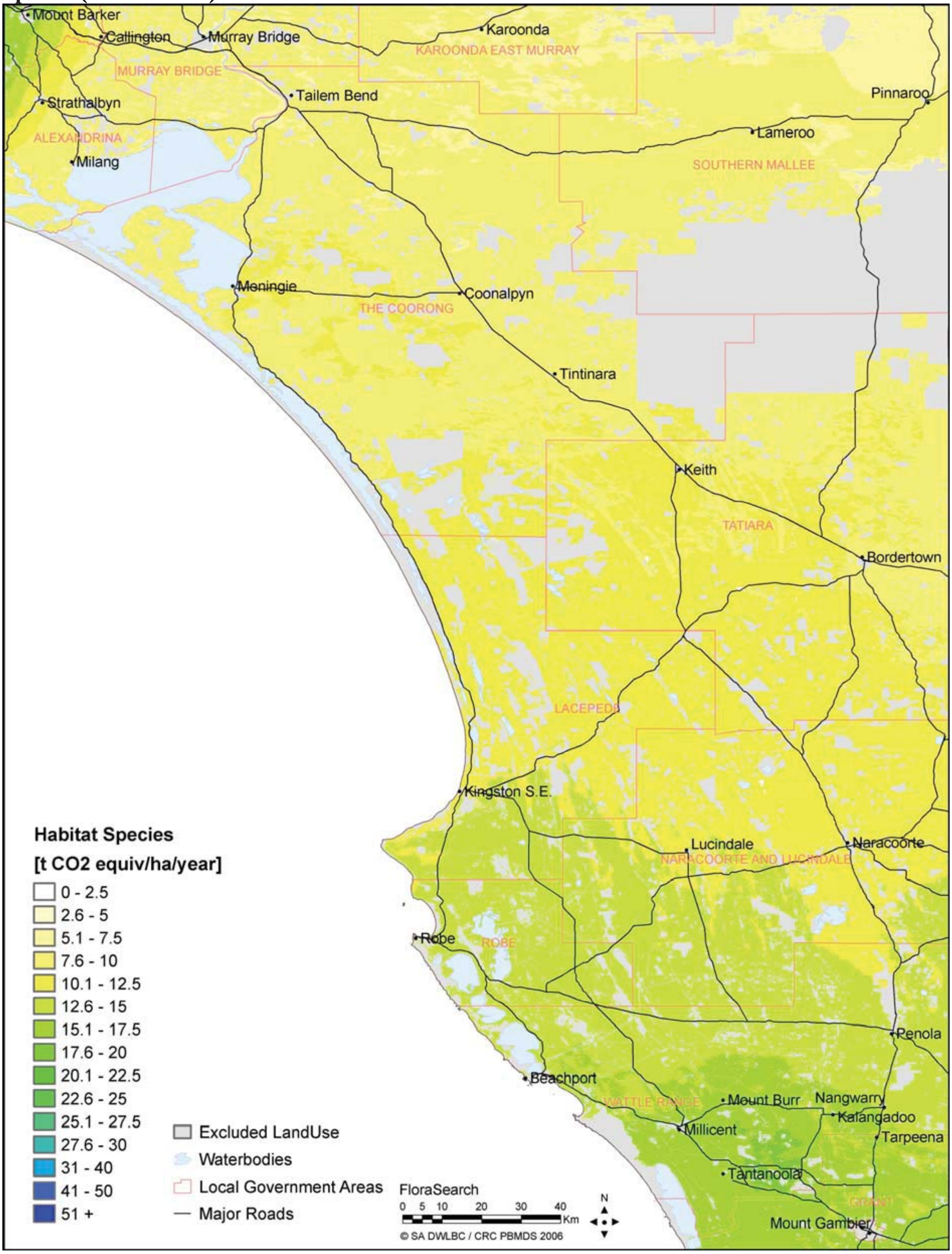


Figure 35 – Estimated annual above-ground carbon dioxide sequestration of Oil Mallee Species (unharvested).

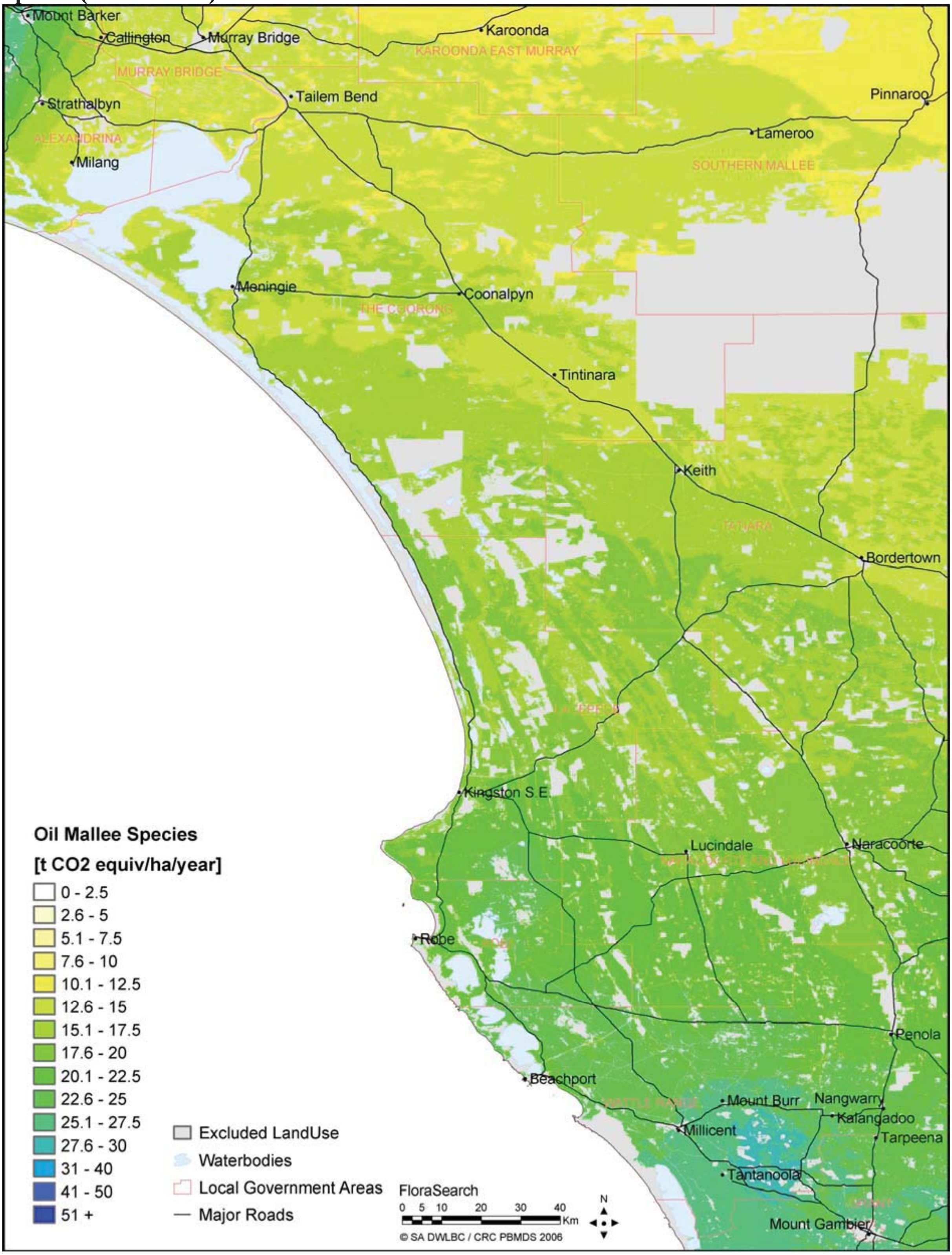


Figure 36 – Estimated annual above-ground carbon dioxide sequestration of Bioenergy Species (unharvested).

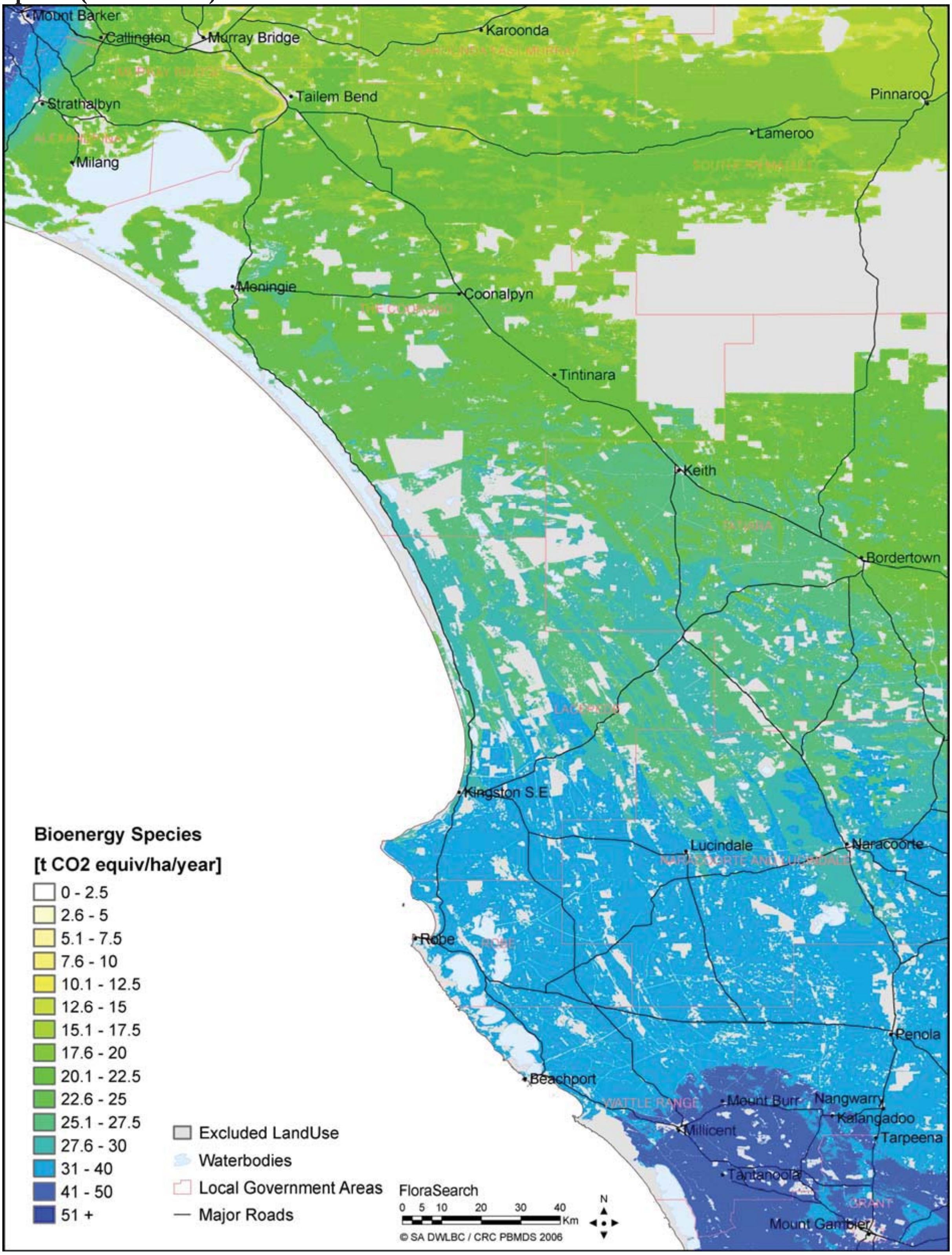


Figure 37 – Estimated annual above-ground carbon dioxide sequestration of Pulp and Fibre Species (unharvested).

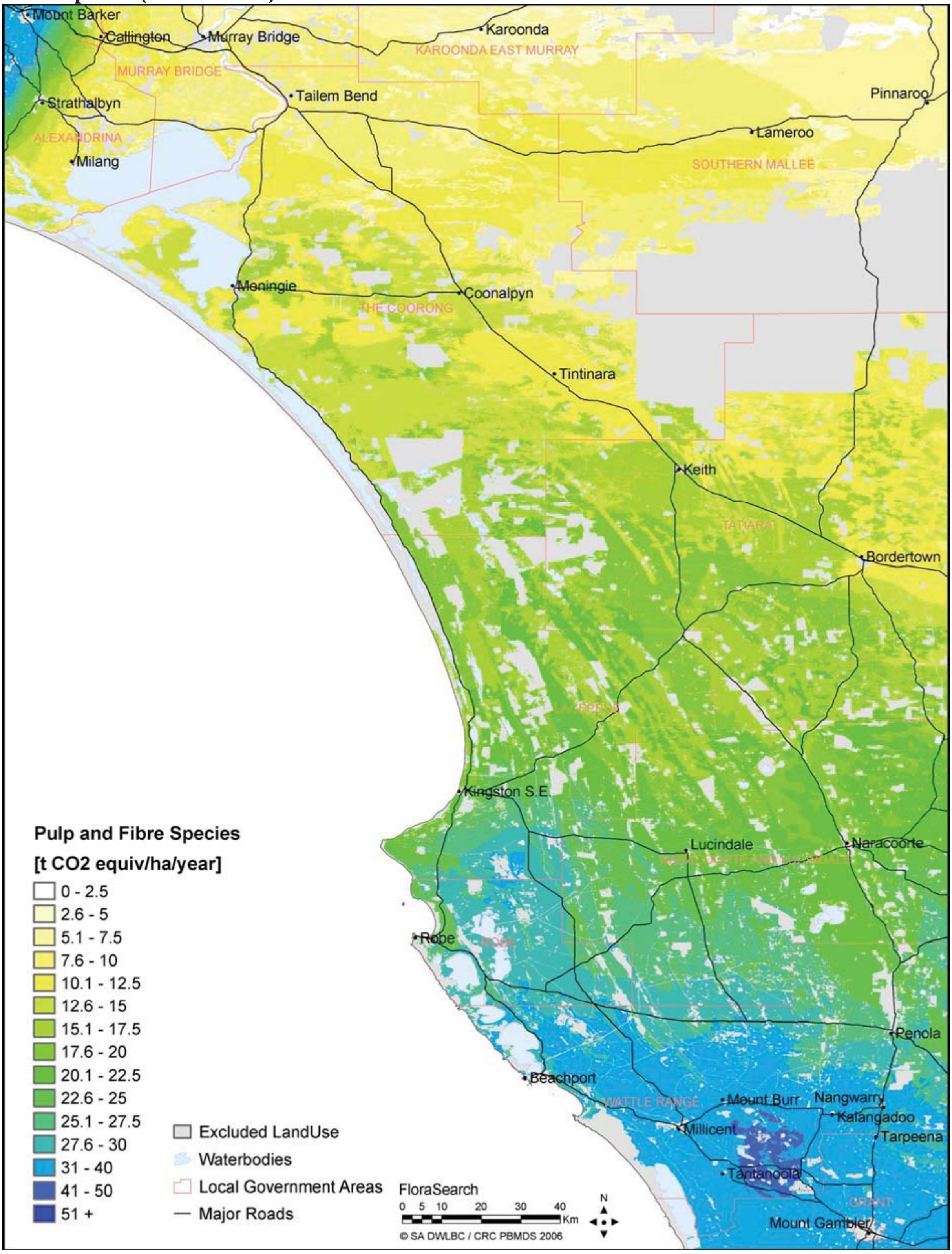
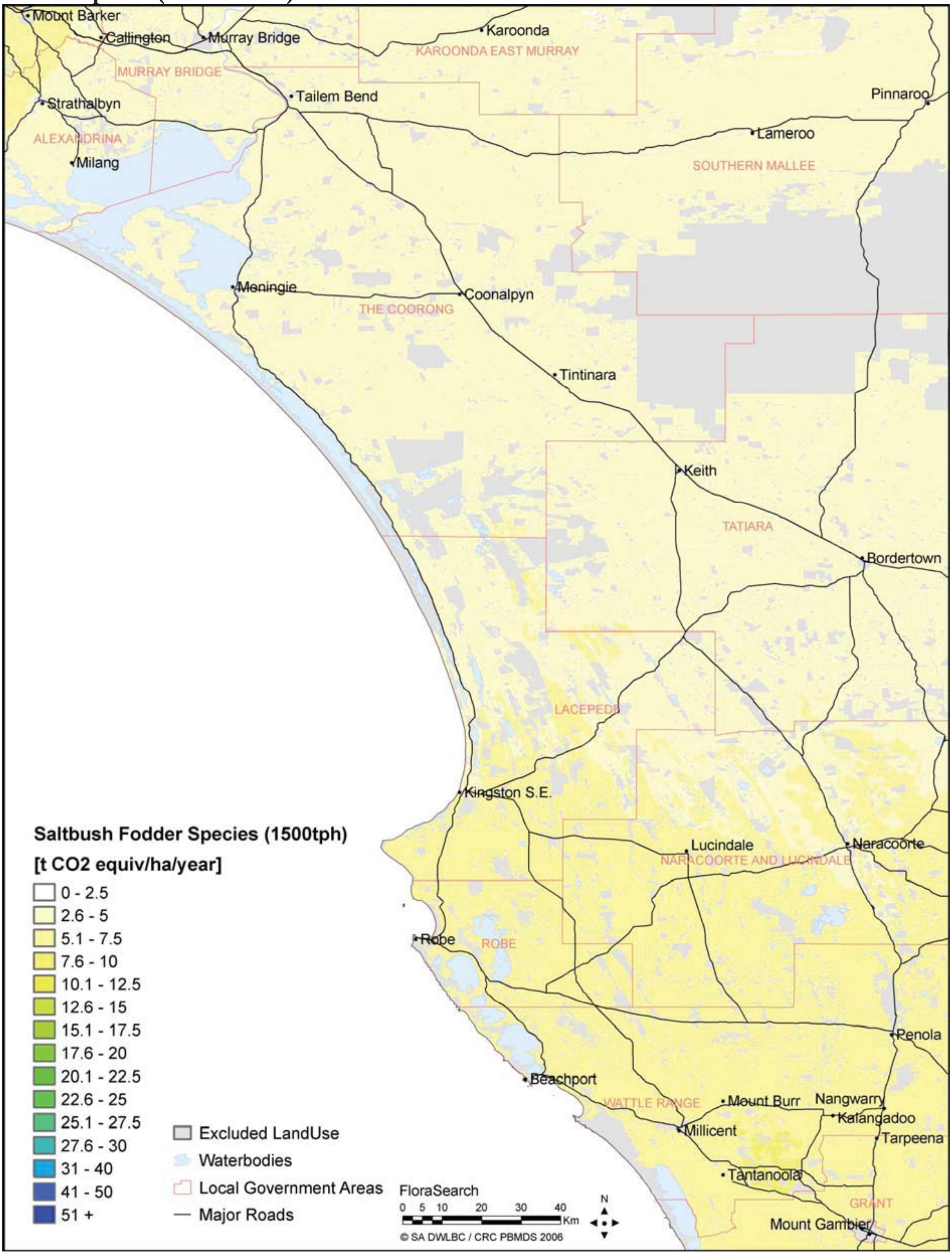


Figure 38 – Estimated annual above-ground carbon dioxide sequestration of Saltbush Fodder Species (unharvested).



4. Biomass Industries - Product and Market Directions

4.1 Introduction

FloraSearch and the WA Search reports (Hobbs *et al.* 2007, Bennell *et al.* 2007, Olsen *et al.* 2004) identified the most prospective industry types for the wheat-sheep zone of southern Australia. They identify the high priority or "best bet" industries and detail some emerging industries that may be serviced by woody crop production in the mid-low rainfall areas of Australia. New biomass related markets are emerging from a world environment of higher fossil fuel costs, climate change, environmental awareness and advances in technology. The following sections provide a summary of high priority industries relevant to South Australia and the Upper South East region.

4.2 High Priority Industry Types

4.2.1 Wood Fibre Industries

Wood fibre industries are already an important landuse in the higher rainfall regions of the southeast of South Australia. Radiata Pine (*Pinus radiata*) and Tasmanian Bluegum (*Eucalyptus globulus ssp. globulus*) are widely planted in the 600+mm annual rainfall zone predominantly south of Naracoorte. Wood pulp and paper products are currently produced at Kimberley-Clark Mills at Millicent and Tantanoola based on softwood fibres. Recently SA government development approvals have been given for a new pulp mill to be established near Penola and is planned to be operational by 2009. The consortium of companies developing this new mill include, Timbercorp, Orica, CellMark, Andritz and Silcar as Penola Pulp Pty Ltd, where they plan to produce hardwood pulp from Tasmanian Bluegum resources. Nearby in the western Victorian town of Heywood a further pulpwood mill is planned to utilise Australia hardwood species. Currently most hardwood chips are destined for export and transported to the deep water port of Portland in Victoria.

In the broader context Australian forest industries consume around 20 million cubic metres of broad-leaved and coniferous logs every year to produce lumber, paper products and panel products for Australian and export markets (ABARE 2004, 2005a, see Table 18). Approximately 71% of this consumption is based on softwood coniferous forests (mainly Pinus spp.) with the remainder based on hardwood Eucalyptus species. Additionally, the export of pulpwood chips consumes around 5.6 million tonnes of chips mainly from hardwood Eucalyptus species (see Table 19, Table 20).

Australian Bureau of Agricultural and Resource Economics (ABARE) statistics on paper and paperboards, fibreboards and particleboards (part of the wood based panel products sector), and woodchip components provide an indication of the scale and value of those market sectors within the current Australian forestry industry. These markets provide opportunities for new industry development in low rainfall zones to supplement or expand capacity in existing industries and markets. The paper and paperboard manufacturing industries consume the largest share by value (62%) of wood fibre supply in Australia, followed by woodchip exports (19%)

and secondary paper manufactures (eg. boxes etc, 12%). The Australian consumption and export of paper products, pulp and woodchips was worth over $ 4506M/year in 2004-2005. The total value of imports and exports of wood fibre panel products in 2004-2005 was $467M/year, and is dominated by medium density fibreboards (81% by value), primarily from export markets. The volume of Australian consumption of total paper and paperboards has increased by over 21% in the last 5 years, 4% for fibre-based wood panels, 146% for recovered paper, 11% for pulp and 12% for woodchips (see Table 21). These trends are also reflected in Australian consumption and exports of paper and paperboard products, fibre-based panel boards and woodchips. Australia imports ($2876M/year) a greater value of manufactured wood fibre products (paper and panel fibre/particleboards) than it exports ($1838M/year).

Table 18 – Volume of round wood consumed by Australian forest industries in recent years.

Roundwood consumed ['000 m^3]	**1997-98**	**1998-99**	**1999-00**	**2000-01**	**2001-02**	**2002-03**	**2003-04**
Broad-leaved							
Saw and veneer logs	3840	4015	4079	3562	3402	3623	3567
Wood based panel products	69	48	50	4	51	23	54
Paper and paperboard	2083	2407	3230	2568	1493	1595	1758
Other	130	111	383	388	421	440	407
Total	*6122*	*6580*	*7742*	*6522*	*5367*	*5681*	*5785*
Coniferous							
Saw and veneer logs	8258	8556	9425	8917	10793	10917	10739
Wood based panel products	1255	1039	1214	1026	953	1209	1012
Paper and paperboard	2412	2841	2623	2570	1881	1879	1951
Other	414	484	478	531	419	419	344
Total	*12338*	*12919*	*13740*	*13043*	*14046*	*14424*	*14046*
Broad-leaved and coniferous							
Saw and veneer logs	12098	12570	13504	12478	14195	14540	14306
Wood based panel products	1323	1087	1264	1029	1005	1233	1066
Paper and paperboard	4495	5248	5853	5138	3374	3474	3708
Other	544	595	861	919	840	859	750
Total	*18553*	*19549*	*21488*	*19565*	*19414*	*19433*	*19831*

Sources: ABARE 2004, 2005a

Table 19 – Quantity and value of wood fibre imports in Australia in the last five years.

Imports Quantity	Unit	2000-01	2001-02	2002-03	2003-04	2004-05
Wood based panels						
Particleboard	'000 m^3	43.9	70.0	93.0	60.5	65.2
Hardboard	'000 m^3	8.2	7.3	8.0	12.8	21.7
Medium density fibreboard	'000 m^3	88.3	81.4	77.3	47.2	27.7
Softboard and other fibreboards	'000 m^3	33.5	19.9	21.9	15.2	17.0
Total	*'000 m^3*	*173.9*	*178.6*	*200.2*	*135.7*	*131.6*
Paper and paperboard						
Newsprint	kt	283.9	224.3	273.3	303.5	314.0
Printing and writing	kt	760.3	822.2	970.6	1099.1	1186.5
Household and sanitary	kt	54.8	55.9	66.7	84.6	77.9
Packaging and industrial	kt	310.8	212.9	144.1	153.7	175.2
Total	*kt*	*1409.8*	*1315.3*	*1454.7*	*1641.0*	*1753.6*
Recovered paper	kt	41.2	31.0	35.2	22.1	55.8
Pulp	kt	303.4	314.5	359.0	376.6	350.3
Woodchips	kt	3.1	0.3	0.4	0.5	0.8
Imports Value	**Unit**	**2000-01**	**2001-02**	**2002-03**	**2003-04**	**2004-05**
Wood based panels						
Particleboard	$m	13.8	18.7	21.5	17.2	24.4
Hardboard	$m	5.5	7.1	6.0	10.7	18.8
Medium density fibreboard	$m	34.7	31.7	29.4	22.9	15.0
Softboard and other fibreboards	$m	9.7	8.3	11.8	7.1	8.4
Total	*$m*	*63.7*	*65.8*	*68.7*	*57.9*	*66.6*
Paper and paperboard						
Newsprint	$m	277.5	219.8	243.9	261.0	260.7
Printing and writing	$m	1181.7	1261.9	1446.1	1422.5	1442.7
Household and sanitary	$m	94.7	102.5	117.9	137.9	127.9
Packaging and industrial	$m	534.1	407.0	303.2	280.8	306.6
Total	*$m*	*2088.0*	*1991.3*	*2111.2*	*2102.1*	*2137.9*
Paper manufactures (secondary)	$m	377.5	372.4	409.9	375.3	442.0
Recovered paper	$m	8.8	4.6	8.0	4.7	2.3
Pulp	$m	316.6	221.3	253.7	235.1	225.1
Woodchips	$m	1.4	1.2	1.5	1.4	2.0

Sources: ABARE 2004, 2005a

Table 20 – Quantity and value of wood fibre exports in Australia in the last five years.

Exports Quantity	**Unit**	**2000-01**	**2001-02**	**2002-03**	**2003-04**	**2004-05**
Wood based panels						
Particleboard	’000 m^3	97.9	100.0	54.5	31.8	13.5
Hardboard	’000 m^3	12.8	11.0	7.7	11.5	7.8
Medium density fibreboard	’000 m^3	389.1	402.6	405.4	357.4	364.6
Softboard and other fibreboards	’000 m^3	10.4	14.1	26.5	17.5	14.5
Total	’000 m^3	*510.2*	*527.7*	*494.1*	*418.2*	*400.4*
Paper and paperboard						
Newsprint	kt	2.4	1.6	2.5	0.3	1.6
Printing and writing	kt	100.3	236.3	199.9	158.7	174.7
Household and sanitary	kt	20.2	23.7	51.2	35.2	36.6
Packaging and industrial	kt	405.7	411.5	483.2	596.5	567.7
Total	*kt*	*529.4*	*673.0*	*736.9*	*790.7*	*780.6*
Recovered paper	kt	246.1	301.5	296.6	343.2	649.8
Pulp	kt	17.8	9.1	3.0	1.2	4.7
Woodchips	kt	5004.1	4720.7	5437.1	5263.9	5598.3
Exports Value	**Unit**	**2000-01**	**2001-02**	**2002-03**	**2003-04**	**2004-05**
Wood based panels						
Particleboard	$m	26.5	26.7	17.4	11.3	6.4
Hardboard	$m	10.6	6.0	4.0	5.8	4.5
Medium density fibreboard	$m	150.6	162.4	145.6	112.4	118.9
Softboard and other fibreboards	$m	6.7	10.2	9.9	9.3	11.4
Total	*$m*	*194.4*	*205.3*	*176.9*	*138.8*	*141.2*
Paper and paperboard						
Newsprint	$m	2.6	1.3	0.9	0.2	0.7
Printing and writing	$m	145.6	284.9	213.2	170.1	182.3
Household and sanitary	$m	80.4	94.8	97.2	117.0	102.2
Packaging and industrial	$m	300.1	315.4	314.4	342.3	336.5
Total	*$m*	*528.8*	*698.7*	*625.7*	*629.6*	*621.7*
Paper manufactures (secondary)	$m	83.8	101.6	156.8	136.1	116.1
Recovered paper	$m	39.7	55.5	49.6	52.6	96.6
Pulp	$m	4.6	2.8	2.1	1.4	4.4
Woodchips	$m	743.8	712.0	808.0	794.4	858.2

Sources: ABARE 2004, 2005a

Table 21 – Volumes of production and imports of wood fibre products in Australia in the last five years.

Production and Import	Unit	2000-01	2001-02	2002-03	2003-04	2004-05
Wood based panels						
Particleboard	’000 m^3	947.9	1035.0	1118.0	1108.5	1008.2
Hardboard	’000 m^3	8.2	7.3	8.0	12.8	21.7
Medium density fibreboard	’000 m^3	800.3	813.4	863.3	842.2	821.7
Softboard and other fibreboards	’000 m^3	33.5	19.9	21.9	15.2	17.0
Total	*’000 m^3*	*1789.9*	*1875.6*	*2011.2*	*1978.7*	*1868.6*
Paper and paperboard						
Newsprint	kt	748.9	619.3	685.3	725.5	737.0
Printing and writing	kt	1314.3	1446.2	1534.6	1684.1	1790.5
Household and sanitary	kt	258.8	253.9	260.7	284.6	273.9
Packaging and industrial	kt	1759.8	1891.9	2036.1	2109.7	2155.2
Total	*kt*	*4081.8*	*4212.3*	*4515.7*	*4805.0*	*4956.6*
Recovered paper	kt	287.3	332.5	331.8	365.3	705.6
Pulp	kt	321.2	323.6	362.0	377.8	355.0
Woodchips	kt	5007.2	4721.0	5437.5	5264.4	5599.1

Sources: ABARE 2004, 2005a

Delivered price

Export woodchips

Export hardwood (broad-leaved) pulpwood chip prices are measured in term of Australian dollars per bone dry tonne ($/bdt). Recently these prices have increased by 11-57% from $93-146/bdt in 2001-02 to $162/bdt in 2005-06 (ABARE 2004, Neilson & Flynn 2006, Gunns 2006) with current exports having greater proportions of plantation woodchips. Timbercorp forestry chief Tim Browning reports that premium prices are paid ($181/bdt) for high quality chips from plantations (“The Age” 01/10/2006). Standards are high within this sector and purchasers demand woodchips virtually free of bark and other contaminants. Using a base price of $162/bdt and with a moisture content of approximately 45% by weight the 2006 freshwood chip value equates to approximate $90/green tonne for dryland plantation Eucalypts.

Australian Pulpwood

Australia pulpwood chips are typically valued per freshwood weight of approximately $80/green tonne for hardwood species and $50/green tonne for softwood species (George Freischmidt, pers. comm. 2006). Feedstocks need to meet high quality standards, with low bark contaminants, to attract the best prices. A feedstock that has already been chipped in-field with significant contaminants removed prior to delivery is likely to have an average value at closer to $85/green tonne at the mill gate.

Medium Density Fibreboard (MDF)

The current mill gate price of logs used for medium density fibreboard production in southeastern Australia is approximately $60/green tonne (range $50-70; George Freischmidt, pers. comm. 2006). These MDF log prices are dependent on logs with low contaminants, especially bark detritus. A feedstock that has already been chipped and cleaned in-field is likely to have an average value at closer to $65/green tonne at the mill gate.

Particleboard
Logs and other raw wood sources for particleboard production in southeastern Australia are currently valued at approximately $40/green tonne at the mill gate (range $30-50; George Freischmidt, pers. comm. 2006). Particleboard production can utilise poorer quality source material than paper and other fibreboard industries and are able to utilise sawdust, filler-like materials (eg. regrind) and other coarser source materials. Particleboard mills often utilise waste wood streams from nearby or adjoining sawmills (such as Benalla Particleboard Mill) which may result in poorer prices paid for alternate feedstock sources. A prechipped feedstock may attract a slightly higher premium of around $43/green tonne.

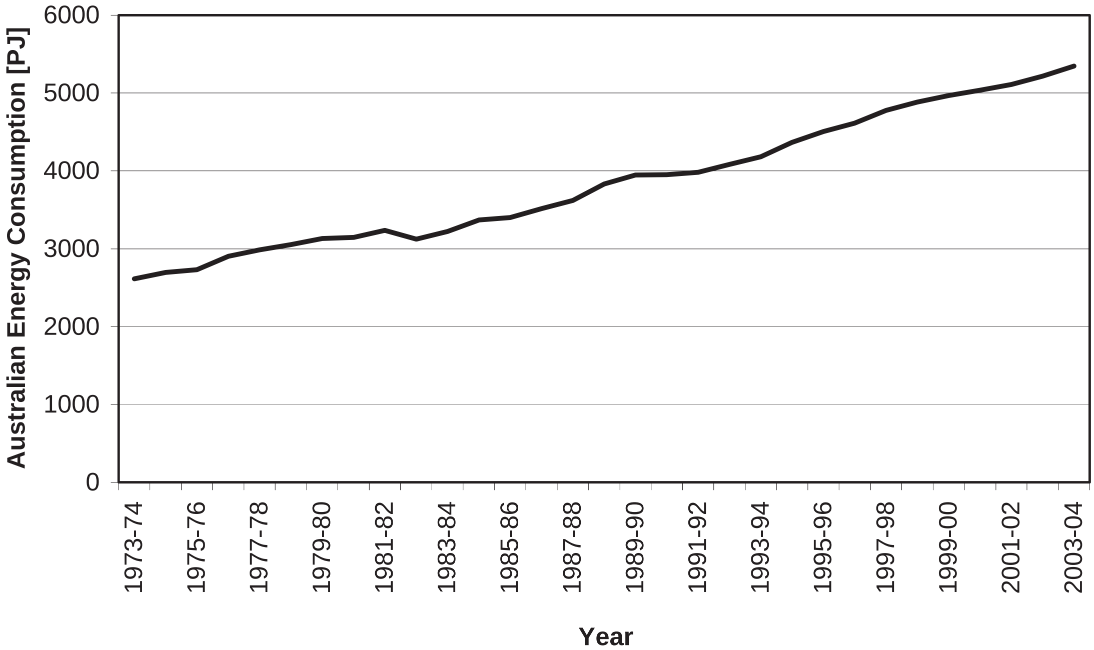
4.2.2 Firewood
There is already a great deal of interest in the production of firewood from the Upper South East region primarily to service the firewood markets in the Adelaide metropolitan and adjacent areas. Firewood is a moderately high value wood product and that can provide farmer returns within a relatively short period after initial investment. Firewood production systems can readily utilise the resprouting or coppicing nature of many Eucalyptus species and alleviates or minimise future woodlot establishment costs. Many of the currently preferred firewood species are well adapted to the Upper South East region, including Sugargum (*Eucalyptus cladocalyx*), Redgum (*E. camaldulensis*) and many mallee eucalypt species.

The commercial viability of firewood production in the Mount Lofty Ranges region of South Australia has been evaluated by several authors in recent years (eg. Bulman *et al.* 2002, Poynter & Borschmann 2002, Geddes Management 2003, Mt Lofty Ranges Private Forestry 2006). They indicate that the Adelaide and outer metropolitan market consumes around 150,000 - 180,000 tonnes of firewood per annum, of which approximately 65,000-90,000 tonnes is acquired through commercial vendors. Modest markets also exist in major regional centres, notably Mount Gambier, Murray Bridge and Naracoorte.

Delivered price
Wholesale delivered prices of cut and split Eucalypt firewood in the metropolitan market is reported at $125 per air dried tonne (Poynter & Borschmann 2002) with allowances for inflation a current price would be in the vicinity of $135 per air dried tonne. This estimate is at the conservative end of 2006 reports of $140 - 150 per air dried tonne with a maximum moisture content of 20% (Peter Bulman, pers. comm.). Assuming no cost for air-drying a conservative price estimate equates to around $100 per fresh weight tonne.

4.2.3 Bioenergy (electricity generation)
Australia currently consumes around 5500 Petajoules (1 PJ = 10^{15} joules) of energy ever year across our industrial, mining, agricultural, commercial and residential sectors (see Figure 39). Approximately 900PJ of energy is used to generate electricity (see Table 22). In Australia electricity generation is predominantly based on black and brown coal deposits with current ABARE (2005b) forecasts expecting this heavy reliance on coal resources to continue. Our major coal resources, used to generate electricity, are widely variable in their inherent energy values largely due to their variable moisture and carbon contents (see Table 23). The value of thermal coals for both domestic and export markets has increased by at least 12% in recent years (ABARE 2005b).

Figure 39 – Total energy consumption across all energy sectors in Australia since 1973-74.



Source: ABARE 2005b

Table 22 – Current and projected electricity generation by fuel type in Australia.

Electricity generation, by fuel	2004-05 [PJ]	2009-10 [PJ]	2014-15 [PJ]	2019-20 [PJ]	2029-30 [PJ]
Thermal					
Black coal	469	513	578	640	757
Brown coal	187	199	211	226	256
Oil	11	11	12	13	15
Gas	128	157	184	221	321
Total thermal	796	880	985	1101	1349
Renewables					
Hydro	58	61	61	62	65
Wind	5.5	13.5	20.9	21.7	28.4
Biomass	3.3	5.4	7.4	11.2	23.1
Biogas	2.1	4.7	5.2	5.8	7.7
Total renewables	69	85	94	101	124

Source: ABARE 2005b

Table 23 – Energy content of major solid fuels in Australia.

Type by Location	GJ/t		GJ/t
Black coal		***Black Coal (cont)***	
New South Wales		Western Australia	
Exports		Steaming coal	19.7
– coking coal	29.0	Tasmania	
– steaming coal	27.0	Steaming coal	22.8
Electricity generation	23.4		
Steelworks	30.0	**Brown Coal / Lignite**	
Washed steaming coal	27.0	Victorian brown coal	9.8
Unwashed steaming coal	23.9	South Australia	15.2
Queensland		Brown coal briquettes	22.1
Exports			
Coking coal	30.0	**Other**	
Steaming coal	27.0	Coke	27.0
Electricity generation	23.4	Wood (dry)	16.2
Other	23.0	Bagasse	9.6

Source: ABARE 2005b

The average gross calorific value of fresh weight biomass from Australian hardwood species is greater than some coal deposits used to generate electricity in Australia (see Table 24). Many current coal powered generation plants can readily accept 5% plant biomass blended with coal with no requirement for engineering modifications. Higher proportions of plant biomass are likely to require only minimal engineering changes in generation facilities. Smaller scale bioenergy plants can readily utilise existing thermal gasifier technologies combined with steam turbine power generation plant and operate solely on woody biomass.

Delivered price

Based on values of export thermal coal prices, relative calorific value of Eucalyptus and Acacia species compared with export grade Australian coal deposits a likely delivered price of whole plant woody biomass for electricity generation would be $28/fresh weight tonne.

Table 24 – The calorific value and carbon content of selected Australian hardwood species.

Species	Gross Calorific Value [#1] [GJ/dry t]	Carbon Content [#1] [%dry weight]	Moisture Content [#2] [%fresh weight]	Gross Calorific Value [GJ/fresh weight t]
Acacia saligna	19.1	49.4	42.7	10.8
Atriplex nummularia	16.8	42.3	50.1	7.1
Corymbia maculata	19.1	48.7	53.2	8.7
Eucalyptus camaldulensis	19.4	49.5	60.3	7.6
Eucalyptus cladocalyx	19.0	49.0	48.3	9.6
Eucalyptus cneorifolia	19.9	49.9	43.1	11.5
Eucalyptus globulus	19.2	49.1	53.4	8.8
Eucalyptus grandis	18.8	48.8	55.0	8.1
Eucalyptus horistes	20.0	49.0	37.7	12.6
Eucalyptus occidentalis	19.0	49.3	49.9	9.3
Eucalyptus sideroxylon	19.9	50.9	48.0	10.5
Eucalyptus polybractea	19.7	48.7	45.0	10.9
Melaleuca uncifolia	20.9	52.0	38.7	13.4
Average Eucalypt/Acacia	**19.4**	**49.3**	**48.8**	**9.9**

Sources: [#1]CSIRO Biofuels Database 2006; [#2]Average moisture content of whole native plants Hobbs & Bennell 2005 & this study.

4.2.4 Eucalyptus Oil

The world consumes around 3000 tonnes/year of Eucalyptus oil (mainly cineole), which is mainly produced in China, Portugal and India (OMC 2006). Australian production is ~7% (200 tonnes) of the world's production and is primarily destined for specialty fragrance markets. Chinese *Eucalyptus globulus* oil production is forecast to produce 5000 tonnes in 2006 with an expectation of prices remaining stable (FDL 2006). The cineole within Eucalyptus oil is used as a degreasing agent and solvent. Large potential markets exist for this purpose after the implementation of measures to eliminate the use of the petrochemical based Trichloroethane, an ozone depleting chemical, during the 1990s. Other essential oils extracted from Eucalyptus leaves are very highly prized for their medicinal, antifouling and other properties which would attract premium prices in niche markets. Recent reports (GHC 2006) have priced this year's *Eucalyptus globulus* oil at US$4.40/kg (A$7.52/kg using US dollar exchange rate of 0.5850, RBA 29/03/2006), Eucalyptol (cineole 99.5%) at US$6.50/kg (A$11.11/kg) and Brazilian *Eucalyptus (Corymbia) citriodora* oil at US$7.50/kg (A$12.82/kg).

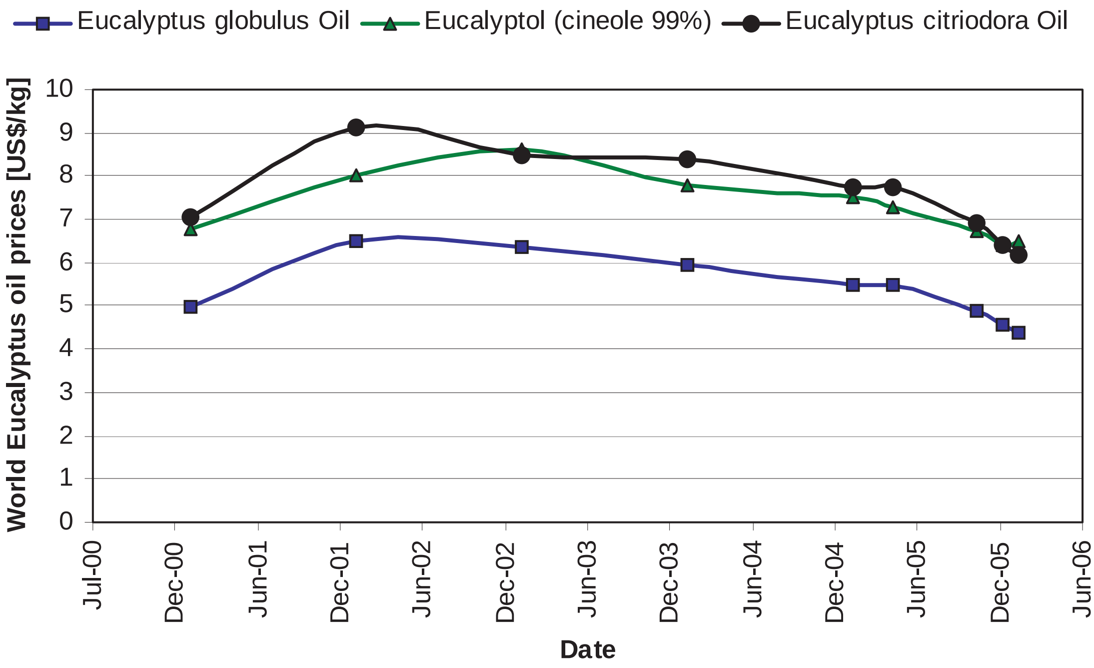
Petrochemical-based solvents and adhesives have increased in cost due to sustained higher world oil prices. Carcinogenic adhesives and preservatives (eg. formaldehyde) are also being phased out of composite wood manufacturing processes around the world. These events have resulted in an improvement market potential and price of many biomass extractives in local and international sectors. ABARE (2004,2005; see Table 25) reports on the high import and export value of wood and biomass extractives, and the stable demand for essential oils and the demonstrated increasing value trend of lacquers, gums and resins in Australian exports and imports.

Table 25 – The value of extractives and other miscellaneous forest products.

Miscellaneous forest products	Unit	2000-01	2001-02	2002-03	2003-04	2004-05
Imports						
Lac, gums and resins	$'000	6289	7998	8307	7288	10087
Essential oils	$'000	10839	10437	12750	11391	11066
Rosins and wood tar	$'000	251	151	97	87	34
Fuel wood	$'000	65	75	79	40	69
Wood charcoal	$'000	354	276	287	590	806
Exports						
Lac, gums, resins etc	$'000	1901	2348	1148	1918	9750
Eucalypt oils	$'000	1981	2175	1783	2965	2003
Rosins and wood tar	$'000	638	533	398	73	12
Fuelwood	$'000	1853	23	20	2003	32
Wood charcoal	$'000	1342	2068	2070	2655	3412

Source: ABARE 2005b

Figure 40 – Trends in world market prices of Eucalyptus oils in recent years.



Source: FDL 2006

Delivered price

The price of Eucalyptus oil produced from Western Australia mallee species currently ranges between $7/kg to $12/kg for specialty and pharmaceutical use (OMC 2006). Industrial grade and volumes of oil are expected to only attract a price of about $3/kg. Current best selections of mallee Eucalypt species have cineole contents of over 8% per dry tonne of leaves. Conservatively, dry leaf oil yields of around 4.6% are more likely and with a leaf moisture content of around 58% the oil content of leaf fresh weight equates to about 2.7%.

Using in-field processing with mobile distillers and a bulk oil price of $3/kg values the leaf fraction at $80/freshweight tonne, and at an oil price of price of $7.52/kg the gum leaves are worth $200/freshweight tonne.

4.2.5 Integrated Wood Processing Plant (oil / charcoal / bioenergy)

The development of an integrated wood or tree processing (IWP or ITP) demonstration plant at Narrogin in WA has been reported in depth by Western Power (2006) and Enecon (2001). Most of the engineering of the IWP plant was completed in 2005 and tested during 2006. The concept is based on utilising in-field chipping harvest technologies to deliver 20,000 tonnes of chipped mallee (Eucalyptus spp.) wood, twigs and leaves to the plant per annum for processing to produce 7.5 GWh/year of electricity, 690 tonnes/year of activated carbon, and 210 tonnes/year of Eucalyptus oil. The IWP plant incorporates a fluidised bed carbonising plant, steam distillation plant, thermal gasifier spent leaf combustor plant and a 1 MW steam turbine power generation plant. Additional benefits will be derived from greenhouse gas abatement scheme from renewable energy generation, rootmass fixation and standing woody crop biomass.

Delivered price

Initial projections valued the delivered feedstock at $30 per green tonne (Enecon 2001). However, given inflation costs since 2001, the increased markets and value of energy resources (> +12% price/tonne for steaming coal), wood charcoal (+149% gross value, see Table 25) and Eucalypt oils (+2% gross value) a higher delivered feedstock value around $36 per green tonne or more could be expected.

4.2.6 Fodder Industries

There are several broad segments of Australian fodder industries, including on-farm meat production, on-farm wool production, feedlot production of meat and livestock feed manufacture. All these segments required a primary resource of livestock fodder, which is presently based on predominantly annual crops of pasture and cereals. However, some herbaceous perennial plant species (predominantly lucerne) are widely utilised, and highly valued, for their provision of green feed or nutritious hay for dry season fodder in the paddock or as a feedlot resource.

On-farm Meat and Wool

Gross value of Australian farm production for livestock slaughterings and production was approximately $17.8 billion dollars in 2004-05 (MLA 2006), based on herds of 102.7 million sheep and lambs, and 27.7 million cattle and calves. The Australian red meat market has strengthened in recent years. The strong demand has generally driven up livestock and meat prices.

The number of sheep currently shorn for wool in Australia (106 million head in 2004-2005; AWI 2006) has decreased by around 32% since 2000-01 (140 million head). Australian Wool Innovation forecasts the 2005-06 shearings will be approximately 106 million head producing around 456 million kilograms of greasy wool. An offset to the lower production values in recent years has been the increasing proportion of production of higher value low micron fine wools.

Australian Feedlots and Stockfeed Manufacturers

The Australian Lot Feeders' Association reported (ALFA 2006) that the turn-off of lotfed cattle for 2005 was a record 2.61 million head. The feedlot holding of cattle in December 2005 was around 734,000 head at 67% of total current capacity (1.1 million head). In the December 2005 period there was 16,654 head of livestock held in South Australian feedlots, representing 2.3% of the national feedlot herd.

The stockfeed manufacturing industry utilises a wide range of agricultural resources, including cereal grains, legume grains, oil seeds, protein meals, cereal milling co-products, hays and other fibre sources, to produce a variety of meals, fibres, supplementary pellets, ration and finishing pellets. Australia's annual consumption of manufactured stockfeed has doubled since 2003 (4.95 million tonnes) to about 10 million tonnes in 2005 (SFMCA 2006). The greatest consumption by volume of manufactured stockfeed is in the dairy (27.2%), poultry (27.1%), feedlot beef (24.6%) and pig (16.4%) industries. The demand and prices of these products is closely tied to local and export livestock markets.

Perennial Shrub Fodder Sources

Lucerne is highly nutritious and widely used forage in southern Australian livestock industries. It is a relatively adaptable species suited to a variety of climates and soil types in Australia. Even with extensive breeding and selection programs lasting many years it still fails to perform as a dryland crop in some areas, especially in lower rainfall regions (<500mm) and on soils that are shallow, acidic, high in exchangeable aluminium or sodium salt, or with hostile subsoils. Many livestock palatable Australian chenopods (eg. saltbushes, bluebushes) are more suited to drier and harsher environments, so are many Australian Acacias, other Fabaceous genera, and other palatable native species. Many species from this group have a long history of use as livestock fodder plants in relatively natural Australian rangelands. Over the years a few species have been planted specifically for use as fodder crops.

The most widely used and valued of these is the easily propagated, fast growing, readily managed and grazing tolerant Oldman Saltbush (*Atriplex nummularia*). Early Australian selection programs commenced around 50 years ago, with some small advances in nutritional status in that time. Over the last decade some further selections and clonal reproduction by private industry has been used to make more nutritious and better forms of Oldman Saltbush (eg. "Eyre's Green" cv Topline Nursery - crude protein [CP] of 14.4% dry matter, digestibility of 34% of dry matter, metabolisable energy [ME] 5.1 MJ/kg dry matter)). Interest also exists in several other Atriplex species (eg. *A. amnicola, A. cinerea, A. vescicaria*). Acacia species, although often palatable to livestock and with some species tolerant to grazing pressure, are generally lower in their nutritional value and harder to digest.

Oldman saltbush and the exotic Tagasaste or Lucerne Tree (*Chamaecytisus* spp.) have been widely used in southern Australia as fodder shrub crops over the last decade. Early research on Oldman Saltbush on saline affected landscapes has painted a poor picture of its nutritional status (Lefroy 2002) largely due to high salt loads in the foliage from these environments. However, the salt load in the foliage is much less significant on non-saline affected sites. Further, Oldman saltbush provides a valuable green feed resource during summer and autumn when other typically annual fodder species are desiccated making its livestock value higher and more equivalent to that of lucerne.

Delivered price

Lucerne hay has an average crude protein (CP) of 20 % of dry matter and metabolisable energy (ME) of 9 MJ/kg dry matter and clover hay has CP 12% and ME 9 MJ/ kg. Other highly valued fodder resources include cereal barley (CP 10%, ME 12) and peas (CP 24 %, ME 13) (FeedTest - Agriculture Victoria, 2006). As Oldman Saltbush's dry weight nutritional value (CP 20-25%, ME 11-12, digestibility 76-80%) often exceeds that of the highly valued lucerne, the fodder value of saltbush is similar to that of lucerne. Recent Autumn season prices of hay for sale from the Australian Fodder Industry Association (March 2006, for SA, Vic. & NSW, moisture content ~10%) shows lucerne hay is valued at $211/t (range $154-242/t), pure clover hay $177/t ($170-180/t), clover/rye pasture hay $153/t ($120-160/t) and oat hay $146/t ($135-150/t).

The value of fodder and hay is seasonally sensitive and may increase by 50% in price over the course of year (even higher during drought events). In 2005 lucerne hay in NSW reached values of $350-400/t (AFIA 2006). Allowing for moisture contents of the different products, and the slight diminishing nutritional value due to salt content in some Oldman Saltbush (*Atriplex nummularia*) stands (say -10%) and seasonal variations in demand, saltbush leaves and fine twigs are worth between around $45/green tonne (winter-spring) when other fodder is readily available, and $65/green tonne (summer-autumn) when competing directly with other equally high quality hay products. In modest drought conditions (like 2005 in NSW) saltbush fodder value could reach $123/green tonne. The current drought affecting much of southeastern Australia will probably push these prices even higher in Autumn 2007.

4.2.7 Carbon Sequestration

The potential for carbon trading has become a significant factor in evaluating the economics of long-term perennial vegetation as permanent sinks but there is also increasing interest in the carbon stores held in harvested perennial crop systems such as classical forestry and other shorter rotation agroforestry crops. European carbon dioxide trading has been active since early 2005 and has since traded well over 400 million tonnes of CO_2 (ICE 2006). In Australia, the carbon trading market has yet to fully take off, but NSW has mandated carbon emissions controls and other state governments and private corporations are already gearing up for carbon trading.

The current European price suggests that carbon sequestration alone may be economically viable for revegetation in some landscapes and regions. Additionally, commercial woody crops may also include the average standing biomass of these crops as a carbon sequestration value, or even the long term carbon stored in the roots and accumulated soil carbon of these crops, as a contributor to the economic value of these perennial farming systems.

Delivered price

International trade currently values a tonne of carbon dioxide at €12.85/tonne (European Climate Exchange average trade-weighted price 29/09/2006; http://www.ecxeurope.com) and with an exchange rate of A$1= €0.5891 (on 29/09/2006, RBA 2006) puts carbon dioxide tradeable value at around A$21.81/t. Near future average prices for 2007 and 2008 are expected to be €13.30/t and €16.15/t respectively. From our destructive samples the average ratio between fresh weight whole plant biomass and carbon dioxide equivalent is 1:0.891. Using this ratio and European September 2006 trade prices equates to a value of A$19.43 per fresh weight tonne of above ground biomass.

4.3 Emerging Industry Types

4.3.1 Industrial Carbon (carbonised wood and charcoal)

The refining of metal oxides requires carbon as a reducing agent. Coke, a derivative of coal, is currently the major source of carbon used for metal refining. The steel industry in Australia consumes around 5.2 million tonnes of black coal for this purpose (ACA 2006). The interest in the use of renewable sources of carbon for mineral processing is increasing. In Australia some mining companies have been exploring the potential of renewable carbon for metal refining. Coal is also used extensively in cement manufacture and uses about 0.9 million tonnes per year. The current developed world traded market for wood charcoal is approximately 1 million tonnes/year (OMC 2006).

Steam treatment of charcoal is used to create the highly valued activated carbon. The special property of activated carbon is its ability to preferentially absorb chemicals, ions and odours. A property utilised widely for water treatment, gold recovery and in the food and beverage industry. The world market for activated carbon around 700,000 tonnes/year (140,000 tonnes/year for water treatment alone) and is currently increasing by about 4-5% each year (OMC 2006). Australian markets for activated carbon (excluding gold refining) is approximately 3000 tonnes/year and is conservatively worth an estimated $1800/tonne.

The metallurgical industry faces increasing pressure to reduce emissions of greenhouse gases (GHG) from production of metals. The substitution of fossil carbon by renewable carbon from biomass has the potential to radically reduce the net carbon emissions from metallurgical processes. The high reactivity and low sulphur content of charcoal makes it an attractive metallurgical reductant. Especially in new technologies, such as bath smelting (eg HIsmelt) which use granular carbon rather than lump size high strength coke, potentially all of the fossil carbon could be replaced by renewable carbon. It may also be possible to substitute charcoal for coal in other processes such as synthetic rutile production in rotary kilns where high reactivity is beneficial and the strength of the carbon is less critical. This opens up a large potential range of markets for wood carbons as reductants.

Current research by the Centre for Sustainable Resources Processing and the Cooperative Research Centre for Plant-based Management of Dryland Salinity shows that there is potential to greatly reduce the charcoal cost and to increase the reactivity of the charcoal by using the twig and leaf fraction of mallee biomass. This material could be valued at ~$10 green tonne and be converted to charcoal at ~$100/tonne bringing it well into the competitive range.

4.3.2 Liquid Fuels from Woody Biomass

Australia's petrol and diesel fuel consumption in 2005 was 34,110ML (45% diesel, 55% petrol; DITR 2006) and the world price of oil has escalated from around US$25 in 2001 to over US$60/barrel in 2006 (EIA 2006). Although initially predictions that the current high price is only a short term prospect there are currently no clear indicators to suggest that oil will return to around US$35 a barrel that was often prophesised in 2004. The Biofuels Taskforce (2005) has recently reported to the Prime Minister on status, potential and issues of biofuels development and adoption in Australia. This report states a target of 350ML of biofuels by 2010 and draws upon Australian Bureau of Agricultural and Resource Economics' analyses of the viability of ethanol and biodiesel in the current policy and market environment. They report that biofuels are currently competitive and will remain so until around 2015 when current government excise assistance is reduced. They recommend that the potential of lignocellulosic feedstocks for ethanol production be thoroughly assessed before any major commitment is made to other ethanol feedstocks and production opportunities.

ABARE's models are based on assumed oil price of US$32/barrel and an US$/A$ exchange rate of 0.65. They also state, *"Should the long-term oil price be higher, all other things being equal, the commercial viability prospects of biofuels would improve."* They conclude, based on an US$/A$ exchange rate of 0.65, that ethanol producers would remain viable beyond 2015 with a oil price of US$42-47/barrel without government assistance, and biodiesel producers would require an oil price of US$52-62/barrel to remain viable without assistance.

The technologies of converting woody biomass to produce ethanol have progressed substantially in the last two years. Globally, there has been significant investment and progress in lignocellulosic ethanol technologies for bio-fuels. Lignocellulosic biomass can be converted to ethanol by hydrolysis where the cellulosic part is converted to sugars and subsequent fermentation converts these sugars to ethanol. To increase the yield of hydrolysis a pre-treatment step softens the biomass and breaks down cell structure to a large extent. There are several options for pre-treatment and hydrolysis but current technological development is focused on enzymic hydrolysis which requires very mild process conditions, while giving good yield, lower capital investment and less environmental risk. This technology is relatively immature requiring an expected 10 years before being industrially adopted but it provides the possibility for significant improvements in production costs.

A number of pilot plants have been commissioned that will adopt these new technology options and include Iogen's plant in Ottawa (http://www.iogen.ca/), Canada that can process 40 t/day of wheat straw and poplar and Abengoa (http://www.abengoabioenergy.com/) is building a 200 million l/yr plant utilising 50% agricultural waste for feedstock. Biodiesel production is mostly derived from oilseed plants such as canola versus pyrolysis from woody feedstock. However, new technologies are emerging to create other bio-oils from woody feedstocks (Enecon 2006).

4.3.3 Other Extractives

There are probably many chemicals that might be commercially extracted from large volume biomass feedstocks. We recognise the potential economic importance of additional revenue that might accrue from being able to extract an additional product. One such product has emerged over the past couple of years due to the work of Professor Bill Foley at ANU. There is a class of chemicals that occur in the leaves of many species of *Eucalyptus* called formylated phloroglucinols compounds (FPCs). One such compound called sideroxylonal has been shown to have potent anti-fouling properties when applied to the hulls of ships. One of the main mallee species used in WA *Eucalyptus loxophleba* spp *lissophloia* has been shown to have the highest recorded content of sideroxylonal. Sideroxylonal content is strongly correlated with eucalyptus oil content. It is not steam extractable and would need a separate process but it appears that such a step could be readily incorporated into an integrated process.

4.4 Summary of Biomass Commodity Values 2006

The estimated 2006 value and likely range of each FloraSearch industry commodity type at corresponding mill gate, port, delivery centre or *in situ* locations is listed in Table 26.

Table 26 – Summary of estimated 2006 delivered feedstock values and markets by industry type.

Industry and Commodity Type	Delivery Location	Likely delivered range [$/freshweight tonne]	Likely delivered value [$/freshweight tonne]	Market Price Trend
Export pulp - woodchip	Port	80 - 100	90	increasing to stable
Australian pulp - woodchip	Mill	75 - 95	85	increasing to stable
Australian MDF - woodchip	Mill	50 - 75	65	increasing
Australian particleboard - woodchip	Mill	30 - 53	43	stable
Firewood (bulk supply)	Distribution Centre	90 - 110	100	stable
Electricity generation - whole plant biomass	Power Plant	25-31	28	increasing
Eucalyptus bulk oil - leaf	Mobile Processing Plant	60 - 100	80	increasing
Eucalyptus essential oil - leaf	Mobile Processing Plant	180 - 220	200	decreasing to stable
Integrated wood processing - whole plant biomass	Processing Plant	32 - 40	36	increasing
Carbon sequestration - whole plant biomass	In situ	10 - 46	20	increasing
Fodder - Saltbush leaf (Autumn)	In situ/Paddock/Mill	55 - 123	65	increasing
Fodder - Saltbush leaf (Spring)	In situ/Paddock/Mill	40 - 65	45	increasing
Activated charcoal - woodchip	Processing Plant			increasing
Industrial carbon - woodchip	Port or Smelter			increasing to stable
Liquid fuels - whole plant biomass	Processing Plant/Refinery			increasing to stable

5. Regional Industry Potential Analysis

5.1 Introduction

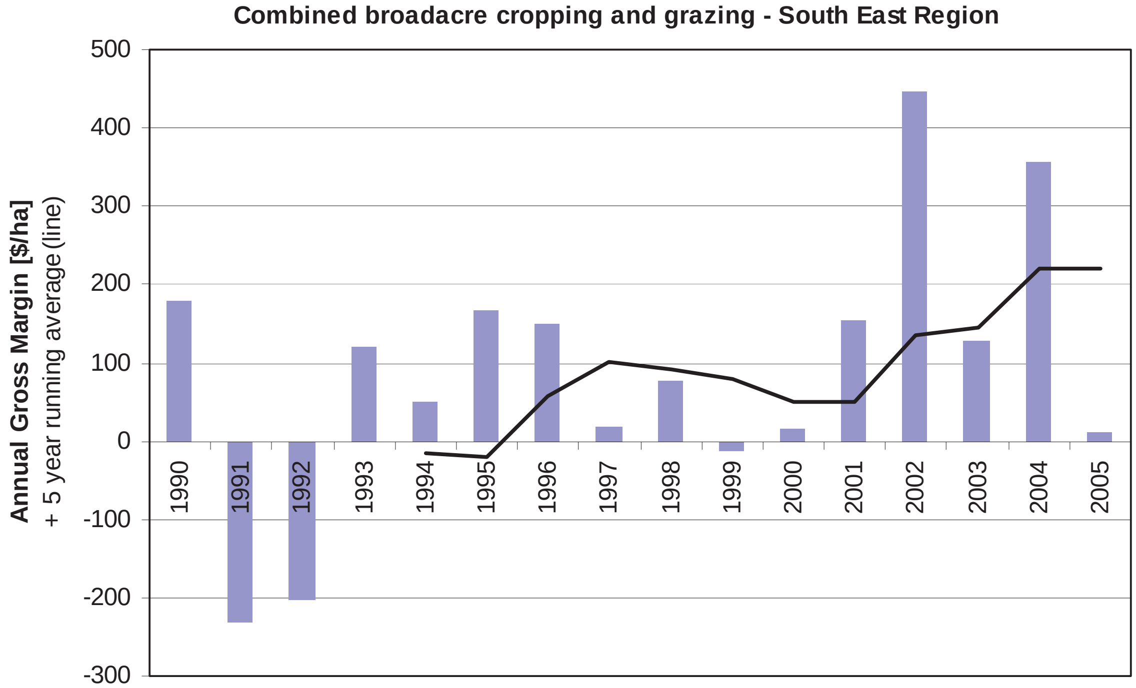
The *Regional Industry Potential Analysis* (*RIPA*) is a methodology for evaluating the potential plantation productivity and industry product yields, economically optimum harvest intervals of woody crops, landholder annual equivalent returns (AER) from each industry type and location, and sensitivity analyses. The methodology of the *Regional Industry Potential Analysis* is detailed in the FloraSearch reports (Bennell *et al.* 2007, Hobbs *et al.* 2007) and should be read prior to reviewing the current outputs. The following sections are based on that methodology, but have expanded to include additional industry types and economic models. Current models include updated transportation costs and delivered feedstock values based on recent price increases and better estimates of product yields and values. *RIPA* allows spatial and economic comparisons between existing agricultural systems, new industries based on existing infrastructure, and hypothetical explorations of new investments in infrastructure or highly prospective industry types.

5.2 Existing Dryland Annual Cropping and Livestock Industries

Livestock production is a major existing industry in the South East Region. As of June 30, 2005, 32% of sheep and lambs in South Australia (4,013,400 head), and 54% of meat cattle (65,000head) were found in the South East Statistical Division (ABS 2006). The majority of these livestock graze on improved pastures, annual crop residues, and to a lesser extent on native grasslands. Other herds are managed in substantial feedlots at Meningie and Naracoorte, with smaller lots at Tintinara, Lameroo, Parrakie and Frances. In 2004-05, 4.9% (96,900 tonnes) of all barley produced in South Australia and 3.6% (94,500 tonnes) of all wheat produced in South Australia came from the South East Statistical Division. The region also produced significant quantities of grain legumes (~37,000t) and oilseeds (mainly canola, ~28,000t).

Australian Bureau of Agricultural and Resource Economics *AgSurf* farm survey statistics for the South East Region (ABARE 2006) illustrate the variability of farmer economic returns from dryland cropping and grazing. Seasonal variations significantly influence crop yields and pasture growth for livestock meat and fibre production. To estimate the gross margin returns in the Upper South East (USE) region we have mapped all annual cropping and grazing lands for the greater South East region, extracted their inherent climate-soil productivity values from CSIRO productivity surfaces (Raupach *et al.* 2001) and projected their proportional contribution to the South East region’s 10 year average of gross margins for combined broadacre cropping and grazing. Figure 42 illustrates the likely spatial variation in gross margin returns in existing annual cropping and grazing lands. Following an identical process we have also mapped the 10 year maximum gross margin return for the region (Figure 43). Summaries of these values for each Hundred subdivision are presented in Table 29.

Figure 41 – Average gross margins per hectare (2005 dollars) of combined cropping and livestock grazing enterprises for years 1990 to 2005.



(Source: ABARE 2006, AgSurf)

5.3 New Industry Modelling Approach

Regional Industry Potential Analysis (*RIPA*) methodologies and national economic evaluations are described in detail in Bennell *et al.* (2007) and Hobbs *et al.* (2007). In summary, the *RIPA* model consists of a series of models predicting potential spatial distributions of individual species based on bioclimatic relationships, spatial plantation productivities and yields of biomass components, point-based economic models of optimised annual equivalent returns from short cycle woody perennial woody crops, and transportation network models for each industry type. Finally, the *RIPA* uses integrates point-based economic models with spatial information to predict agroforestry equivalents to gross margin analyses (used to evaluate the short-term economic performance of crops and livestock). The integrated *RIPA* model is not scale dependant - early versions undertook broadscale analyses at a one kilometre resolution. In the Upper South East (USE) region landuse, vegetation and soil mapping is available at a scale of one hectare and this is the native resolution of the *RIPA* predictions in this region. ArcGIS 9.1 (ESRI 2005) geographic information system software is used for these spatial models and analyses.

Figure 42 – Estimated gross margin (2005 dollars) of combined cropping and livestock grazing enterprises, based on the 10 year average for 1996 to 2005.

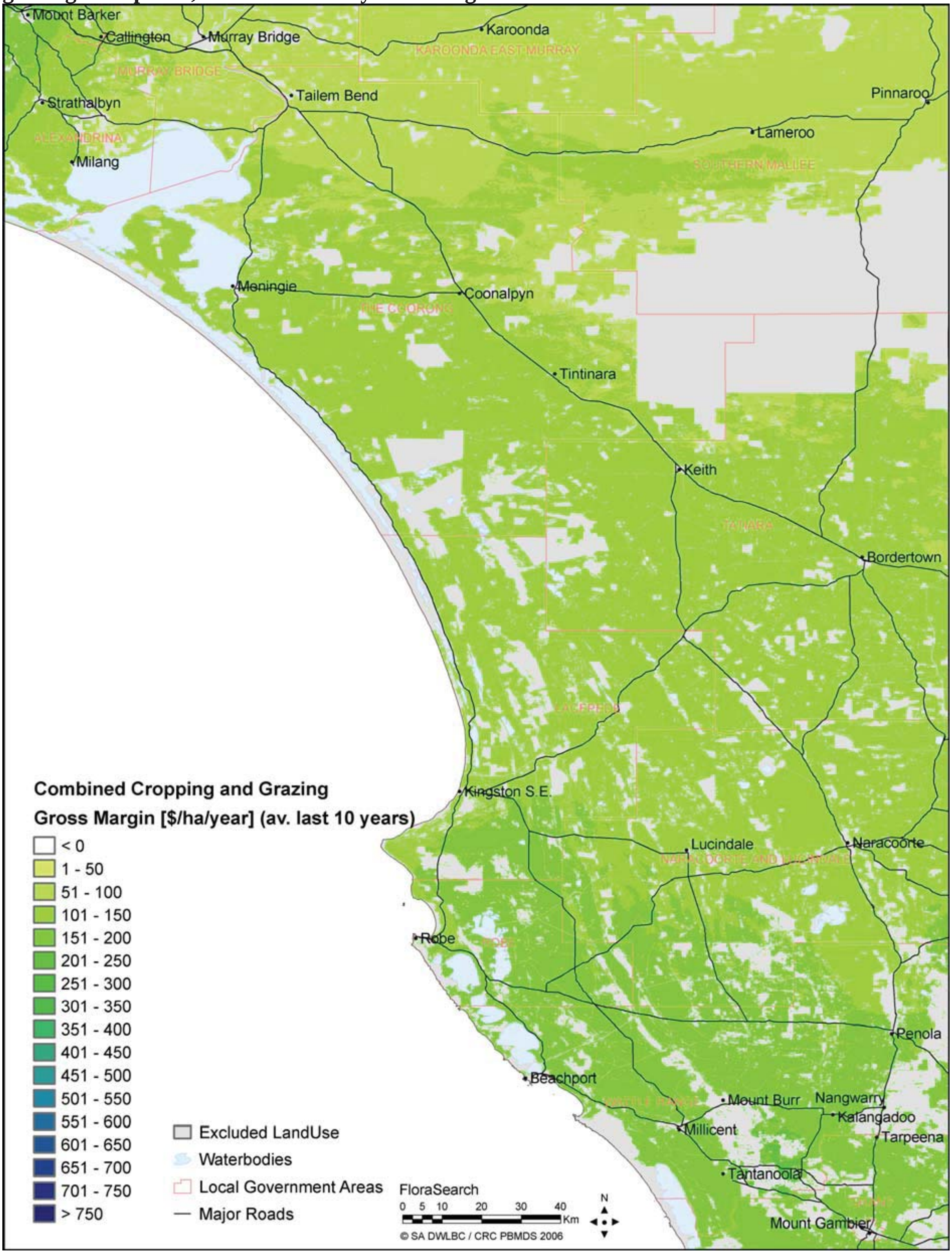
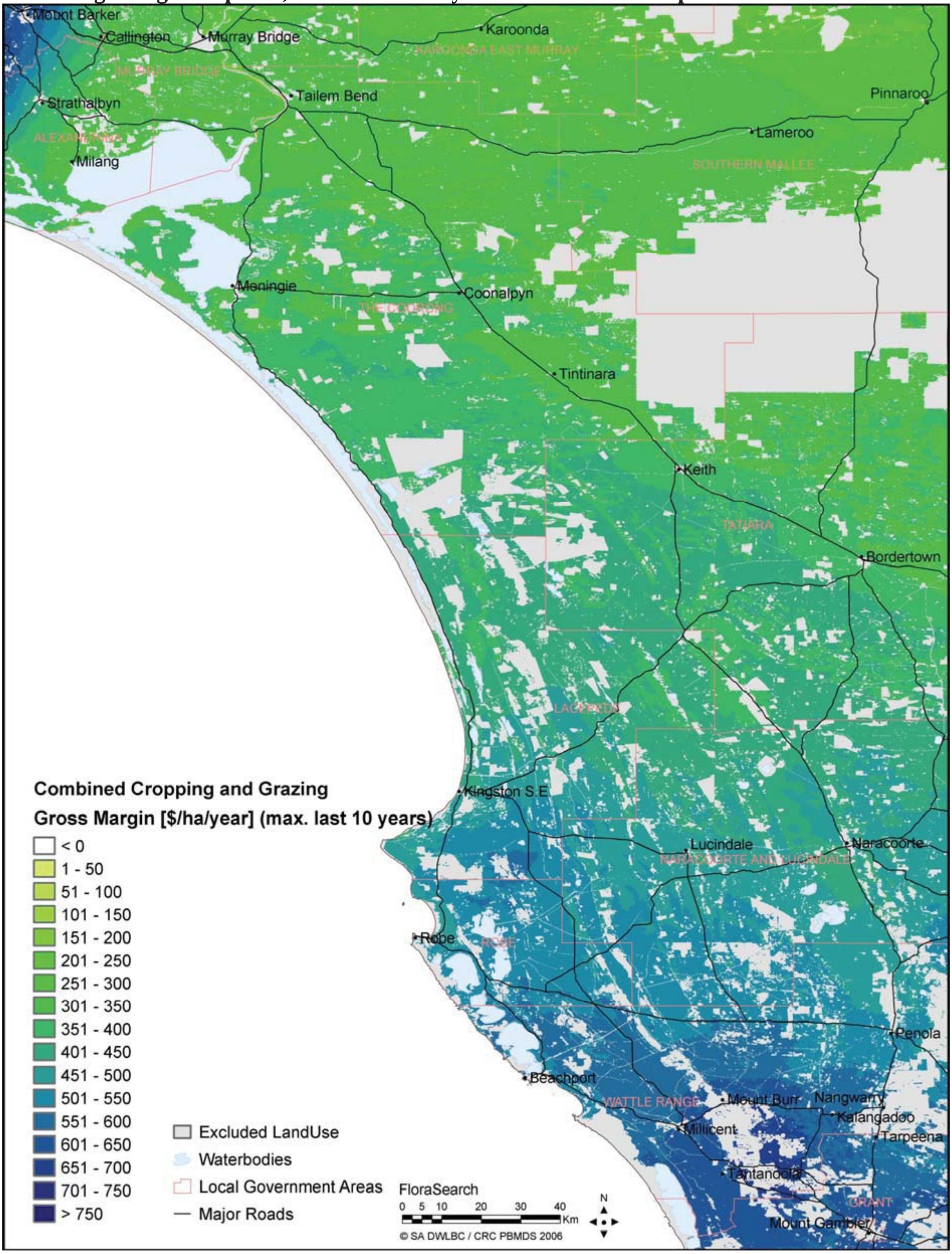


Figure 43 – Estimated maximum gross margin (2005 dollars) of combined cropping and livestock grazing enterprises, based on the 10 year maximum for the period 1996 to 2005.



n.

The first step in this process is to determine which agroforestry, fodder shrub or other woody biomass industry is to be evaluated. Species are then selected that match the product specifications of that industry type (eg. from laboratory pulp yields test for pulpwood species). Bioclimatic models predict the regional suitability of the species chosen, and observations of plantation productivities from field trials and agroforestry plots used to predicted growth rates and yields across the study area (as described in earlier sections of this report). Coppicing species have a 30% increase in total biomass productivity resulting from having effectively more stems per hectare and established investments in root biomass. For unharvested carbon sequestration biomass crops we have incorporated an estimate of below ground biomass as a proportion of above ground biomass (ie. mallees +20%, tree and shrubs +10%, +15% average for habitat species).

We have mapped existing infrastructure which may be utilised for each potential industry type (eg. roads, processing plants, ports etc.; see Figure 45) and geographically placed hypothetical new infrastructure to support prospective new industry type (eg. hypothetical Integrated Tree Processing plant at Keith). Transport paths and associated freight costs have been mapped and evaluated between each hectare of land potentially available for new woody biomass industries and each existing or hypothetical facility.

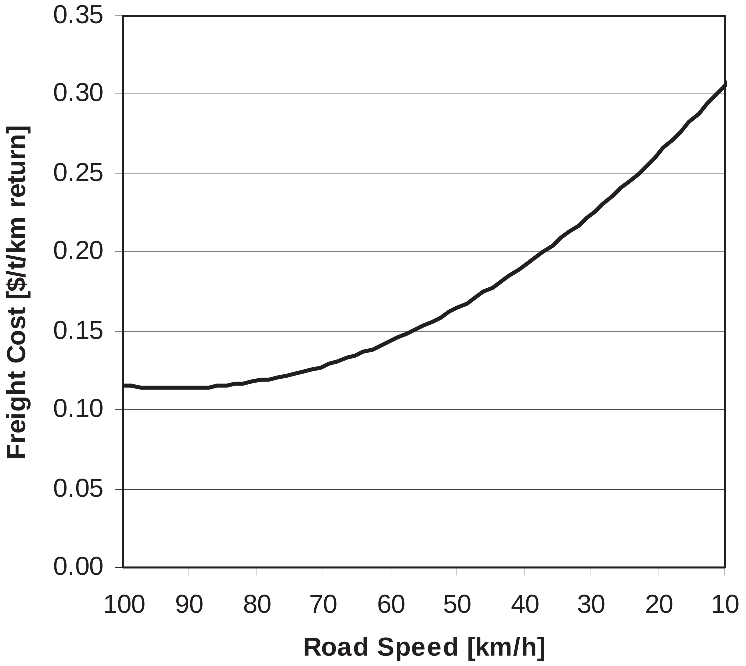
Freight costs are a significant contributor to the economics of biomass commodity industries, especially for producers of high volume / relatively low value product that need to be transported to distant mills and processing plants (Bennell *et al.* 2007, Hobbs *et al.* 2007). Transport costs are dependant on vehicle travel speeds and are variable in their proportion of running costs and driver salaries. To increase the accuracy of spatial economic models we detailed different road types and surfaces, speed restrictions on all roads and tracks servicing the Upper South East and transport routes to Port Adelaide. The following equation was used in our models to account for transport costs by road networks:

$$\textbf{Transport cost multiplier} = \mathbf{0.0002466 * Road\ Speed^2 - 0.04553 * Road\ Speed + 3.092}$$

Using the base cost of $0.115/t/km return trip included, and road speed information Figure 44 demonstrates the range of freight costs from highway to farm tracks.

The economic module of the *RIPA* model incorporates all plantation establishment and maintenance costs for each biomass industry group of species. Planting densities are set at 1000 plants per hectare for all biomass industry species groups except for Saltbush Fodder Species Group which uses 1500 shrubs per hectare. Establishment costs are based on those reported by Hobbs *et al.* (2007) for broadacre biomass industries and Bulman (2002) and Mt Lofty Ranges Private Forestry (2006) for farm forestry woodlots in the Adelaide Hills. For this study we have used a generous establishment cost of $875/ha for trees and mallees and $825/ha for fodder shrubs. However, broadacre agroforestry establishment costs in flat, simple and sandy landscapes are likely to be around 15% less than this figure. Average annual maintenance costs have been set at $10/ha/year to include occasional and sporadic activities such as firebreak control, supplementary fertilisers, follow-up weed and pest control. Harvest cost varies depending on each industry type and the degree of biomass sorting and product quality controls. For wood fibre, bioenergy and oil mallee costs are based on continuous flow in-field biomass chipping technologies described by Enecon Pty Ltd (2001) or in-field log chippers used in existing Tasmanian Bluegum (Eucalyptus globulus) industries (Timbercorp 2006). Firewood harvest costs are based on small and medium scale harvesting systems described by Poynter and Borschmann (2002) and Mt Lofty Ranges Private Forestry (2006). Off-farm fodder harvest costs are based on forage harvesters. A summary of establishment, harvest and transport costs are presented in Table 27.

Figure 44 - Influence of road speed on freight costs used in spatial economic models.



The economics module then combines information on plantation productivities, changes in plantation product component yields (ie. biomass fractions) with plant age, establishment costs, maintenance costs, harvest costs and delivered feedstock values (see Table 26), a financial discount rate of 7%, and conducts sensitivity analyses to determine economically optimal harvest cycles for each industry type. Spatial economics models are constructed for each industry type and applied to spatial surfaces of plantation productivities and road transport costs (where applicable) for every hectare of land potentially available to revegetation industries in the region. Cash flows over the first 20 years of each production system (under a financial discount rate of 7%) are converted to *Annual Equivalent Returns* (AER) which allows direct comparisons with annual gross margin analyses for existing annual agricultural.

5.4 New Industry Economic and Spatial Evaluations

Regional Industry Potential Analysis (*RIPA*) models have been applied for the most prospective woody biomass industries type in the Upper South East. Model outputs include parts of neighbouring Lower South East and Southern Mallee regions. However, our productivity models have not been calibrated for higher rainfall regions (eg. >700mm) and greater caution is required in interpreting economic results for these high rainfall areas. The *RIPA* model outputs of *Annual Equivalent Returns* for each biomass industry type are present in Figure 46 to Figure

60. Summaries of predicted farmer returns for each Hundred subdivision in the Upper South East region are presented in Table 29.

Overall, many new biomass industries can bring substantial financial returns to many districts in the Upper South East (USE) depending on farmer access to existing and potential markets or corporate/government/cooperative investment in new infrastructure. Immediate access can be gained to livestock fodder and firewood industry markets which is reflected in existing farm diversification in the region. Low to medium rainfall pulpwood industries for export or delivery to the new pulp mill planned for Penola are feasible over much of the region and are likely to create the greatest return per hectare in many districts. Delivery of feedstock to the particleboard mill at Mount Gambier is not viable anywhere in the USE region due to relatively low feedstock values and modest transportation costs. Prospective bioenergy and oil mallee systems (Integrated Tree Processing) could provide substantial returns in the region but these require a reasonable investment in new infrastructure to be viable. In-field mallee harvesting and distillation of Eucalyptus oil could also provide significant returns in landscapes suited to oil mallee species with minimal investments in infrastructure.

Carbon sequestration in unharvested habitat or oil mallee revegetation using low planting density (1000tph) and high-cost establishment techniques (tubestock plantings used in our analysis cf. cheaper direct seeding) provide minimal returns for farmers at present without co investment from governments. Carbon sequestration using unharvested *Bioenergy* species and current world carbon prices could provide reasonable returns to land holders when carbon trading is available in South Australia. Equally, if the average standing biomass and root biomass of harvested woody crops was included in carbon sequestration trading it could provide additional income streams to extractive agroforestry enterprises in the region.

Table 27 - Primary production, freight costs and discount rate used in regional industry potential analysis.

Primary Production Costs ($/ha) by Plantation Type	**Planting density**	**Site planning, setup & land preparation**	**Seedlings, planting, fertiliser & watering**	**Weed/Pest management & control**	**Total Establishment costs [$/ha]**
Agroforestry/Biomass	1,000 trees/ha	290	510	75	875
Fodder Shrubs	1,500 shrubs/ha	270	480	75	825
Average Maintenance Costs ($/ha/year)	10				
Harvest Costs ($/freshweight tonne of total biomass)	**Wood Fibres**	**Bioenergy/ ITP Oil Mallee**	**In-field Eucalyptus Oil**[#1]	**Off-farm Harvested Fodder**	**Grazed Fodder / CO2 Seq.**
	20	10	28	5	0
Freight costs – includes truck return trip ($/t/km)	base of 0.115 (depending on road/track surface, see Figure 44)				
Discount rate	7%				

[#1] includes oil extraction, based on Abadi et al. (2006)

Table 28 - Economically optimum harvest cycles, delivery locations and estimated 2006 delivered feedstock values by industry type used in regional industry potential analysis.

Industry and Commodity Type	Optimum Harvest Cycle (First, Subsequent)	Delivery Location	Delivered Feedstock Value [$/freshweight tonne]
Export pulp - woodchip	11, 9	Port	90
Australian pulp - woodchip	11, 9	Mill	85
Australian particleboard - woodchip	14, 12	Mill	43
Firewood (bulk supply) - cut and split billets	14, 12	Distribution Centre	100
Electricity generation - whole plant biomass	7, 4	Power Plant	28
Eucalyptus bulk oil - leaf	4, 3	Mobile Processing Plant	80
Integrated wood processing - whole plant biomass	7, 4	Processing Plant	36
Fodder - Saltbush leaf (Autumn)	3, 2	In situ/ Paddock /Feedlot /Mill	65
Fodder - Saltbush leaf (Spring)	3, 2	In situ/ Paddock	45
Carbon Sequestration - all biomass	Not Harvested	In situ	20

Figure 45 - Existing infrastructure relating to biomass industries in the region.

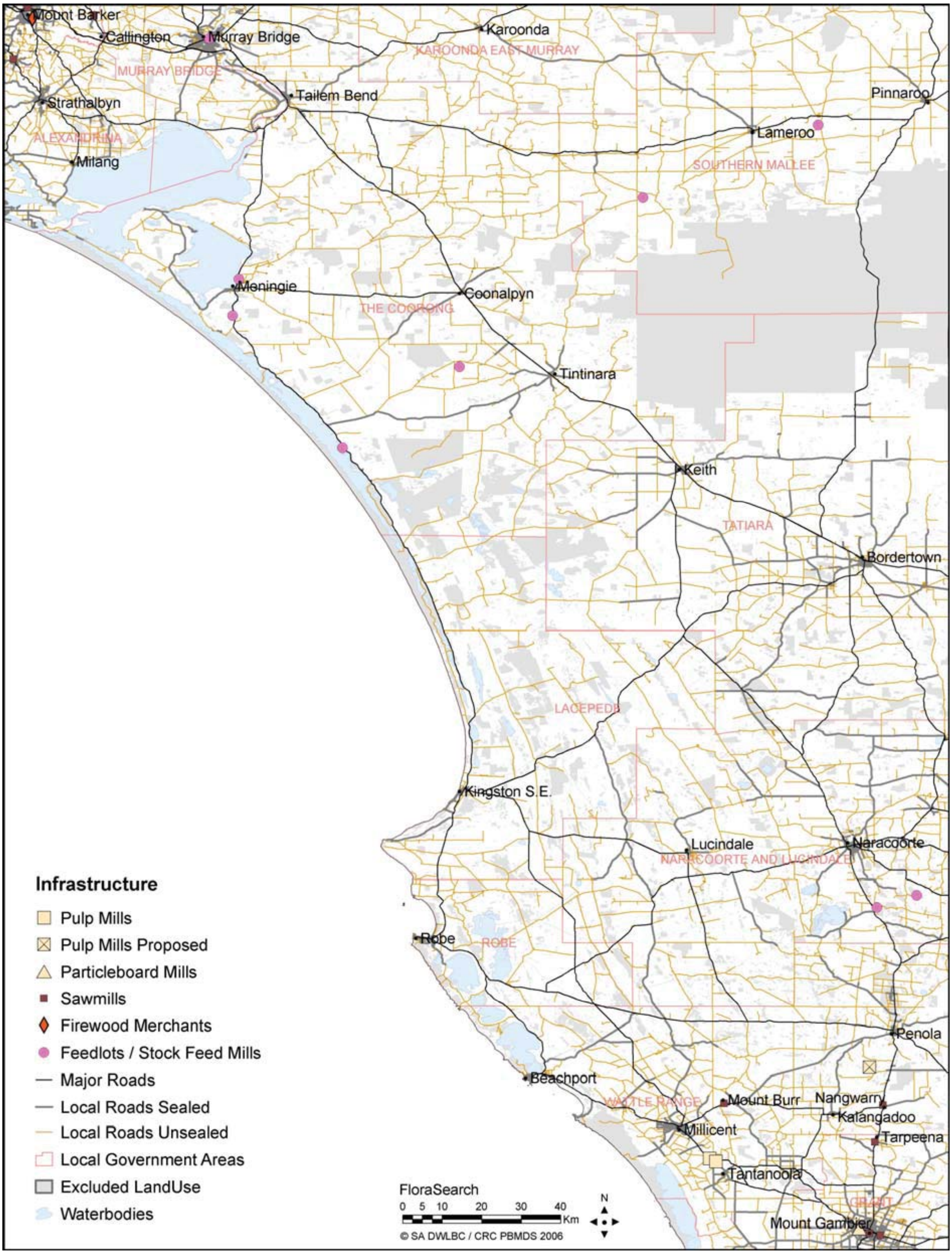


Figure 46 - Estimated primary producer returns from Export Pulpwood scenario delivered to existing bulk port facilities at both Port Adelaide and Portland.

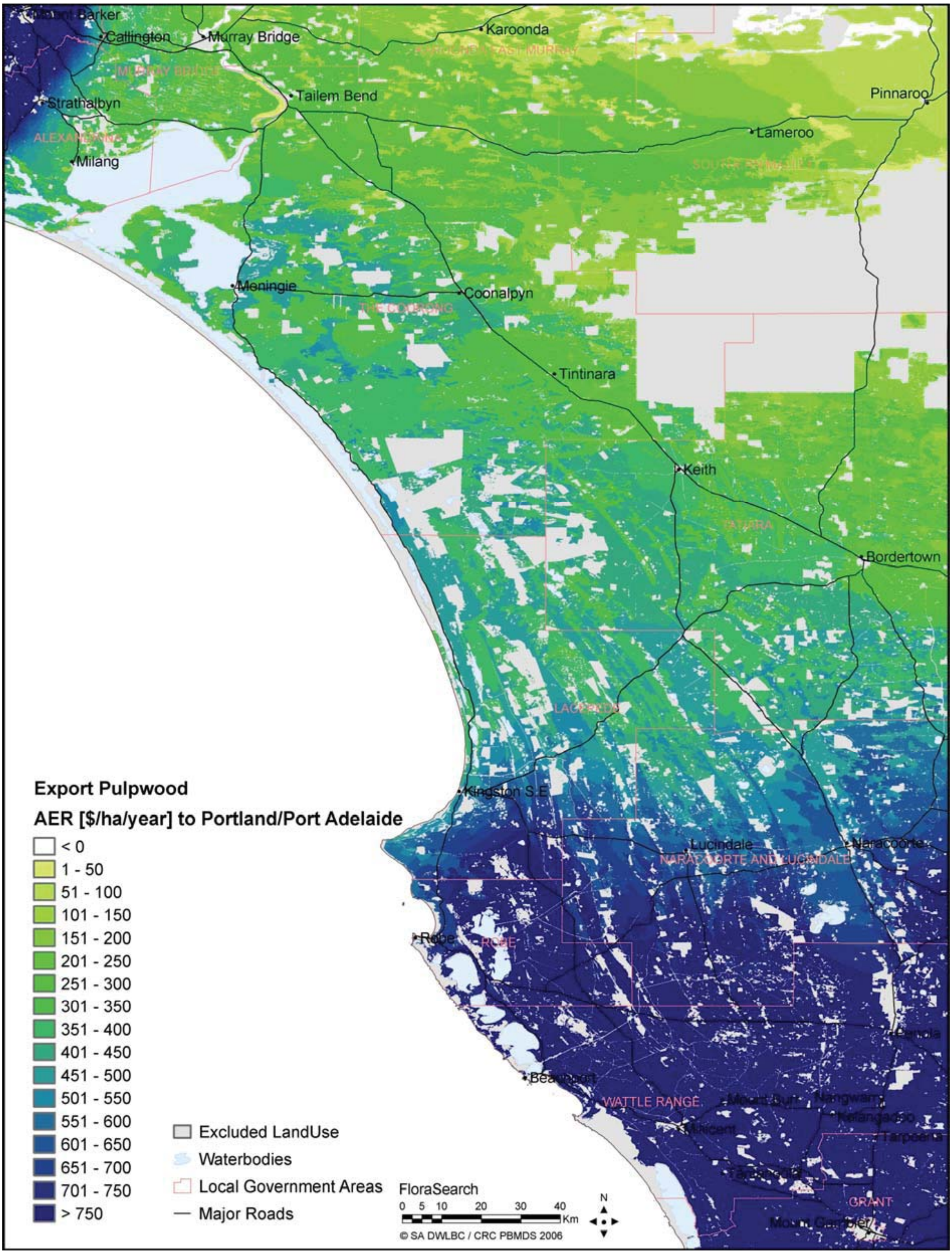


Figure 47 - Estimated primary producer returns from Export Pulpwood scenario delivered to existing bulk port facilities at Portland only.

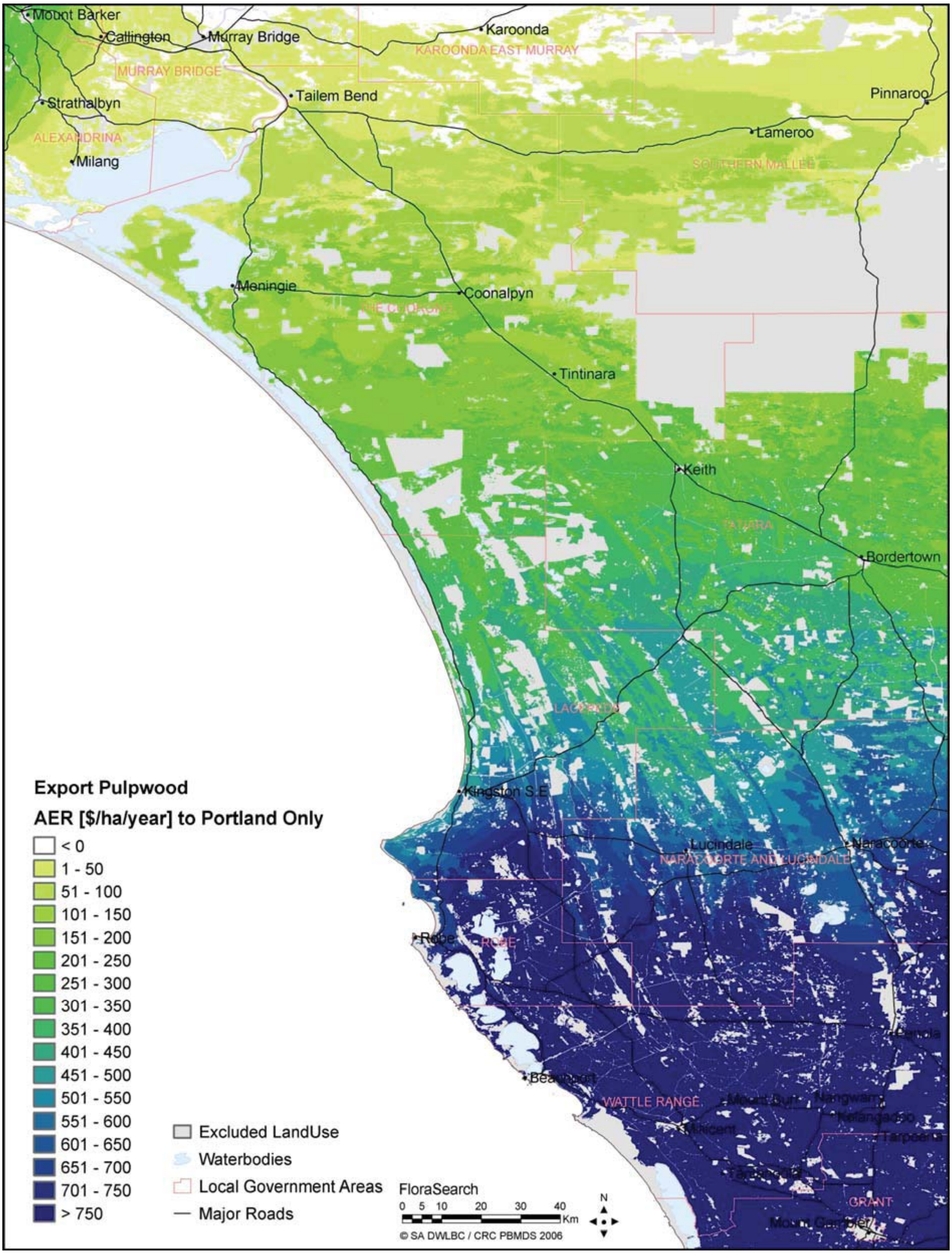


Figure 48 - Estimated primary producer returns from Australian Pulpwood scenario delivered to existing (Millicent, Tantanoola) and proposed (Penola) pulp mill facilities.

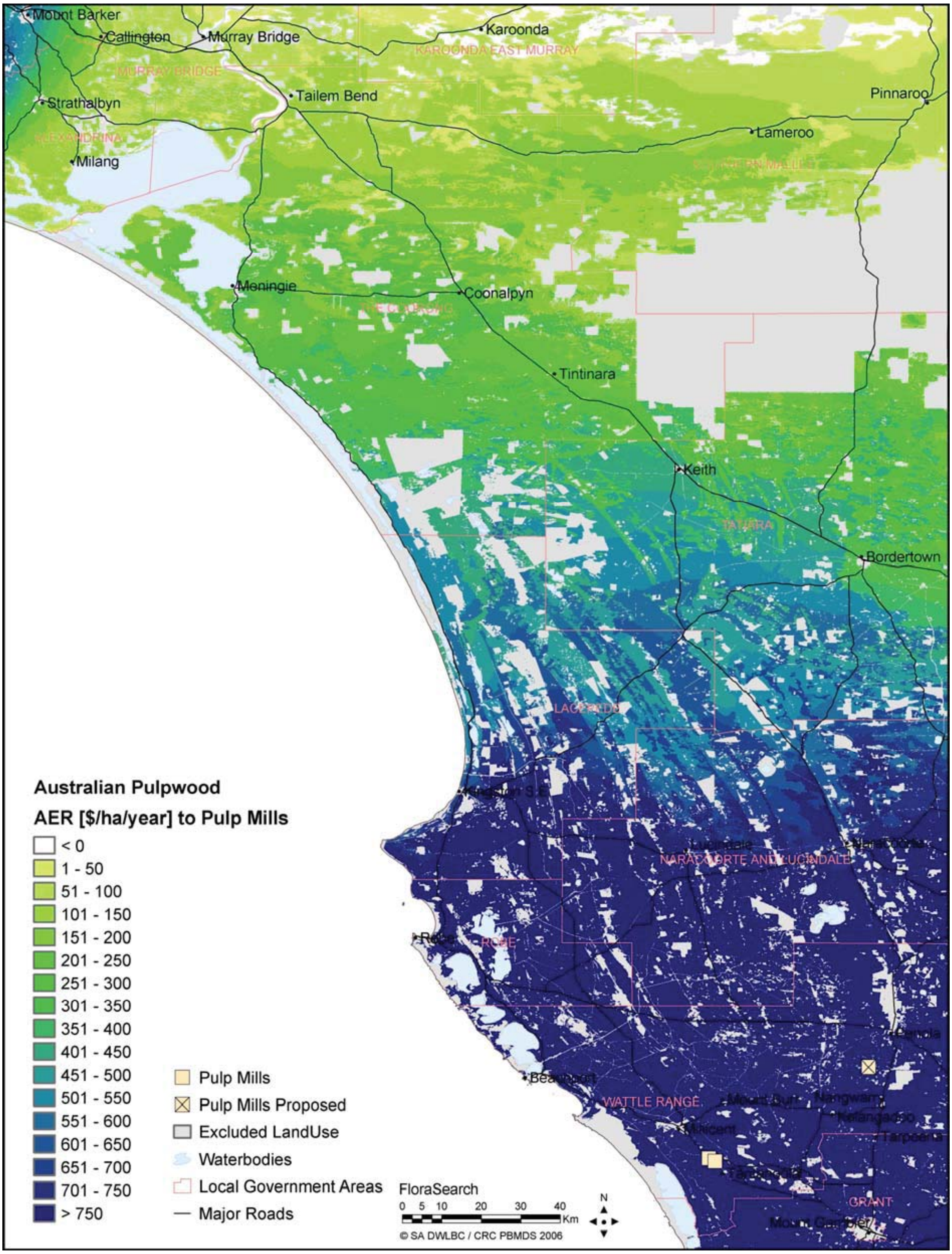


Figure 49 - Estimated primary producer returns from Particleboard scenario delivered to the existing particleboard mill at Mount Gambier.

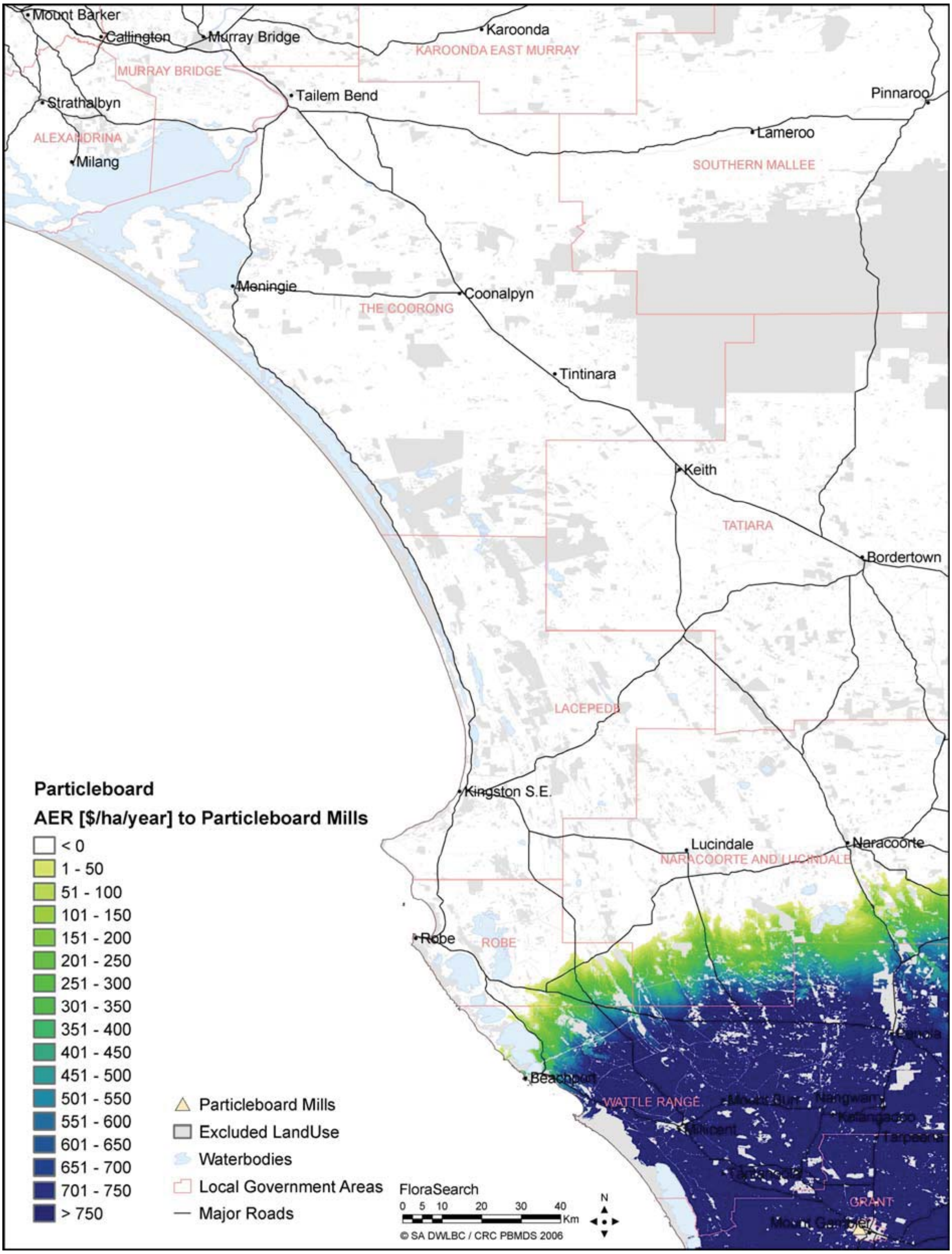


Figure 50 - Estimated primary producer returns from bulk firewood delivered to Mount Barker using small scale harvesting methods.

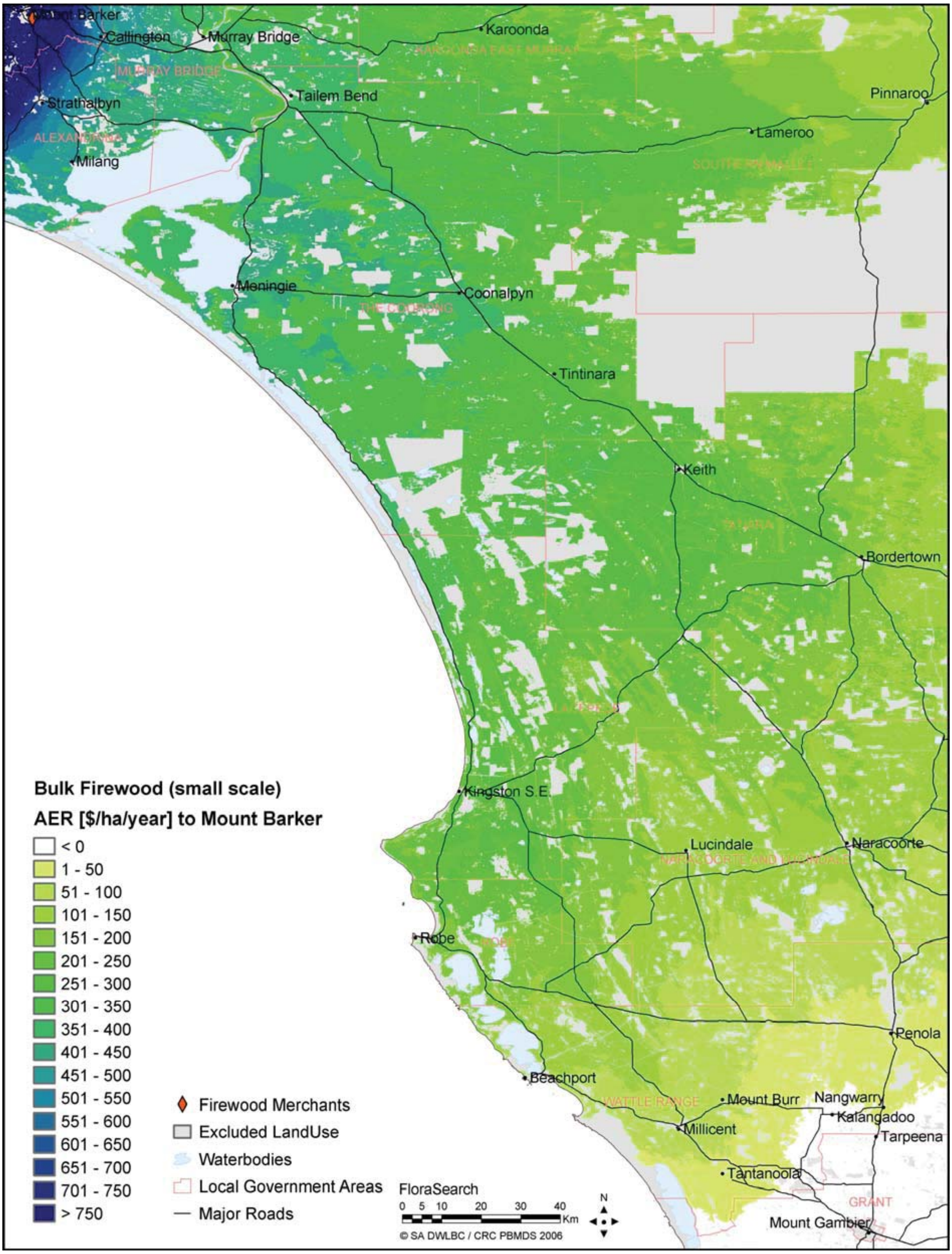


Figure 51 - Estimated primary producer returns from bulk firewood delivered to Mount Barker using medium scale harvesting methods.

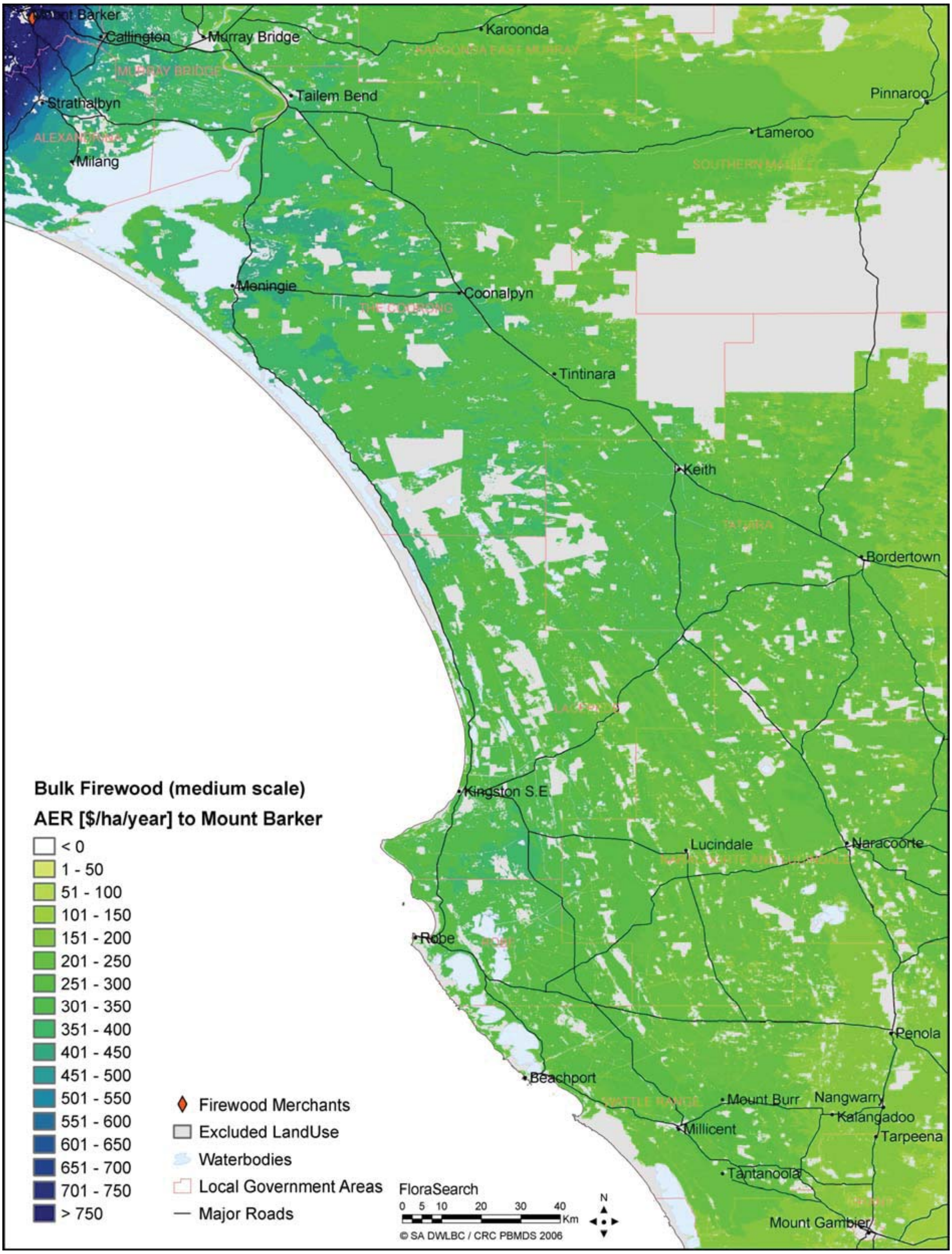


Figure 52 - Estimated primary producer returns from *In situ* Farm Fodder (Autumn value) scenario using saltbush.

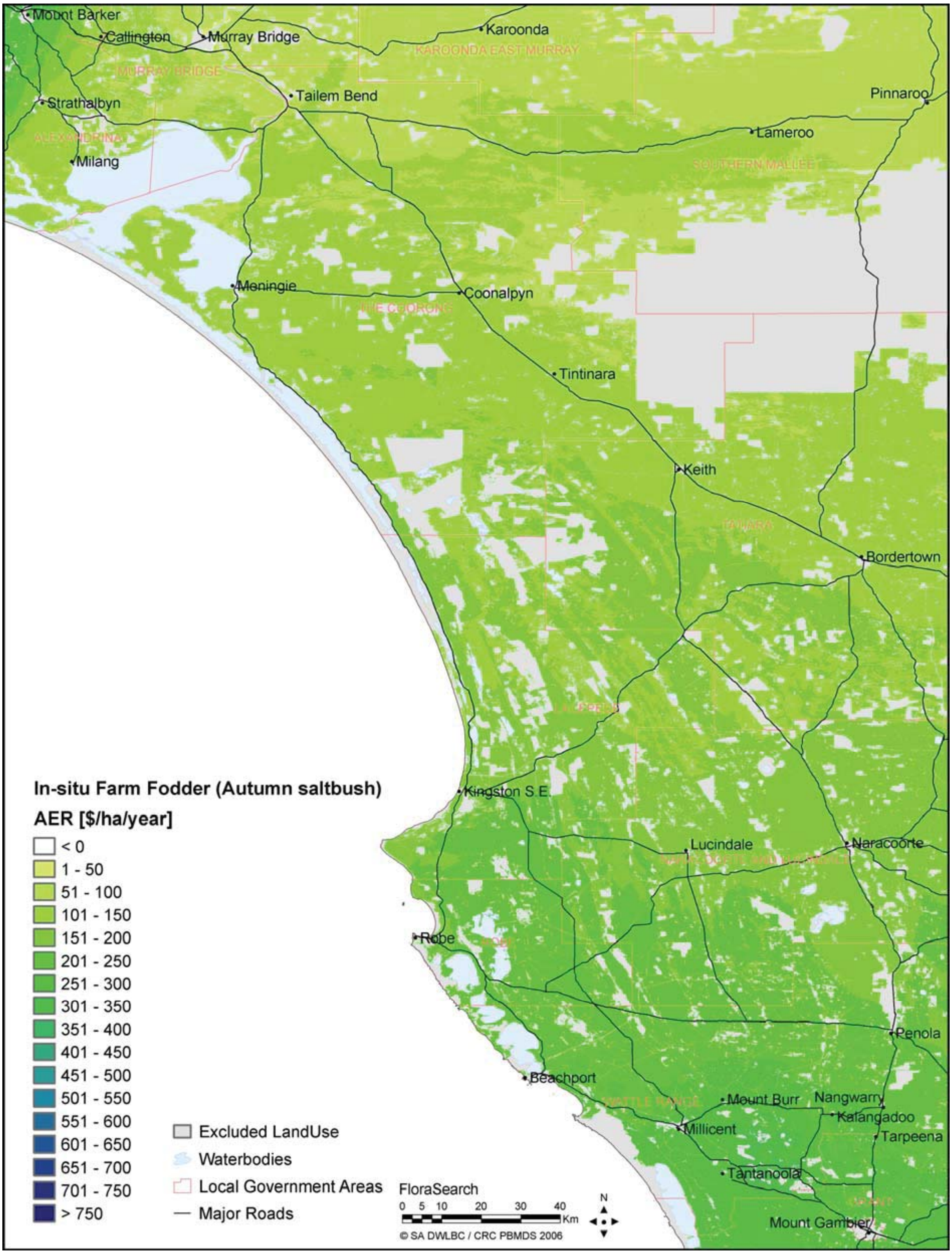


Figure 53 - Estimated primary producer returns from *In situ* Farm Fodder (Spring value) scenario using saltbush.

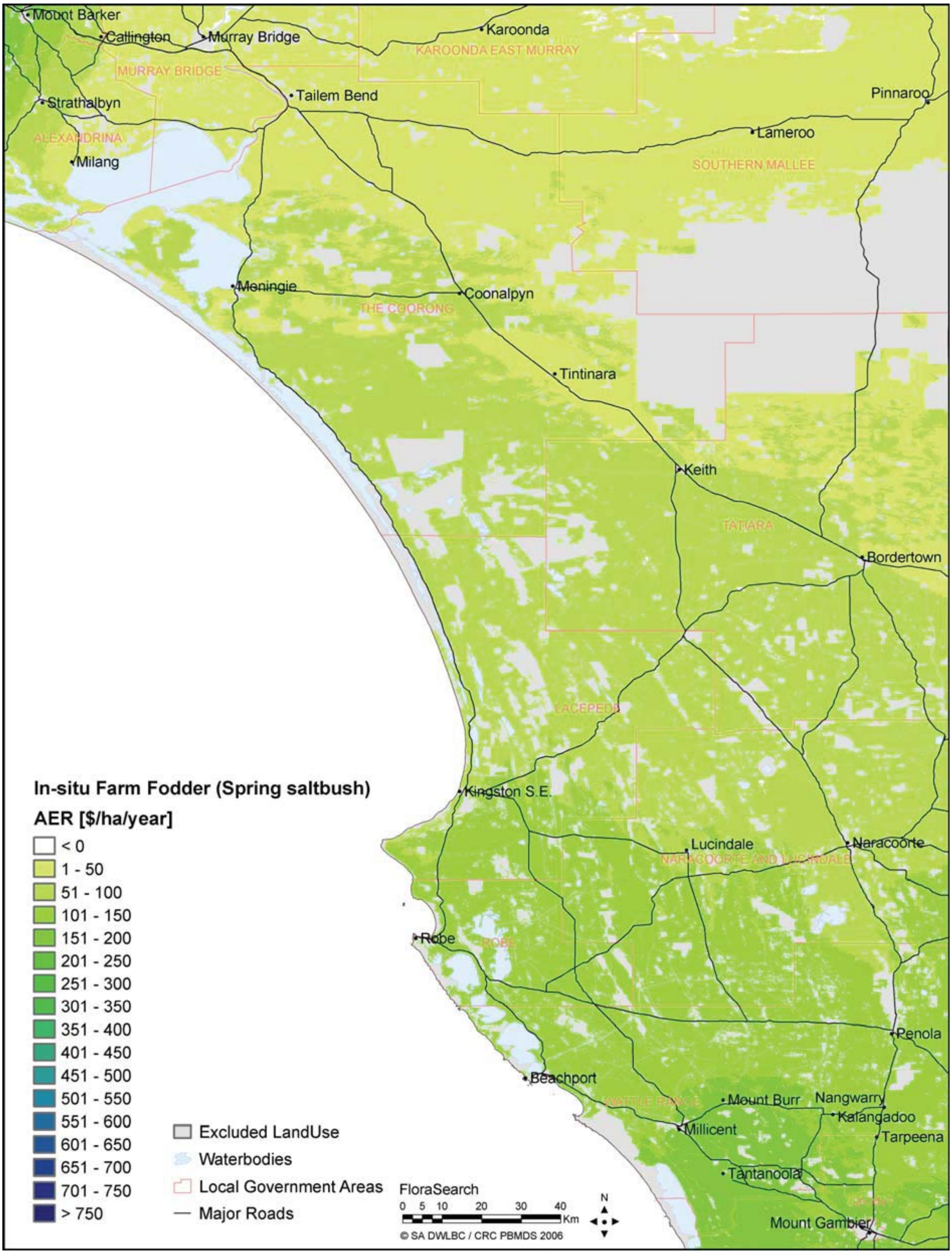


Figure 54 - Estimated primary producer returns from Off-farm Fodder (saltbush) scenario delivered to existing feedlots and stockfeed manufacturing facilities.

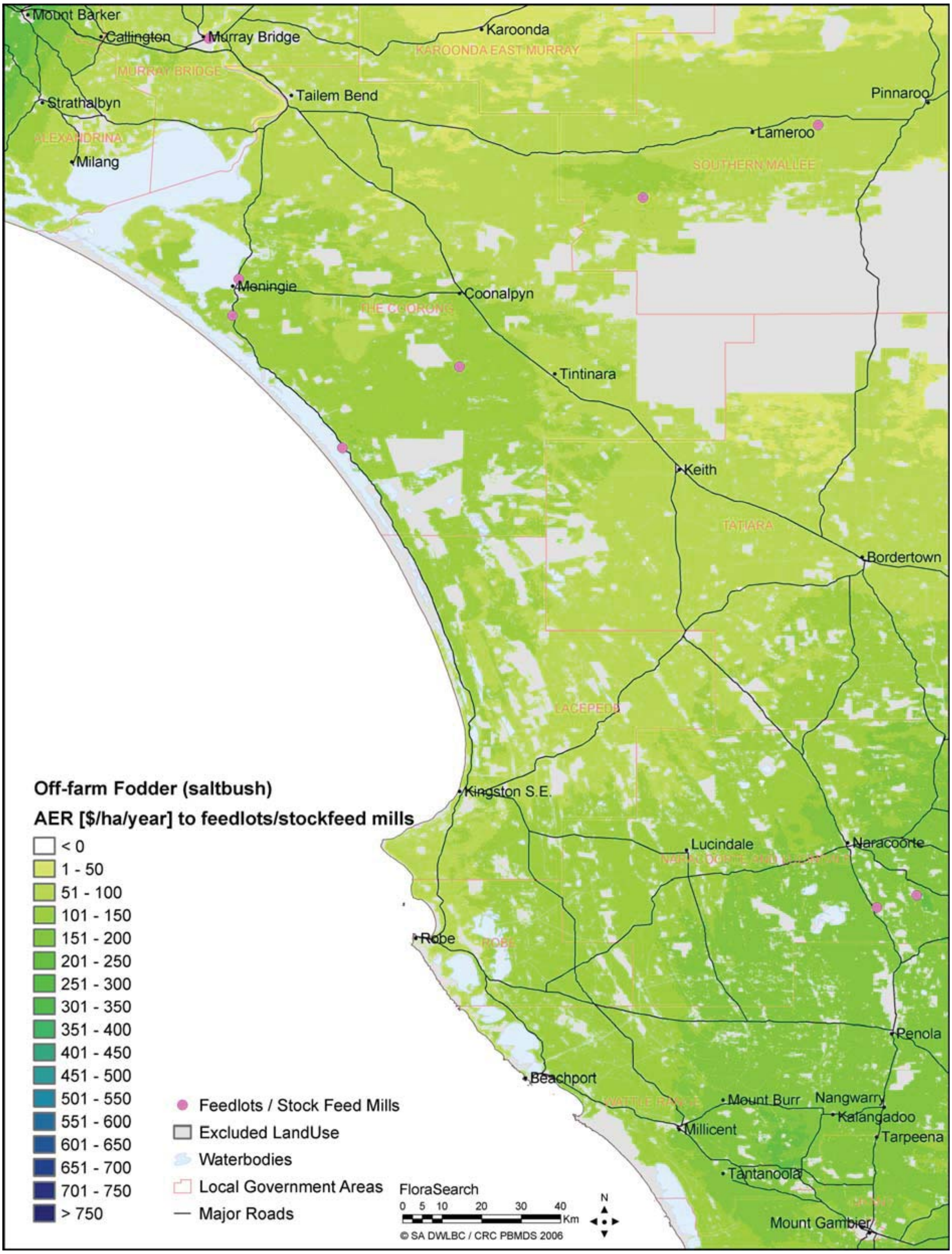


Figure 55 - Estimated primary producer returns from Eucalyptus Oil Only ($3.00/kg price) scenario using mobile oil distillation plants with refined product freighted to ports.

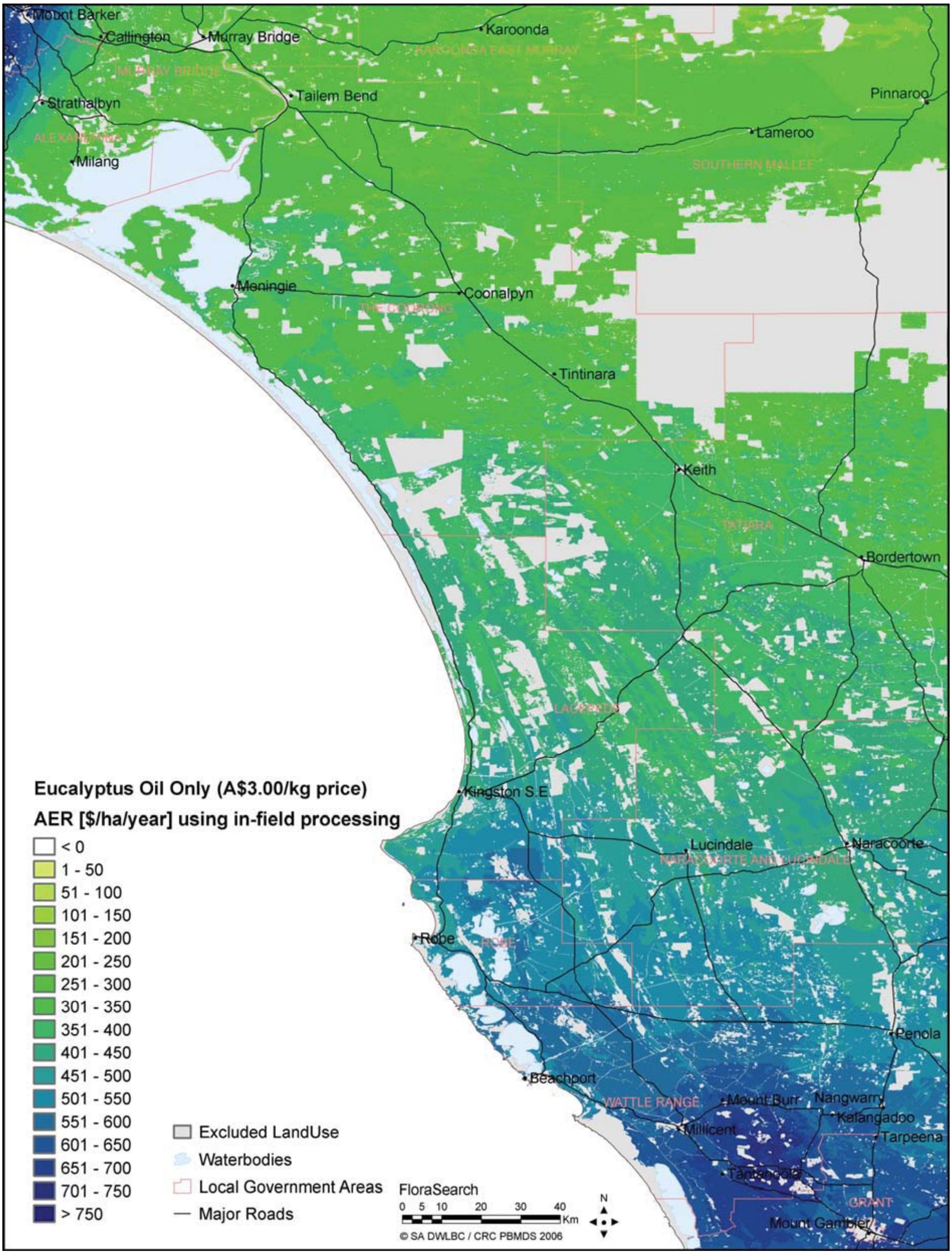


Figure 56 - Estimated primary producer returns from a Bioenergy Only scenario delivered to a new bioenergy plant located at Keith.

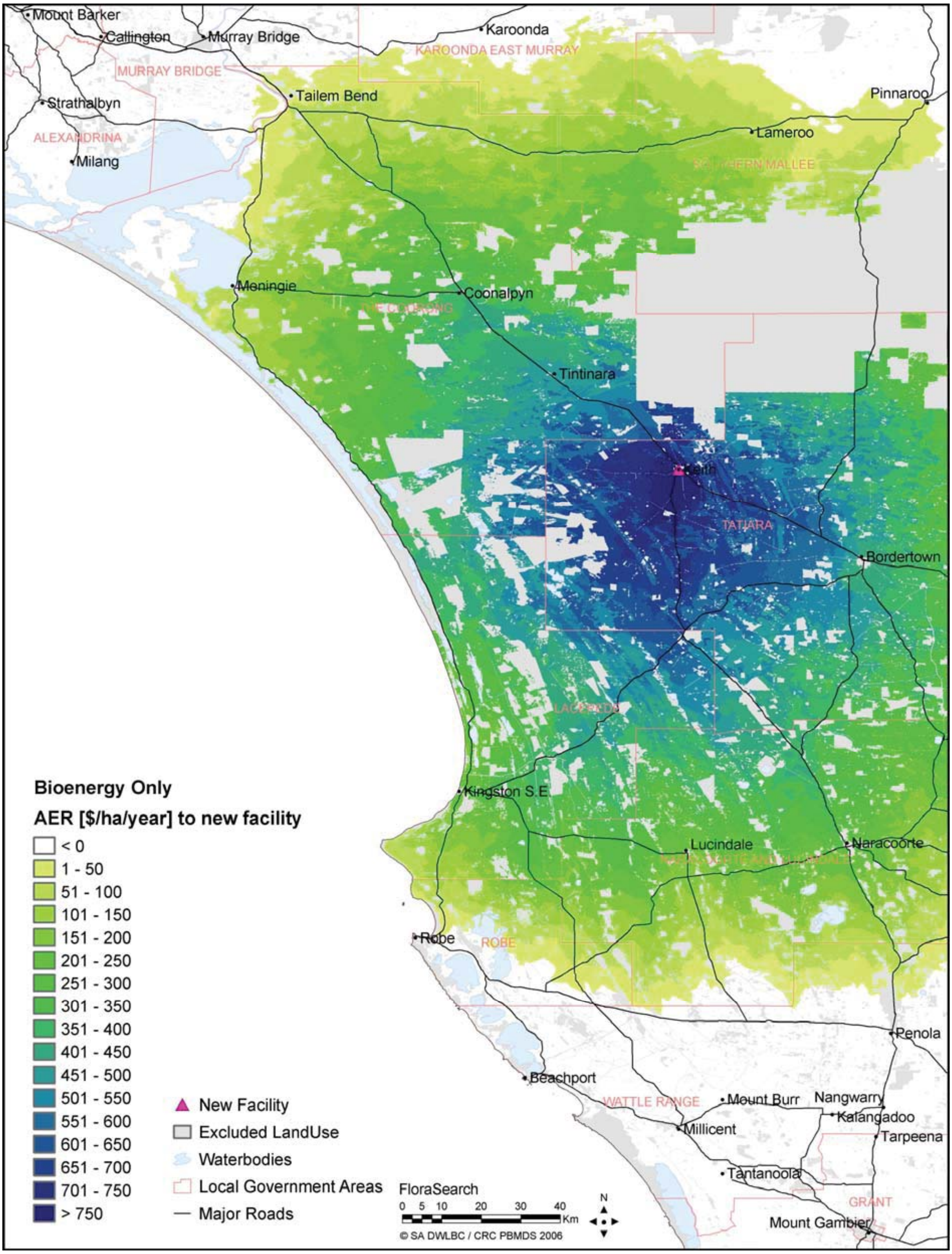


Figure 57 - Estimated primary producer returns from Integrated Tree Processing scenario delivered to a new ITP plant located at Keith.

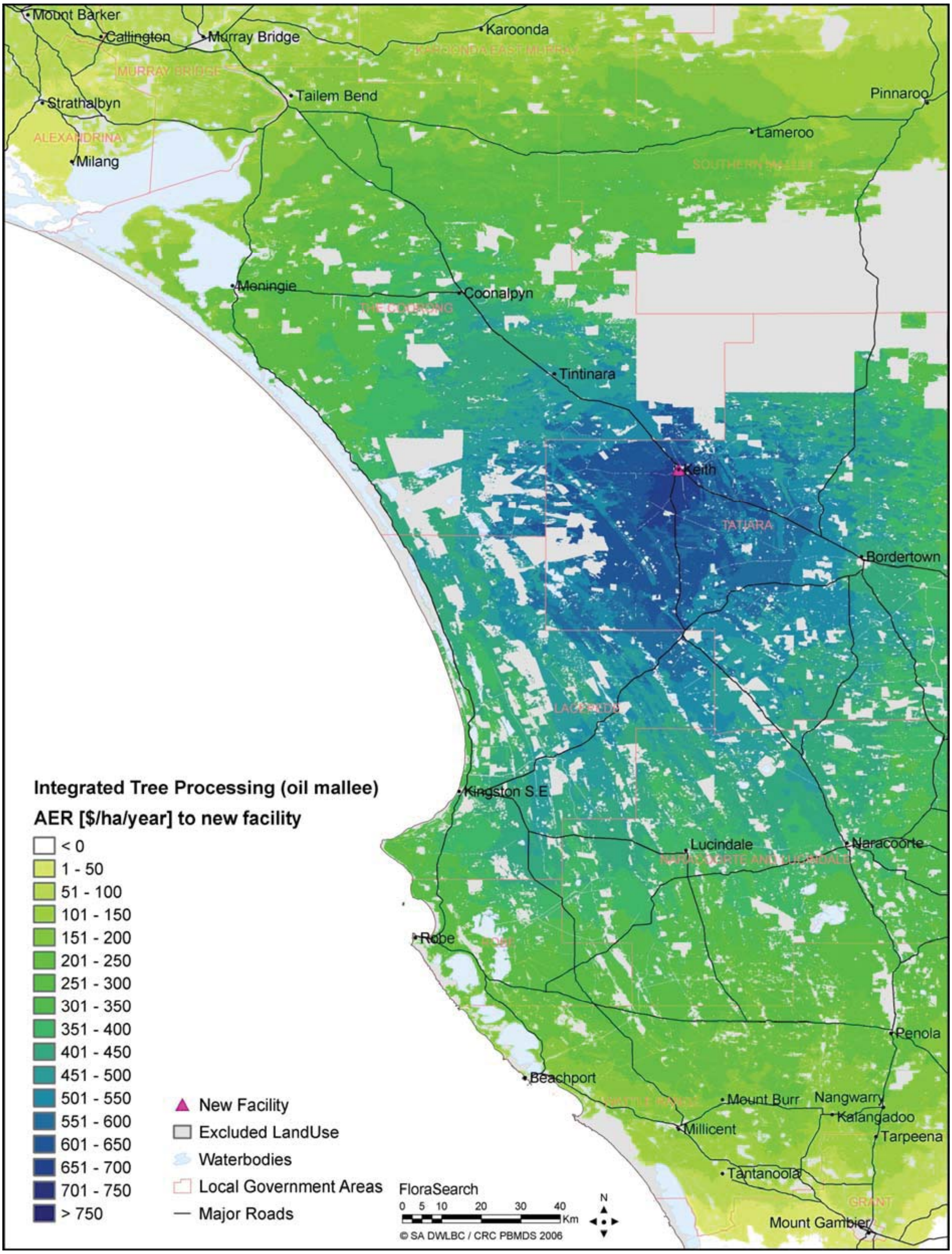


Figure 58 - Estimated primary producer returns from carbon sequestration using Habitat Species (above-ground biomass +15% root biomass).

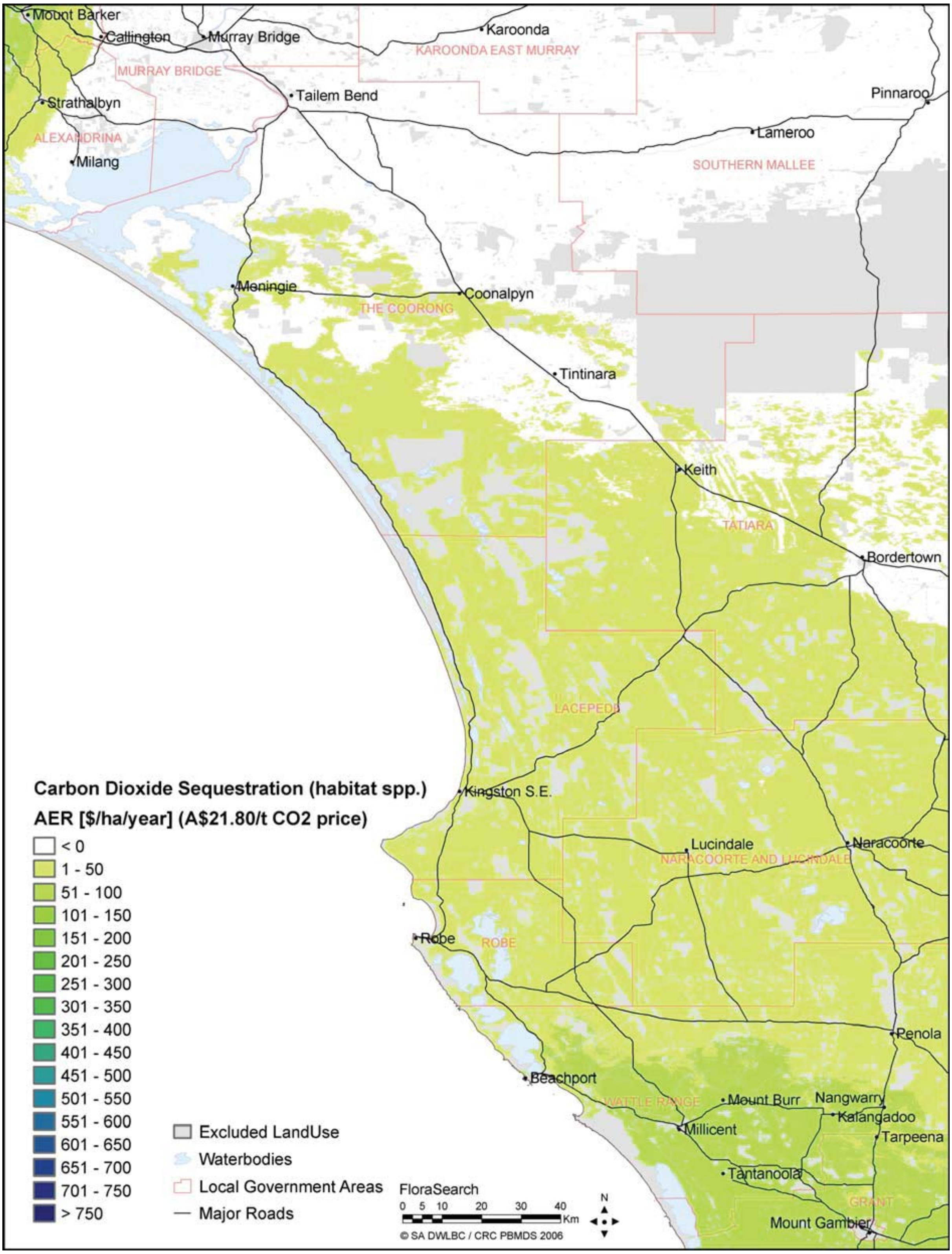


Figure 59 - Estimated primary producer returns from carbon sequestration using Oil Mallee Species (above-ground biomass +20% root biomass).

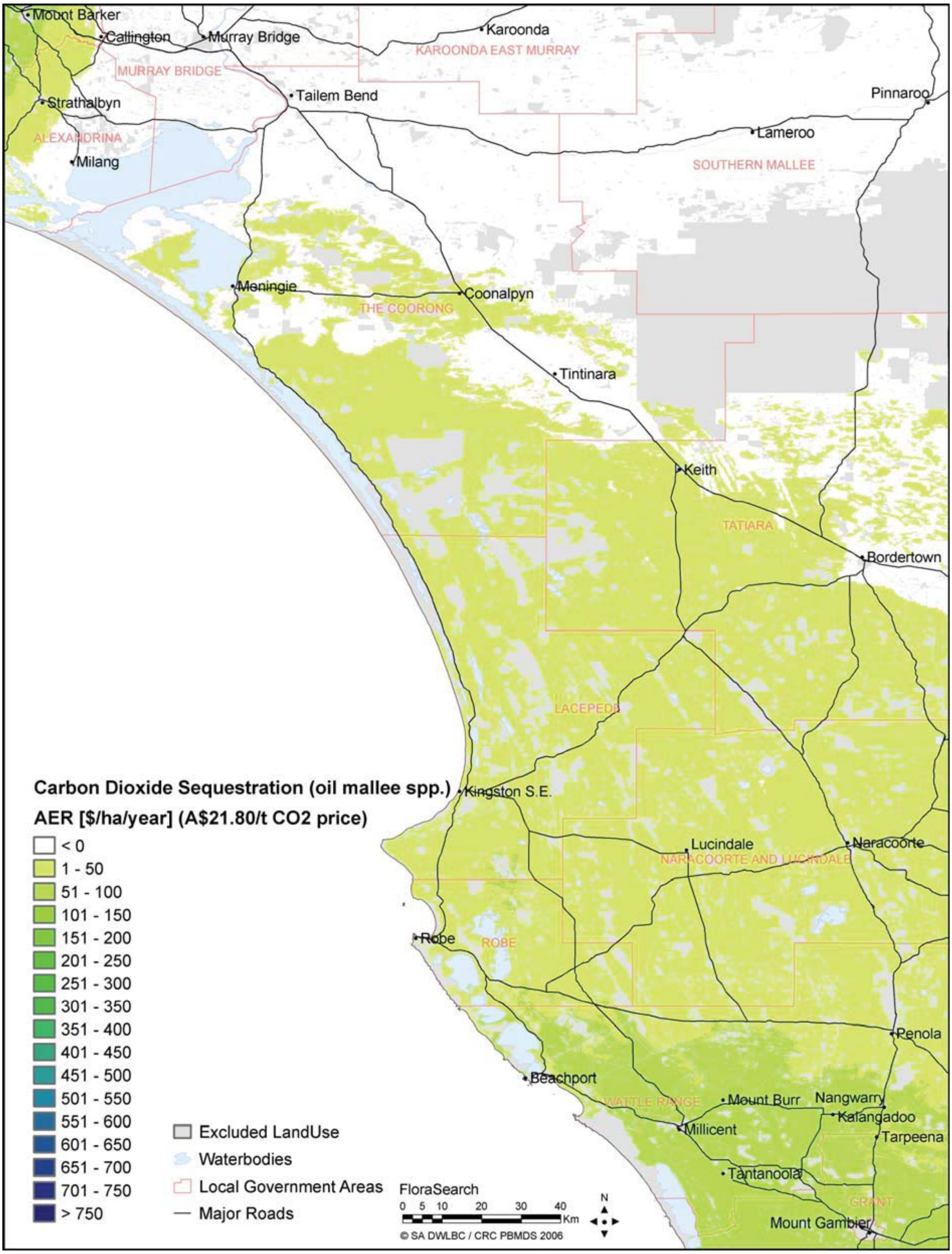


Figure 60 - Estimated primary producer returns from carbon sequestration using Bioenergy Species (above-ground biomass +10% root biomass).

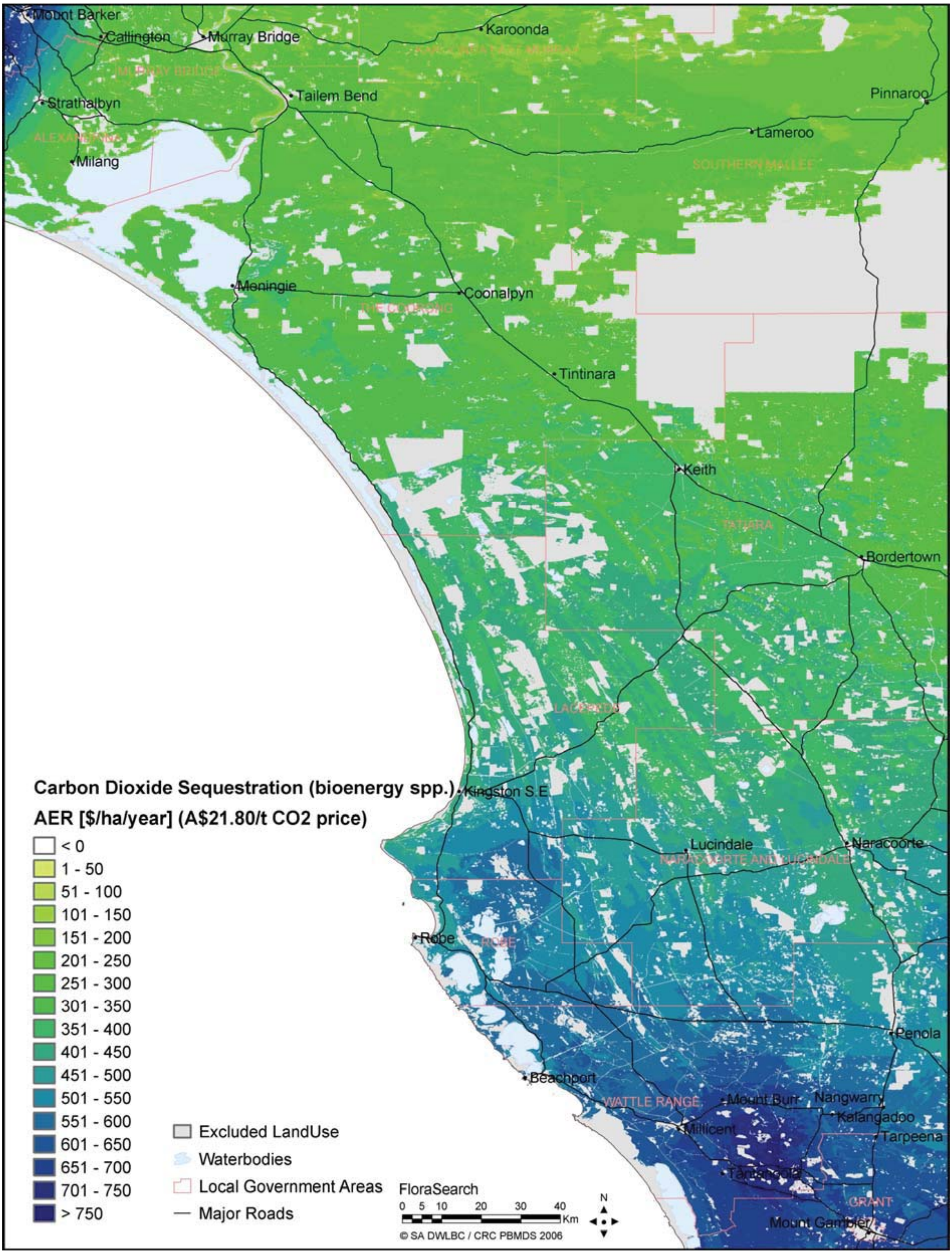


Table 29 - Summaries of expected annual equivalent returns [$/ha/yr] from existing cropping and grazing industries, and new agroforestry industries by subdivision.

Hundred	Rainfall [mm]	Potential Agroforestry Area [ha]	Gross Margin Cropping - Grazing Avg Last 10 years	Gross margin Cropping - Grazing Max Last 10 years	Export Pulpwood All Ports	Export Pulpwood Portland Only	Australian Pulpwood	Particleboard	Firewood (small scale)	Firewood (medium scale)	In situ Fodder (Autumn)	In situ Fodder (Spring)	Off farm Fodder
Archibald	443	9850	110	368	318	232	329	-2023	259	287	126	57	83
Beeamma	507	30388	124	413	434	434	553	-1208	162	237	153	76	114
Binnum	527	35965	132	439	565	565	682	-722	118	216	168	86	150
Bowaka	644	20717	160	533	764	764	1006	-831	246	346	224	125	114
Cannawigara	445	34640	110	368	277	272	350	-1779	185	234	126	57	65
Carcuma	400	25433	93	310	186	62	122	-2181	244	253	92	34	78
Colebatch	473	28081	113	376	375	189	302	-2732	317	332	131	61	122
Coneybeer	427	30525	108	360	351	162	254	-2568	335	338	121	54	108
Coombe	441	42515	105	349	284	174	259	-2088	267	285	115	49	88
Duffield	509	19462	125	417	411	381	535	-1702	257	306	156	77	99
Field	472	24233	113	376	392	177	299	-2793	342	350	131	61	113
Geegeela	496	27963	121	404	433	433	526	-1183	141	218	148	72	126
Glen Roy	512	21780	125	417	454	454	586	-1031	173	247	155	77	108
Glyde	478	24433	113	376	396	185	307	-2685	349	355	131	60	121
Hynam	532	33077	132	439	548	548	687	-689	146	236	168	86	139
Jeffries	440	20796	108	361	369	131	236	-2900	360	356	122	54	103
Jessie	549	21516	139	463	671	671	806	-239	100	213	182	96	169
Joyce (North)	567	16378	140	465	613	613	787	-483	128	234	183	97	130
Kirkpatrick	408	23036	105	348	339	117	202	-2745	358	350	115	49	86
Lacepede	557	17272	140	466	543	543	735	-1323	249	321	184	97	96
Laffer	473	38493	119	396	390	295	410	-2188	282	316	143	69	94
Landseer	524	18924	130	431	431	423	582	-1635	237	297	164	83	90
Lewis	418	30160	99	330	239	115	187	-2174	260	272	104	42	82
Livingston	393	29982	101	335	284	102	178	-2489	318	316	107	44	81
Lochaber	534	21317	130	432	512	512	663	-835	149	236	164	83	122
Makin	428	14153	101	335	207	167	231	-1900	183	220	107	44	49
Marcollat	505	34748	127	421	428	428	568	-1405	203	269	158	79	87
McCallum	434	16811	104	346	217	198	264	-1932	166	212	114	48	49
McNamara	500	26875	122	405	422	285	416	-2540	302	334	148	72	111
Messent	507	9421	119	396	402	261	399	-2472	295	325	143	69	116
Minecrow	561	26887	137	457	536	536	709	-1124	189	274	179	93	92
Mount Benson	601	22305	150	499	635	635	851	-1251	234	323	203	110	90
Murrabinna	578	16142	143	475	577	577	775	-1200	236	315	189	101	94
Naracoorte	549	20284	135	449	604	604	757	-315	121	223	174	90	157
Neville	493	15517	126	419	450	343	498	-2198	304	341	157	78	121
Ngarkat	401	7551	94	314	183	70	132	-2205	223	239	94	35	86
Parsons	508	19066	123	409	409	409	533	-1289	187	253	151	74	94
Peacock	519	30706	127	424	412	411	559	-1556	202	270	159	80	74
Pendleton	454	36069	112	374	305	275	362	-1883	221	263	130	60	67
Petherick	503	31951	127	422	410	381	519	-1968	244	299	158	79	82
Richards	459	37753	108	361	331	181	276	-2393	301	314	122	54	109
Santo	489	10064	120	400	436	265	405	-2493	336	356	145	70	136
Senior	438	36751	107	355	245	245	313	-1725	140	197	119	52	65
Shaugh	437	34322	105	348	206	203	268	-1965	134	190	115	49	55
Spence (North)	558	19019	139	463	615	615	792	-515	128	233	182	96	146
Stirling	459	36320	117	391	367	303	415	-1930	265	301	140	66	85
Strawbridge	440	19887	110	367	378	157	257	-2848	352	353	126	57	106
Tatiara	462	48028	109	364	297	297	370	-1434	148	206	124	56	88
Townsend	597	26681	147	490	663	663	861	-663	175	278	198	107	121
Wells	512	26543	125	417	420	350	501	-2111	266	313	156	77	102
Willalooka	492	35928	124	412	397	384	511	-1689	244	295	152	75	77
Wirrega	481	54898	122	406	383	381	494	-1630	213	270	149	73	88
Woolumbool	528	30838	130	431	483	483	633	-981	151	236	164	83	100
Avg. or [Total]	*482*	*1392454*	*121*	*402*	*415*	*352*	*476*	*-1714*	*229*	*280*	*147*	*71*	*101*

Table 29 - Summaries of expected annual equivalent returns [$/ha/yr] from existing cropping and grazing industries, and new agroforestry industries by subdivision. (cont.)

Hundred	Rainfall [mm]	Potential Agroforestry Area [ha]	Gross Margin Cropping Grazing Avg Last 10 years	Gross margin Cropping Grazing Max Last 10 years	Eucalyptus Oil Only	Bioenergy Only @ Keith	Integrated Tree Processing @ Keith	CO2 Sequestration Bioenergy Spp	CO2 Sequestration Oil Mallee Spp	CO2 Sequestration Habitat Spp
Archibald	443	9850	110	368	340	641	570	324	3	1
Beeamma	507	30388	124	413	393	400	448	385	14	12
Binnum	527	35965	132	439	425	242	368	419	21	19
Bowaka	644	20717	160	533	534	248	424	546	45	43
Cannawigara	445	34640	110	368	337	508	491	324	3	1
Carcuma	400	25433	93	310	274	226	293	247	-11	-13
Colebatch	473	28081	113	376	352	373	413	335	5	3
Coneybeer	427	30525	108	360	333	372	405	313	1	-1
Coombe	441	42515	105	349	318	513	486	298	-2	-4
Duffield	509	19462	125	417	396	305	394	391	15	13
Field	472	24233	113	376	352	275	355	335	5	3
Geegeela	496	27963	121	404	383	344	410	373	12	10
Glen Roy	512	21780	125	417	398	433	469	390	15	13
Glyde	478	24433	113	376	352	201	310	335	5	3
Hynam	532	33077	132	439	425	329	419	420	21	19
Jeffries	440	20796	108	361	335	207	306	315	1	-1
Jessie	549	21516	139	463	455	168	338	451	27	25
Joyce (North)	567	16378	140	465	455	231	376	454	28	25
Kirkpatrick	408	23036	105	348	321	225	311	298	-2	-4
Lacepede	557	17272	140	466	454	261	394	456	28	26
Laffer	473	38493	119	396	373	652	589	362	10	8
Landseer	524	18924	130	431	412	387	449	409	19	17
Lewis	418	30160	99	330	297	360	385	273	-7	-8
Livingston	393	29982	101	335	305	249	319	280	-5	-7
Lochaber	534	21317	130	432	415	347	425	410	19	17
Makin	428	14153	101	335	300	506	476	280	-5	-7
Marcollat	505	34748	127	421	401	523	523	395	16	14
McCallum	434	16811	104	346	312	446	444	295	-2	-4
McNamara	500	26875	122	405	384	534	523	374	12	10
Messent	507	9421	119	396	373	408	443	362	10	8
Minecrow	561	26887	137	457	443	378	457	443	26	23
Mount Benson	601	22305	150	499	492	135	339	499	36	34
Murrabinna	578	16142	143	475	464	343	446	468	30	28
Naracoorte	549	20284	135	449	438	245	376	433	24	21
Neville	493	15517	126	419	400	398	450	393	16	14
Ngarkat	401	7551	94	314	277	238	302	252	-11	-12
Parsons	508	19066	123	409	387	483	495	379	13	11
Peacock	519	30706	127	424	403	473	496	399	17	15
Pendleton	454	36069	112	374	345	616	558	332	4	2
Petherick	503	31951	127	422	401	605	573	397	17	14
Richards	459	37753	108	361	334	446	451	315	1	-1
Santo	489	10064	120	400	379	314	390	367	11	9
Senior	438	36751	107	355	323	379	408	307	0	-2
Shaugh	437	34322	105	348	313	351	387	297	-2	-4
Spence (North)	558	19019	139	463	453	255	389	451	27	25
Stirling	459	36320	117	391	366	722	628	354	9	7
Strawbridge	440	19887	110	367	342	295	362	323	3	1
Tatiara	462	48028	109	364	335	397	422	319	2	0
Townsend	597	26681	147	490	483	262	407	487	34	32
Wells	512	26543	125	417	397	459	484	391	15	13
Willalooka	492	35928	124	412	390	650	594	383	14	12
Wirrega	481	54898	122	406	382	566	542	375	12	10
Woolumbool	528	30838	130	431	414	349	427	409	19	17
Avg. or [Total]	*482*	*1392454*	*121*	*402*	*380*	*382*	*433*	*370*	*12*	*10*

6. Discussion

Any woody biomass industry development is underpinned by the selection of the appropriate species to match the product and yield specifications of each industry type. Once the selected species (or groups of species) have proven to meet elementary industry requirements the primary driver towards economic development is the ability to produce sufficient economic volumes of biomass. The few studies of plantation productivity in the Upper South East (and most other low-mid rainfall areas of Australia) have mainly been limited to the evaluation of stemwood production rates of known forestry species from higher rainfall environments on lower rainfall sites. Most of these studies have been aimed at long-cycle hardwoods for lumber production with distant-future economic returns. Biomass productivities of species aimed at short-cycle woody crops are generally poorly known, or currently available growth data is limited to simple measurement of heights and stem diameter. Measuring total plant biomass for evaluating or developing woody biomass industries can be a labour intensive task. To increase the efficiency of determining existing and future plantation productivities, and to evaluate and value-add to previously collected trial site data, we have analysed relationships between simple plant measurements and stemwood volumes, total above-ground biomass and carbon contents.

The biometrics study provides very strong allometric relationships between simple measures of plant morphology and standing plant biomass (r^2=0.88). Analyses also show that simple classifications of species groups and lifeforms can improve the predictive capability of these models by a further 4%. Combined data for the *Upper South East* and *River Murray Corridor* biomass studies provide robust relationships that can be applied across South Australian environments and a wider range of species. Based on our measurements and destructive sampling we note that the currently published and widely used allometric biomass equations (Kiddle *et al.* 1987, Snowdon *et al.* 2000) can seriously miscalculate standing biomass on average by between 35-56% (and high as 71% for some lifeform classes) in the Upper South East region.

With access to robust allometric relationships we have been able to undertake efficient field measurements and evaluations of plantation biomass productivities of targeted species. We now have access to more detailed evaluations of trial site data gathered from PIRSA and Forestry SA established sites. The combined dataset has allowed us to readily evaluate and compare the productive potential of a number of species growing in the region, develop more reliable models of biomass production across the region, and provide a basis to quantifying potential feedstocks for new industry development.

The specific green biomass productivity rates and above ground carbon accumulation rates reported in this study should be considered conservative estimates only, as optimum planting rates for each species and site has not been determined. Using higher planting rates is likely to increase plantation total biomass production by ~50% or more in the Upper South East. The above-ground biomass from dryland plantations of local native "habitat species" can sequester around 10.5 tonnes of carbon dioxide per hectare per year in the region with higher average values for "bioenergy species" of around 26 tonnes of carbon dioxide per hectare per year (see

Table 30). A further component of annual carbon dioxide sequestration rates (but not accurately quantified in our study) is the additional biomass within plantation root systems (Gifford 2000).

Dryland plantations of native species can provide many environmental services and economic opportunities in the Upper South East region. The value of perennial plant systems to reduce salinity and carbon sequestration is well recognised, with correctly managed and designed planting providing an additional positive contribution to ecosystems, habitats and biodiversity. A number of commercial opportunities exist for extending existing biomass industries in the Upper South East (USE) region. Biomass production rates and infrastructure support the expansion of livestock fodder industries, firewood for Adelaide metropolitan and surrounding markets, and pulpwood industries.

Fodder shrubs are already a part of the existing livestock industries in the Upper South East region and much potential exists for further expansion of fodder shrubs to both increase livestock production and provide greater income stability when rainfall is less reliable. Firewood markets, especially to service our major population centres, are currently attractive to farmers in the region. Reasonable profits can be expected from firewood sales especially when landholders access the additional margins that can be gained from more mechanised harvesting systems. Pulpwood industries are extensive in the Lower South East region and much of the existing infrastructure can support expansion of these industries into lower rainfall regions in the neighbouring Upper South East. The planned new pulp mill at Penola will provide further opportunities for expansion. New industries based on bioenergy and *Eucalyptus* oil or combined in an *Integrated Tree Processing* plant (eg. Narrogin WA oil mallee based plant) would deliver economic returns to farmers in the region if there was a significant investment in the necessary infrastructure in the central part of the USE region.

Existing broadacre annual cropping and livestock grazing provide an average gross margin return of around $121 per hectare (based on average returns 1996-2005, see Table 30). As could be expected with annual-based crops and pastures these returns are highly variable over time, ranging from losses of over $-200/ha to profits of over $400/ha in good seasons. Woody perennial crops provide more consistent returns as the robust woody crops generally survive droughted conditions and can make the most of unseasonal rainfalls. Our integrated spatial analysis of plantation productivity and farm economics (Regional Industry Potential Analysis) for several industry types show that expanded pulpwood industries could provide annual equivalent returns of between $132 - 1006/ha (region average range = $415 - 476/ha). Firewood industry average annual returns for the region would be in the vicinity $229 - 280/ha, and fodder shrubs in Autumn would be worth $147/ha. The prospective industries of bioenergy and Eucalyptus oil extraction based on new infrastructure at Keith would provide annual returns of around $380 - 433/ha, and single purpose carbon sequestration planting would create annual returns up to $43/ha (average $10 - 12/ha) for habitat and oil mallee plantings but could be higher than $500/ha (average $370/ha) for permanent woodlots of Sugargum (*Eucalyptus cladocalyx*) or similar species.

Several of the woody biomass industries analysed here could provide economic returns which are competitive with existing cropping and grazing landuses in the region. Rather than a total displacement of existing annual cropping and grazing systems in the Upper South East region, we envisage these new woody biomass industries will provide new options and opportunities for farmers and existing industries of the region. These new options can be strategically placed to become an integral part of a healthy mosaic of new woody perennial-based and existing annual-based primary industries. In our landscapes that are subject to the risks of rising water tables, dryland salinity, soil erosion, habitat loss, climate change, and economic and community sustainability, there appears to be a sound future for woody perennial cropping in the Upper South East region.

Table 30 - Summaries of expected plantation productivities, environmental risks and landholder annual equivalent returns from existing and potential biomass industries (minimum, maximum and average values for 53 Hundred subdivisions).

Plantation Productivity	**Min.**	**Max.**	**Average**
Stemwood Productivity [m³/ha/year]			
Pulpwood Species	8.79	30.06	17.57
Bioenergy Species	19.29	36.21	26.27
Oil Mallee Species	4.52	7.76	5.85
Saltbush Fodder Species	2.35	4.03	3.04
Habitat Species	4.29	7.36	5.55
Green Biomass Productivity [t/ha/year]			
Pulpwood Species	9.65	33.00	19.29
Bioenergy Species	21.53	40.40	29.31
Oil Mallee Species	14.33	24.59	18.56
Saltbush Fodder Species	4.92	8.44	6.37
Habitat Species	9.19	15.77	11.91
Carbon Dioxide Sequestration [t CO_2 equiv/ha/year]			
Pulpwood Species	8.29	28.32	16.56
Bioenergy Species	19.16	35.97	26.10
Oil Mallee Species	12.99	22.29	16.82
Saltbush Fodder Species	3.48	5.97	4.50
Habitat Species	8.10	13.90	10.49
Environment	**Min.**	**Max.**	**Average**
Rainfall [mm]	393	644	482
Deep Drainage [mm/ha/year]	20.4	37.8	26.0
Risk Indices (0=low, 1=high)			
Index Dry Saline Land	0.00	0.28	0.05
Index Habitat Areas [#1]	0.06	0.99	0.76
Index Salinity [#2] - water table induced	0.00	0.52	0.13
Index Wind Erosion Risk [#3]	0.02	0.67	0.38
Index Overall (average [#1],[#2],[#3])	0.23	0.62	0.44
Industry Annual Returns ($/ha)	**Min.**	**Max.**	**Average**
Cropping/Grazing - Avg Last 10 years	93	160	121
Cropping/Grazing - Max Last 10 years	310	533	402
Export Pulpwood All Ports	183	764	415
Export Pulpwood Portland Only	62	764	352
Australian Pulpwood	122	1006	476
Particleboard	-2900	-239	-1714
Firewood (small scale)	100	360	229
Firewood (medium scale)	190	356	280
In situ Fodder (Autumn)	92	224	147
In situ Fodder (Spring)	34	125	71
Off farm Fodder	49	169	101
Eucalyptus Oil Only	274	534	380
Bioenergy Only at Keith	135	722	382
Integrated Tree Processing at Keith	293	628	433
CO_2 Sequestration Bioenergy Species	247	546	370
CO_2 Sequestration Oil Mallee Species	-11	45	12
CO_2 Sequestration Habitat Species	-13	43	10

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Appendix A – Additional Productivity Data

Table 31 – Average and maximum observed productivity of plots for each species at each site from trial sites and surveys in the Upper South East region and neighbouring districts.

Species	Average Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	Average of Plots: MAI Stemwood Volume (x1000) [m^3 $plant^{-1}$ yr^{-1}]	Average of Plots: MAI Green Biomass [t $plant^{-1}$ yr^{-1}]	Average of Plots: MAI CO_2 equiv. [t $plant^{-1}$ yr^{-1}]	Maximum of Plots: MAI Stemwood Volume (x1000) [m^3 $plant^{-1}$ yr^{-1}]	Maximum of Plots: MAI Green Biomass [t $plant^{-1}$ yr^{-1}]	Maximum of Plots: MAI CO_2 equiv. [t $plant^{-1}$ yr^{-1}]
Acacia dealbata	671	3.4	3.5	904	0.99	1.24	1.12	1.66	2.13	1.91
Acacia mearnsii	492	12.5	9.9	3017	6.43	10.95	11.59	6.43	10.95	11.59
Acacia mearnsii	559	4.3	4.0	947	0.81	1.00	1.06	0.81	1.00	1.06
Acacia melanoxylon	559	8.4	4.5	947	1.12	1.49	1.33	1.12	1.49	1.33
Acacia melanoxylon	613	7.4	5.0	928	1.23	1.63	1.46	1.23	1.63	1.46
Acacia melanoxylon	671	3.4	4.6	904	1.66	2.15	1.93	2.56	3.39	3.04
Acacia melanoxylon	698	7.4	6.2	1600	3.68	5.40	4.85	3.68	5.40	4.85
Acacia melanoxylon	698	10.4	7.3	1231	6.56	10.75	9.65	14.64	25.78	23.15
Acacia melanoxylon	741	7.0	2.7	400	0.26	0.31	0.28	0.35	0.42	0.38
Acacia pycnantha	387	7.0	3.4	1000	2.07	9.73	9.15	2.07	9.73	9.15
Acacia salicina	492	9.3	3.5	684	0.87	1.14	1.02	0.87	1.14	1.02
Acacia stenophylla	492	9.3	4.9	684	1.07	1.43	1.28	1.07	1.43	1.28
Allocasuarina verticillata	492	10.9	8.6	444	17.96	33.57	36.13	17.96	33.57	36.13
Atriplex nummularia	466	3.0	1.6	966	1.89	3.97	2.80	1.89	3.97	2.80
Callitris columellaris	348	10.0	2.5	370	0.17	0.21	0.19	0.23	0.28	0.25
Casuarina cunninghamiana	698	10.4	8.0	1600	4.33	6.79	6.09	8.40	13.95	12.52
Casuarina glauca	480	8.5	4.2	961	0.73	0.95	0.85	1.01	1.33	1.20
Casuarina glauca	492	9.3	6.9	684	2.49	3.70	3.33	5.72	9.00	8.08
Casuarina glauca	509	10.3	7.4	684	3.57	5.52	4.95	10.54	17.90	16.07
Casuarina glauca	559	8.4	6.7	947	3.47	5.19	4.66	5.63	8.77	7.87
Casuarina glauca	610	8.7	3.3	1185	0.49	0.62	0.55	0.57	0.73	0.65
Casuarina glauca	625	8.6	3.8	948	0.56	0.71	0.64	0.67	0.86	0.78
Casuarina glauca	698	10.4	7.9	1600	4.54	7.06	6.34	5.02	7.88	7.08
Casuarina obesa	480	8.5	4.0	961	0.61	0.78	0.70	1.08	1.44	1.29
Casuarina obesa	610	8.7	2.8	1185	0.26	0.31	0.28	0.38	0.46	0.42
Casuarina obesa	625	8.6	2.9	948	0.26	0.31	0.28	0.38	0.47	0.42
Casuarina pauper (cristata)	364	11.4	3.7	370	0.21	0.25	0.23	0.21	0.25	0.23
Corymbia citriodora	466	5.8	2.3	1000	0.12	0.70	0.61	0.17	0.80	0.71
Corymbia maculata	466	5.8	2.8	1000	0.22	0.93	0.79	0.32	1.15	0.98
Corymbia maculata	492	10.8	9.0	556	9.24	12.53	10.68	9.24	12.53	10.68
Corymbia maculata	492	6.9	10.2	1111	12.69	18.62	15.86	12.69	18.62	15.86
Corymbia maculata	613	7.4	9.1	928	5.43	8.85	7.54	9.77	15.12	12.89
Eucalyptus astringens	320	7.3	4.3	625	0.79	2.02	1.78	0.79	2.02	1.78
Eucalyptus astringens	364	11.4	6.7	370	4.03	6.70	5.89	7.12	10.78	9.48
Eucalyptus astringens	559	8.4	7.9	947	8.17	12.70	11.17	10.79	16.02	14.09
Eucalyptus botryoides	492	9.3	9.9	684	8.51	12.94	11.38	8.51	12.94	11.38
Eucalyptus botryoides	698	7.4	10.8	1600	16.11	22.84	20.08	16.35	23.12	20.33
Eucalyptus brockwayi	348	7.0	3.6	370	1.68	3.21	2.82	4.56	7.60	6.69
Eucalyptus brockwayi	671	3.4	2.3	904	0.22	1.20	1.05	0.34	1.49	1.31
Eucalyptus camaldulensis	362	7.6	5.7	142	4.09	7.17	5.23	4.09	7.17	5.23

Species	Average Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	Average of Plots: MAI Stemwood Volume (x1000) [m^3 $plant^{-1}$ yr^{-1}]	Average of Plots: MAI Green Biomass [t $plant^{-1}$ yr^{-1}]	Average of Plots: MAI CO_2 equiv. [t $plant^{-1}$ yr^{-1}]	Maximum of Plots: MAI Stemwood Volume (x1000) [m^3 $plant^{-1}$ yr^{-1}]	Maximum of Plots: MAI Green Biomass [t $plant^{-1}$ yr^{-1}]	Maximum of Plots: MAI CO_2 equiv. [t $plant^{-1}$ yr^{-1}]
Eucalyptus camaldulensis	376	7.7	9.6	1079	9.52	14.05	10.24	9.52	14.05	10.24
Eucalyptus camaldulensis	445	19.4	8.5	863	2.46	4.09	2.98	2.75	4.48	3.27
Eucalyptus camaldulensis	460	10.7	11.4	952	20.70	25.68	18.72	20.70	25.68	18.72
Eucalyptus camaldulensis	492	9.9	8.2	1429	4.59	7.47	5.44	4.59	7.47	5.44
Eucalyptus camaldulensis	559	5.5	3.8	947	1.08	2.51	1.83	2.47	4.91	3.58
Eucalyptus camaldulensis	741	7.0	2.7	400	0.44	1.28	0.94	0.91	2.26	1.65
Eucalyptus camaldulensis	492	9.3	8.1	684	5.82	9.17	6.69	12.95	18.29	13.33
Eucalyptus camaldulensis	509	9.4	12.2	684	20.85	26.23	19.12	44.41	50.64	36.92
Eucalyptus camaldulensis	698	10.1	6.5	1600	7.93	11.54	8.42	19.73	25.41	18.53
Eucalyptus cladocalyx	444	19.4	10.6	1171	3.21	5.10	4.74	3.45	5.41	5.02
Eucalyptus cladocalyx	447	19.4	8.2	1032	1.38	2.55	2.37	1.48	2.70	2.51
Eucalyptus cladocalyx	460	6.7	5.6	833	3.56	6.53	6.17	3.56	6.53	6.17
Eucalyptus cladocalyx	460	6.7	5.0	1111	4.26	7.81	7.13	4.26	7.81	7.13
Eucalyptus cladocalyx	460	6.7	6.4	1212	5.10	8.85	8.22	5.10	8.85	8.22
Eucalyptus cladocalyx	460	19.3	12.3	668	6.58	9.21	8.56	7.09	9.80	9.11
Eucalyptus cladocalyx	460	10.7	14.9	625	30.55	35.65	33.13	30.55	35.65	33.13
Eucalyptus cladocalyx	466	11.0	6.1	1000	1.95	3.73	3.46	6.47	10.05	9.34
Eucalyptus cladocalyx	613	10.3	9.9	928	17.73	22.91	21.29	33.28	39.21	36.43
Eucalyptus cladocalyx	698	10.3	12.8	1600	26.38	31.35	29.13	56.38	60.57	56.28
Eucalyptus cneorifolia	492	9.3	3.9	684	0.98	3.26	3.16	0.98	3.26	3.16
Eucalyptus cneorifolia	559	8.4	3.6	947	0.38	1.61	1.57	0.42	1.74	1.69
Eucalyptus cornuta	559	8.4	9.3	947	12.59	18.20	16.00	12.59	18.20	16.00
Eucalyptus diversifolia	460	12.7	5.5	1279	4.04	13.77	13.16	4.04	13.77	13.16
Eucalyptus dumosa	348	10.3	3.6	370	0.32	1.35	1.43	0.32	1.35	1.43
Eucalyptus dumosa	387	12.0	3.8	1000	1.07	3.32	3.51	1.07	3.32	3.51
Eucalyptus dundasii	348	10.3	6.6	370	2.68	4.92	4.33	2.68	4.92	4.33
Eucalyptus dundasii	364	11.4	8.2	370	5.02	8.08	7.11	5.92	9.27	8.15
Eucalyptus dundasii	671	3.4	2.6	904	0.25	1.29	1.14	0.25	1.29	1.14
Eucalyptus famelica	509	10.3	2.4	684	0.08	0.59	0.58	0.08	0.59	0.58
Eucalyptus fasciculosa	492	9.3	1.5	684	0.01	0.27	0.24	0.01	0.27	0.24
Eucalyptus globulus	444	16.6	14.2	1165	8.62	11.81	10.05	9.52	12.83	10.91
Eucalyptus globulus	445	19.4	18.3	893	15.90	19.08	16.23	17.31	20.47	17.42
Eucalyptus globulus	457	14.2	14.2	550	10.18	13.94	11.86	11.25	15.14	12.89
Eucalyptus globulus	460	19.3	14.3	785	11.65	14.77	12.57	12.36	15.52	13.21
Eucalyptus globulus	460	10.7	12.5	1190	12.26	16.40	13.95	12.26	16.40	13.95
Eucalyptus globulus	492	6.8	11.1	1250	14.65	21.10	17.95	14.65	21.10	17.95
Eucalyptus globulus	492	15.7	18.2	1173	18.90	22.84	19.43	20.80	24.74	21.05
Eucalyptus globulus	497	13.3	13.1	973	6.94	10.21	8.69	12.44	16.63	14.15
Eucalyptus globulus	506	19.1	15.8	1231	6.29	8.90	7.57	6.70	9.37	7.97
Eucalyptus globulus	506	16.9	13.6	663	7.21	10.15	8.64	8.90	12.09	10.29
Eucalyptus globulus	510	16.7	15.5	906	7.53	10.57	8.99	7.78	10.85	9.23
Eucalyptus globulus	511	14.2	13.1	831	7.15	10.42	8.87	7.21	10.49	8.93
Eucalyptus globulus	540	27.1	25.5	1244	14.82	16.98	14.45	16.47	18.55	15.78
Eucalyptus globulus	554	18.7	17.6	967	7.86	10.70	9.11	9.21	12.23	10.41
Eucalyptus globulus	566	20.8	21.4	2037	8.02	10.70	9.11	8.73	11.48	9.77

Species	Average Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	Average of Plots: MAI Stemwood Volume (x1000) [m^3 $plant^{-1}$ yr^{-1}]	Average of Plots: MAI Green Biomass [t $plant^{-1}$ yr^{-1}]	Average of Plots: MAI CO_2 equiv. [t $plant^{-1}$ yr^{-1}]	Maximum of Plots: MAI Stemwood Volume (x1000) [m^3 $plant^{-1}$ yr^{-1}]	Maximum of Plots: MAI Green Biomass [t $plant^{-1}$ yr^{-1}]	Maximum of Plots: MAI CO_2 equiv. [t $plant^{-1}$ yr^{-1}]
Eucalyptus globulus	569	16.3	18.0	1006	11.71	15.23	12.96	15.61	19.37	16.48
Eucalyptus globulus	583	14.1	13.9	1195	7.13	10.40	8.85	7.52	10.87	9.25
Eucalyptus globulus	606	4.9	18.0	1143	42.78	54.54	46.40	42.78	54.54	46.40
Eucalyptus globulus	606	4.9	19.2	1136	43.03	54.89	46.71	43.03	54.89	46.71
Eucalyptus globulus	625	9.8	10.6	1600	7.33	11.15	9.49	13.17	18.40	15.66
Eucalyptus globulus	659	9.7	10.4	1600	5.01	8.22	6.99	7.74	11.88	10.11
Eucalyptus gomphocephala	460	12.0	12.4	500	60.85	60.63	54.42	60.85	60.63	54.42
Eucalyptus gomphocephala	559	8.4	9.5	947	33.52	40.88	35.95	33.52	40.88	35.95
Eucalyptus gracilis	364	10.3	2.7	370	0.40	1.60	1.55	0.40	1.60	1.55
Eucalyptus grandis	492	15.7	11.0	1121	4.93	7.53	6.62	5.05	7.68	6.75
Eucalyptus grandis	492	6.8	10.6	1250	13.20	19.44	17.45	13.20	19.44	17.45
Eucalyptus grandis	583	14.1	11.5	1166	4.38	6.96	6.12	4.87	7.61	6.69
Eucalyptus grandis	698	7.4	9.2	1600	8.77	13.81	12.15	9.94	15.33	13.48
Eucalyptus incrassata	374	8.0	3.7	1120	1.68	5.19	5.20	1.68	5.19	5.20
Eucalyptus incrassata	460	12.7	3.6	1235	1.49	7.24	7.25	1.49	7.24	7.25
Eucalyptus kondininensis	559	4.3	2.3	947	0.16	0.92	0.81	0.16	0.92	0.81
Eucalyptus kondininensis	671	3.4	3.5	904	0.68	2.25	1.98	0.68	2.25	1.98
Eucalyptus largiflorens	492	9.3	6.2	684	2.42	4.62	4.06	2.42	4.62	4.06
Eucalyptus largiflorens	559	7.4	3.0	947	0.20	0.78	0.69	0.34	1.11	0.98
Eucalyptus largiflorens	613	7.4	3.4	928	0.16	0.70	0.61	0.16	0.70	0.61
Eucalyptus leptophylla	348	10.3	3.1	370	0.12	0.72	0.70	0.14	0.77	0.75
Eucalyptus leptophylla	364	10.3	2.9	370	0.28	1.23	1.20	0.28	1.23	1.20
Eucalyptus leucoxylon	492	10.7	8.6	1088	6.75	10.03	9.68	6.75	10.03	9.68
Eucalyptus leucoxylon	320	7.3	3.2	625	0.11	0.57	0.55	0.20	0.79	0.76
Eucalyptus leucoxylon	364	11.4	7.8	370	4.42	7.22	6.97	6.27	9.71	9.37
Eucalyptus leucoxylon	364	13.1	7.7	500	5.54	8.51	8.22	7.80	11.35	10.95
Eucalyptus leucoxylon	492	9.3	10.8	684	13.73	18.94	18.28	22.18	28.54	27.54
Eucalyptus leucoxylon	559	8.4	6.6	947	8.18	12.56	12.12	11.84	17.30	16.69
Eucalyptus leucoxylon	613	10.3	9.3	928	12.03	16.34	15.77	33.66	39.58	38.20
Eucalyptus leucoxylon	698	10.4	10.5	1600	20.55	25.95	25.05	37.33	43.06	41.56
Eucalyptus obliqua	613	7.4	7.9	928	5.97	10.08	8.86	5.97	10.08	8.86
Eucalyptus occidentalis	320	7.3	4.6	625	0.71	1.74	1.59	1.86	3.92	3.59
Eucalyptus occidentalis	364	11.4	8.8	370	6.64	10.07	9.22	16.35	21.42	19.63
Eucalyptus occidentalis	460	6.7	8.2	980	7.31	11.90	11.09	7.31	11.90	11.09
Eucalyptus occidentalis	460	6.7	10.2	1190	13.32	19.42	17.79	13.32	19.42	17.79
Eucalyptus occidentalis	460	6.5	12.1	1111	18.93	26.44	24.22	18.93	26.44	24.22
Eucalyptus occidentalis	460	5.7	9.8	833	19.13	27.20	24.49	19.13	27.20	24.49
Eucalyptus occidentalis	492	9.9	10.5	1389	9.06	13.14	12.04	9.06	13.14	12.04
Eucalyptus occidentalis	492	9.3	13.0	684	21.40	27.39	25.10	46.50	52.64	48.23
Eucalyptus occidentalis	494	5.5	2.5	1000	0.39	1.33	1.22	0.63	1.85	1.69
Eucalyptus occidentalis	509	5.5	1.8	1000	0.09	0.65	0.59	0.17	0.84	0.77
Eucalyptus occidentalis	509	10.3	6.9	1251	3.00	5.34	4.89	9.37	13.77	12.62
Eucalyptus occidentalis	509	10.3	11.6	684	17.44	22.79	20.88	29.17	35.17	32.22
Eucalyptus occidentalis	559	8.4	11.4	947	17.58	23.85	21.85	27.00	34.18	31.31
Eucalyptus oleosa	387	6.8	3.0	2083	1.36	4.44	5.04	1.36	4.44	5.04

Species	Average Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	Average of Plots			Maximum of Plots		
					MAI Stemwood Volume (x1000) [m^3 $plant^{-1}$ yr^{-1}]	MAI Green Biomass [t $plant^{-1}$ yr^{-1}]	MAI CO_2 equiv. [t $plant^{-1}$ yr^{-1}]	MAI Stemwood Volume (x1000) [m^3 $plant^{-1}$ yr^{-1}]	MAI Green Biomass [t $plant^{-1}$ yr^{-1}]	MAI CO_2 equiv. [t $plant^{-1}$ yr^{-1}]
Eucalyptus ovata	492	9.3	10.1	684	12.08	17.27	15.19	12.08	17.27	15.19
Eucalyptus ovata	559	4.3	2.8	947	0.30	1.25	1.10	0.30	1.25	1.10
Eucalyptus ovata	698	7.4	7.8	1600	7.41	12.01	10.56	8.83	13.91	12.24
Eucalyptus porosa	348	10.3	5.8	370	1.62	4.86	4.20	1.62	4.86	4.20
Eucalyptus porosa	364	11.4	4.8	370	1.59	4.60	3.98	4.47	11.36	9.82
Eucalyptus porosa	387	6.7	3.9	2083	3.43	9.79	8.46	3.43	9.79	8.46
Eucalyptus saligna	492	6.8	9.1	1068	10.00	15.40	13.83	10.00	15.40	13.83
Eucalyptus saligna	583	14.1	11.5	1166	4.38	6.96	6.12	4.87	7.61	6.69
Eucalyptus saligna	698	7.4	9.7	1600	10.13	15.56	13.68	11.00	16.67	14.66
Eucalyptus tereticornis	509	9.4	11.0	684	14.68	19.91	17.51	23.26	29.66	26.08
Eucalyptus tereticornis	559	4.3	2.6	947	0.29	1.22	1.07	0.60	1.91	1.68
Eucalyptus tereticornis	613	9.4	11.9	928	13.42	18.69	16.43	22.96	29.35	25.81
Eucalyptus tereticornis	698	9.3	6.0	1600	5.67	9.28	8.16	5.67	9.28	8.16
Eucalyptus viminalis	460	5.7	10.0	714	20.58	28.24	22.29	20.58	28.24	22.29
Eucalyptus viminalis	492	9.9	11.1	1157	15.02	20.31	16.03	15.02	20.31	16.03
Eucalyptus viminalis	497	13.3	9.6	973	3.54	5.91	4.66	3.54	5.91	4.66
Eucalyptus viminalis	554	18.7	19.6	684	11.71	14.91	11.77	13.01	16.28	12.85
Eucalyptus viminalis	492	9.3	8.6	684	14.84	20.47	16.16	14.84	20.47	16.16
Melaleuca cuticularis	492	9.3	3.4	684	0.84	1.75	1.44	0.84	1.75	1.44
Melaleuca cuticularis	509	9.4	1.5	684	0.040	0.055	0.045	0.040	0.055	0.045
Melaleuca uncinata	348	10.3	1.6	370	0.003	0.004	0.003	0.003	0.004	0.003
Melaleuca uncinata	492	9.3	1.5	684	0.003	0.004	0.003	0.003	0.004	0.003

Table 32 – Observed productivity of best performing plots within each species at each site (top 10% within species and site) from trial sites and surveys in the Upper South East region and neighbouring districts.

Species and Provenance	Av. Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	MAI Stemwood Volume (x1000) [m^3 $plant^{-1}$ yr^{-1}]	MAI Green Biomass [t $plant^{-1}$ yr^{-1}]	MAI CO_2 equiv. [t $plant^{-1}$ yr^{-1}]
Acacia dealbata ssp. dealbata [Errinundra Plateau CS16271]	671	3.4	4.3		1.66	2.13	1.91
Acacia mearnsii [Kyneton CS18979]	559	4.3	4.0	355	0.81	1.00	1.06
Acacia mearnsii [Lanark Branxholme]	492	12.5	9.9	3017	6.43	10.95	11.59
Acacia melanoxylon [Blackwood Park CS15863]	698	10.4	8.9	308	14.64	25.78	23.15
Acacia melanoxylon [Cressy TFC_1998.01]	671	3.4	5.1		2.56	3.39	3.04
Acacia melanoxylon [Furner TFL_1992.02]	559	8.4	4.5	710	1.12	1.49	1.33
Acacia melanoxylon [Silver Creek CS15614]	613	7.4	5.0	928	1.23	1.63	1.46
Acacia melanoxylon [Silver Creek CS15614]	698	7.4	6.2	1400	3.68	5.40	4.85
Acacia melanoxylon [WF601]	741	7.0	2.8	244	0.35	0.42	0.38
Acacia pycnantha	387	7.0	3.4	528	2.07	9.73	9.15
Acacia salicina [Yacka FTI_P_1992.01]	492	9.3	3.5	598	0.87	1.14	1.02
Acacia stenophylla [Riverland FTI_W_1992.01]	492	9.3	4.9	171	1.07	1.43	1.28
Allocasuarina verticillata	492	10.9	8.6	395	17.96	33.57	36.13
Atriplex nummularia	466	3.0	1.6	966	1.89	3.97	2.80
Callitris columellaris [Mambray Creek BSC_1992.01]	348	9.4	2.9	370	0.23	0.28	0.25
Casuarina cunninghamiana ssp. cunninghamiana [Hunter River CS13127]	698	10.4	9.1	1400	8.40	13.95	12.52
Casuarina glauca	480	8.5	4.5	961	1.01	1.33	1.20
Casuarina glauca	610	8.7	3.7	948	0.55	0.70	0.62
Casuarina glauca	610	8.7	3.4	948	0.57	0.73	0.65
Casuarina glauca	625	8.6	3.9	877	0.67	0.86	0.78
Casuarina glauca [Coffs Harbour CS13987]	559	8.4	7.5	947	5.05	7.77	6.98
Casuarina glauca [Coffs Harbour CS13987]	559	8.4	6.5	947	5.63	8.77	7.87
Casuarina glauca [Mangrove Creek CS13143]	492	9.3	8.6	427	5.72	9.00	8.08
Casuarina glauca [Myall Lakes CS15934]	509	10.3	10.2	598	10.54	17.90	16.07
Casuarina glauca [Singleton CS13128]	698	10.4	8.5	1600	5.02	7.88	7.08
Casuarina obesa	480	8.5	4.5	865	1.08	1.44	1.29
Casuarina obesa	610	8.7	3.1	1125	0.38	0.46	0.42
Casuarina obesa	625	8.6	3.6	687	0.38	0.47	0.42
Casuarina pauper (cristata) [Flinders Range BSC_1992.02]	364	11.4	3.7	231	0.21	0.25	0.23
Corymbia citriodora ssp. variegata	466	5.8	2.6	563	0.17	0.80	0.71
Corymbia citriodora ssp. variegata	466	5.8	2.5	547	0.17	0.80	0.71
Corymbia maculata	466	5.8	3.0	734	0.29	1.09	0.93
Corymbia maculata	466	5.8	3.1	906	0.30	1.11	0.95
Corymbia maculata	466	5.8	3.1	781	0.32	1.15	0.98
Corymbia maculata	492	10.8	9.0	432	9.24	12.53	10.68
Corymbia maculata	492	6.9	10.2	685	12.69	18.62	15.86
Corymbia maculata [Orbost CS13608]	613	7.4	11.2	928	9.77	15.12	12.89
Eucalyptus astringens [Boyagin Rock CS17670]	364	11.4	7.6	370	7.12	10.78	9.48
Eucalyptus astringens [Cuballing CALM D921]	559	8.4	8.6	592	10.79	16.02	14.09
Eucalyptus astringens [Dryandra CALM 91038]	559	8.4	9.2	828	10.27	15.39	13.53
Eucalyptus astringens [Dryandra CS12842]	320	7.3	4.3	625	0.79	2.02	1.78

Species and Provenance	Av. Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	MAI Stemwood Volume (x1000) [m^3 $plant^{-1}$ yr^{-1}]	MAI Green Biomass [t $plant^{-1}$ yr^{-1}]	MAI CO_2 equiv. [t $plant^{-1}$ yr^{-1}]
Eucalyptus astringens [Ravensthorpe CS17685]	559	8.4	7.3	237	9.75	14.74	12.96
Eucalyptus botryoides [Narooma CS15529]	492	9.3	9.9	427	8.51	12.94	11.38
Eucalyptus botryoides [Termeil CS12134]	698	7.4	10.6	1600	15.87	22.55	19.83
Eucalyptus botryoides [Termeil CS12134]	698	7.4	11.1	1600	16.35	23.12	20.33
Eucalyptus brockwayi [Davyhurst CALM 9081]	671	3.4	2.4		0.34	1.49	1.31
Eucalyptus brockwayi [Kondinin CALM 9042]	348	10.3	6.2	139	4.56	7.60	6.69
Eucalyptus camaldulensis	445	19.4	8.8	609	2.75	4.48	3.27
Eucalyptus camaldulensis	492	9.9	8.2	1103	4.59	7.47	5.44
Eucalyptus camaldulensis [Crystal Brook FTI_TD_1996.01]	559	7.4	5.4	473	2.44	4.87	3.55
Eucalyptus camaldulensis [Crystal Brook FTI_TD_1996.01]	559	7.4	5.1	473	2.47	4.91	3.58
Eucalyptus camaldulensis [Culburra cult. (P05)]	460	10.7	11.4	793	20.70	25.68	18.72
Eucalyptus camaldulensis [Kalangadoo FTI_H_1992.01]	698	10.4	9.3	1400	19.73	25.41	18.53
Eucalyptus camaldulensis [Mt. Wedge, Eyre Penn.]	376	7.7	9.6	1027	9.52	14.05	10.24
Eucalyptus camaldulensis [Sherlock cult.]	362	7.6	5.7	142	4.09	7.17	5.23
Eucalyptus camaldulensis [WF607]	741	7.0	3.2	376	0.91	2.26	1.65
Eucalyptus camaldulensis [WF608]	741	7.0	3.5	392	0.84	2.14	1.56
Eucalyptus camaldulensis var. camaldulensis [Lake Albacutya CS15029]	509	9.4	15.7	513	44.41	50.64	36.92
Eucalyptus camaldulensis var. obtusa [Lake Indoon CS15799]	492	9.3	6.9	513	12.95	18.29	13.33
Eucalyptus cladocalyx	444	19.4	10.4	1085	3.28	5.19	4.82
Eucalyptus cladocalyx	444	19.4	10.1	1077	3.45	5.41	5.02
Eucalyptus cladocalyx	447	19.4	7.6	811	1.35	2.51	2.33
Eucalyptus cladocalyx	447	19.4	9.0	939	1.48	2.70	2.51
Eucalyptus cladocalyx	460	19.3	12.8	470	7.09	9.80	9.11
Eucalyptus cladocalyx [Culburra cult. (P18B)]	460	6.7	5.6	793	3.56	6.53	6.17
Eucalyptus cladocalyx [Culburra cult. (P27)]	460	10.7	14.9	440	30.55	35.65	33.13
Eucalyptus cladocalyx [Culburra cult. (P34A)]	460	6.7	5.0	939	4.26	7.81	7.13
Eucalyptus cladocalyx [Culburra cult. (P34A)]	460	6.7	6.4	1024	5.10	8.85	8.22
Eucalyptus cladocalyx [Flinders Chase NP KI CS16022]	698	10.4	11.0	200	56.38	60.57	56.28
Eucalyptus cladocalyx [Genotype 9]	466	10.9	7.3	200	6.47	10.05	9.34
Eucalyptus cladocalyx [Kangaroo Island TFL_1993.02]	613	10.3	12.9	348	33.28	39.21	36.43
Eucalyptus cneorifolia [Kingscote CS16023]	492	9.3	3.9	171	0.98	3.26	3.16
Eucalyptus cneorifolia [Kingscote CS16023]	559	8.4	3.5	473	0.42	1.74	1.69
Eucalyptus cornuta [Albany CS11256]	559	8.4	9.3	473	12.59	18.20	16.00
Eucalyptus diversifolia [Culburra (P37A)]	460	12.7	5.5	1279	4.04	13.77	13.16
Eucalyptus dumosa	387	12.0	3.8	836	1.07	3.32	3.51
Eucalyptus dumosa [Lameroo GA_1993.04]	348	10.3	3.6	324	0.32	1.35	1.43
Eucalyptus dundasii [FTI_1996.01]	671	3.4	2.6		0.25	1.29	1.14
Eucalyptus dundasii [Norseman CS12260]	348	10.3	6.6	185	2.68	4.92	4.33
Eucalyptus dundasii [Norseman CS12260]	364	11.4	8.0	231	5.92	9.27	8.15
Eucalyptus famelica [Ravensthorpe NS-03871]	509	10.3	2.4	171	0.08	0.59	0.58
Eucalyptus fasciculosa [Willalooka FTI_J_1994.02]	492	9.3	1.5	85	0.01	0.27	0.24
Eucalyptus globulus	444	16.6	14.1	930	8.79	12.01	10.22
Eucalyptus globulus	444	16.6	14.9	929	9.52	12.83	10.91
Eucalyptus globulus	445	19.4	17.8	547	17.31	20.47	17.42

Species and Provenance	Av. Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	MAI Stemwood Volume (x1000) [m^3 $plant^{-1}$ yr^{-1}]	MAI Green Biomass [t $plant^{-1}$ yr^{-1}]	MAI CO_2 equiv. [t $plant^{-1}$ yr^{-1}]
Eucalyptus globulus	457	14.2	14.3	491	11.25	15.14	12.89
Eucalyptus globulus	460	19.3	14.3	549	12.36	15.52	13.21
Eucalyptus globulus	492	6.8	11.1	1010	14.65	21.10	17.95
Eucalyptus globulus	492	15.7	18.2	294	20.80	24.74	21.05
Eucalyptus globulus	506	19.1	15.3	1124	6.01	8.56	7.29
Eucalyptus globulus	506	19.1	15.8	1070	6.18	8.77	7.46
Eucalyptus globulus	506	19.1	16.3	1100	6.70	9.37	7.97
Eucalyptus globulus	506	16.9	14.5	666	8.02	11.11	9.45
Eucalyptus globulus	506	16.9	14.8	417	8.07	11.16	9.50
Eucalyptus globulus	506	16.9	14.2	416	8.54	11.70	9.95
Eucalyptus globulus	506	16.9	14.0	416	8.65	11.82	10.05
Eucalyptus globulus	506	16.9	13.6	380	8.77	11.95	10.17
Eucalyptus globulus	506	16.9	14.3	390	8.89	12.08	10.28
Eucalyptus globulus	506	16.9	14.7	421	8.90	12.09	10.29
Eucalyptus globulus	510	16.7	16.0	863	7.29	10.29	8.75
Eucalyptus globulus	510	16.7	15.0	870	7.78	10.85	9.23
Eucalyptus globulus	511	14.2	13.4	702	7.09	10.35	8.80
Eucalyptus globulus	511	14.2	12.9	739	7.21	10.49	8.93
Eucalyptus globulus	540	27.1	26.8	770	16.47	18.55	15.78
Eucalyptus globulus	554	18.7	18.2	829	8.38	11.31	9.62
Eucalyptus globulus	554	18.7	18.5	878	9.21	12.23	10.41
Eucalyptus globulus	566	20.8	21.2	1641	8.02	10.71	9.12
Eucalyptus globulus	566	20.8	21.4	1617	8.73	11.48	9.77
Eucalyptus globulus	569	16.3	19.9	911	15.14	18.89	16.07
Eucalyptus globulus	569	16.3	19.9	928	15.61	19.37	16.48
Eucalyptus globulus	583	14.1	14.0	1059	7.26	10.56	8.98
Eucalyptus globulus	583	14.1	14.0	963	7.52	10.87	9.25
Eucalyptus globulus [APP]	625	9.8	12.2	1200	11.97	17.01	14.47
Eucalyptus globulus [APP]	625	9.8	13.0	800	13.07	18.29	15.56
Eucalyptus globulus [APP]	659	9.7	11.4	1600	7.10	11.07	9.42
Eucalyptus globulus [Culburra cult. (P05)]	460	10.7	12.5	898	12.26	16.40	13.95
Eucalyptus globulus [Flinders Island]	497	13.3	14.7	924	11.14	15.19	12.92
Eucalyptus globulus [Flinders Island]	497	13.3	14.5	973	12.44	16.63	14.15
Eucalyptus globulus [Flinders Island]	625	9.8	12.6	1600	12.03	17.07	14.53
Eucalyptus globulus [Flinders Island]	625	9.8	11.0	1200	12.12	17.18	14.62
Eucalyptus globulus [Flinders Island]	625	9.8	12.7	1600	13.17	18.40	15.66
Eucalyptus globulus [Flinders Island]	659	9.7	11.3	1600	7.47	11.54	9.82
Eucalyptus globulus [Flinders Island]	659	9.7	11.7	1600	7.70	11.82	10.06
Eucalyptus globulus [Jeeralang]	659	9.7	10.9	1600	7.23	11.23	9.56
Eucalyptus globulus ssp. globulus [cult. Worrolong]	659	9.7	11.8	1600	7.74	11.88	10.11
Eucalyptus globulus ssp. globulus [cult.]	606	4.9	18.0	1143	42.78	54.54	46.40
Eucalyptus globulus ssp. globulus [cult.]	606	4.9	19.2	1136	43.03	54.89	46.71
Eucalyptus globulus ssp. pseudoglobulus	659	9.7	11.8	1600	7.01	10.95	9.31
Eucalyptus globulus ssp. pseudoglobulus	659	9.7	11.7	1600	7.23	11.23	9.55
Eucalyptus gomphocephala [Culburra cult. (P23B)]	460	12.0	12.4	500	60.85	60.63	54.42
Eucalyptus gomphocephala [Ludlow CS12308]	559	8.4	9.5	355	33.52	40.88	35.95

Species and Provenance	Av. Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	MAI Stemwood Volume (x1000) [m³ plant^{-1} yr^{-1}]	MAI Green Biomass [t plant^{-1} yr^{-1}]	MAI CO_2 equiv. [t plant^{-1} yr^{-1}]
Eucalyptus gracilis [Karoonda GA_1992.02]	364	10.3	2.7	139	0.40	1.60	1.55
Eucalyptus grandis	492	15.7	10.8	445	4.81	7.38	6.49
Eucalyptus grandis	492	15.7	11.2	498	5.05	7.68	6.75
Eucalyptus grandis	583	14.1	12.2	995	4.63	7.29	6.41
Eucalyptus grandis	583	14.1	12.2	995	4.63	7.29	6.41
Eucalyptus grandis	583	14.1	11.3	712	4.87	7.61	6.69
Eucalyptus grandis	583	14.1	11.3	712	4.87	7.61	6.69
Eucalyptus grandis [Coffs Harbour CS13020]	698	7.4	9.5	1600	9.94	15.33	13.48
Eucalyptus grandis [Shepparton]	492	6.8	10.6	945	13.20	19.44	17.45
Eucalyptus incrassata	374	8.0	3.7	1120	1.68	5.19	5.20
Eucalyptus incrassata [Culburra cult. (P37A)]	460	12.7	3.6	712	1.49	7.24	7.25
Eucalyptus kondininensis [FTx37079]	671	3.4	3.5		0.68	2.25	1.98
Eucalyptus kondininensis [Varley FTI_1999.03]	559	4.3	2.3	118	0.16	0.92	0.81
Eucalyptus largiflorens [Renmark CS16528]	492	9.3	6.2	598	2.42	4.62	4.06
Eucalyptus largiflorens [Renmark CS16528]	559	7.4	3.3	592	0.34	1.11	0.98
Eucalyptus largiflorens [Renmark CS16528]	613	7.4	3.4	928	0.16	0.70	0.61
Eucalyptus leptophylla [Lameroo GA_1993.02]	348	10.3	3.5	370	0.14	0.77	0.75
Eucalyptus leptophylla [Lameroo GA_1993.02]	364	10.3	2.9	46	0.28	1.23	1.20
Eucalyptus leucoxylon [Williamstown]	492	10.7	8.6	1088	6.75	10.03	9.68
Eucalyptus leucoxylon ssp. leucoxylon [Kangaroo Island CS13046]	492	9.3	12.7	684	22.18	28.54	27.54
Eucalyptus leucoxylon ssp. leucoxylon [Kangaroo Island CS13046]	559	8.4	7.6	710	11.84	17.30	16.69
Eucalyptus leucoxylon ssp. leucoxylon [Kangaroo Island CS13046]	613	10.3	12.2	580	33.66	39.58	38.20
Eucalyptus leucoxylon ssp. leucoxylon [Kangaroo Island CS13046]	698	10.4	13.4	1200	35.30	41.11	39.68
Eucalyptus leucoxylon ssp. leucoxylon [Kangaroo Island CS13046]	698	10.4	13.1	1600	37.33	43.06	41.56
Eucalyptus leucoxylon ssp. leucoxylon [Naracoorte CS16527]	492	9.3	12.1	684	21.65	27.97	27.00
Eucalyptus leucoxylon ssp. leucoxylon [Rushworth CS09608]	364	11.4	9.1	370	5.60	8.86	8.55
Eucalyptus leucoxylon ssp. leucoxylon [Rushworth CS09608]	364	11.4	9.7	370	6.27	9.71	9.37
Eucalyptus leucoxylon ssp. leucoxylon [Wirrabara CS16012]	320	7.3	3.9	469	0.20	0.79	0.76
Eucalyptus leucoxylon ssp. leucoxylon [Wirrabara CS16012]	364	11.4	8.2	370	5.88	9.22	8.90
Eucalyptus leucoxylon ssp. megalocarpa [Nelson CS12456]	364	13.1	6.8	500	7.80	11.35	10.95
Eucalyptus obliqua [Smithton CS13156]	613	7.4	7.9	928	5.97	10.08	8.86
Eucalyptus occidentalis	492	9.9	10.5	1198	9.06	13.14	12.04
Eucalyptus occidentalis [Bremer Bay CS13640]	509	10.3	9.8	256	27.88	33.88	31.04
Eucalyptus occidentalis [Bremer Bay CS13640]	509	10.3	11.3	85	29.17	35.17	32.22
Eucalyptus occidentalis [Bremer Bay CS13640]	559	8.4	10.8	828	25.45	32.55	29.82
Eucalyptus occidentalis [Broomehill CS13634]	509	10.3	14.2	598	27.97	33.97	31.12
Eucalyptus occidentalis [Culburra cult. (P18A)]	460	5.7	9.8	708	19.13	27.20	24.49
Eucalyptus occidentalis [Culburra cult. (P34A)]	460	6.7	8.2	828	7.31	11.90	11.09
Eucalyptus occidentalis [Culburra cult. (P34A)]	460	6.5	12.1	1111	18.93	26.44	24.22
Eucalyptus occidentalis [Culburra cult.(P34A)]	460	6.7	10.2	1133	13.32	19.42	17.79
Eucalyptus occidentalis [Genotype 45]	509	10.3	8.3	250	9.37	13.77	12.62

Species and Provenance	Av. Annual Rainfall [mm]	Age [years]	Height [m]	Trees Per Hectare	MAI Stemwood Volume (x1000) [m^3 $plant^{-1}$ yr^{-1}]	MAI Green Biomass [t $plant^{-1}$ yr^{-1}]	MAI CO_2 equiv. [t $plant^{-1}$ yr^{-1}]
Eucalyptus occidentalis [Grass Patch CS13647]	364	11.4	11.4	231	16.35	21.42	19.63
Eucalyptus occidentalis [Jerramungup CALM A92122]	492	9.3	13.6	342	46.50	52.64	48.23
Eucalyptus occidentalis [Jerramungup CALM A92122]	559	8.4	11.7	473	27.00	34.18	31.31
Eucalyptus occidentalis [Pallerup Rock CS15406]	320	7.3	6.4	469	1.86	3.92	3.59
Eucalyptus occidentalis [Prov. 11]	494	5.5	3.0	889	0.61	1.81	1.66
Eucalyptus occidentalis [Prov. 11]	509	5.5	2.1	672	0.15	0.79	0.73
Eucalyptus occidentalis [Prov. 12]	509	5.5	2.4	594	0.17	0.83	0.76
Eucalyptus occidentalis [Prov. 20]	494	5.5	3.0	848	0.63	1.85	1.69
Eucalyptus occidentalis [Prov. 20]	509	5.5	2.1	547	0.17	0.84	0.77
Eucalyptus occidentalis [Prov. 9]	494	5.5	2.9	892	0.61	1.80	1.65
Eucalyptus oleosa	387	6.8	3.0	1585	1.36	4.44	5.04
Eucalyptus ovata [Willunga FTI_1999.01]	559	4.3	2.8	828	0.30	1.25	1.10
Eucalyptus ovata [Yundi BSC_1994.01]	492	9.3	10.1	598	12.08	17.27	15.19
Eucalyptus ovata [Yundi BSC_1994.01]	698	7.4	8.5	1600	8.83	13.91	12.24
Eucalyptus porosa [cult. (Cattle)]	387	6.7	3.9	1522	3.43	9.79	8.46
Eucalyptus porosa [Tailem Bend FR FTI_JF_1992.01]	348	10.3	5.8	370	1.62	4.86	4.20
Eucalyptus porosa [Tailem Bend FR FTI_JF_1992.01]	364	11.4	7.0	324	4.47	11.36	9.82
Eucalyptus saligna	492	6.8	9.1	880	10.00	15.40	13.83
Eucalyptus saligna	583	14.1	12.2	995	4.63	7.29	6.41
Eucalyptus saligna	583	14.1	12.2	995	4.63	7.29	6.41
Eucalyptus saligna	583	14.1	11.3	712	4.87	7.61	6.69
Eucalyptus saligna	583	14.1	11.3	712	4.87	7.61	6.69
Eucalyptus saligna [Relligen CS13015]	698	7.4	9.8	1600	11.00	16.67	14.66
Eucalyptus tereticornis ssp. tereticornis [Lochsport CS13302]	698	9.3	6.0	800	5.67	9.28	8.16
Eucalyptus tereticornis ssp. tereticornis [Yurrammie SF CS17768]	509	9.4	13.3	598	23.26	29.66	26.08
Eucalyptus tereticornis ssp. tereticornis [Yurrammie SF CS17768]	559	4.3	2.9	237	0.60	1.91	1.68
Eucalyptus tereticornis ssp. tereticornis [Yurrammie SF CS17768]	613	9.4	13.8	696	22.96	29.35	25.81
Eucalyptus viminalis	497	13.3	9.6	827	3.54	5.91	4.66
Eucalyptus viminalis	554	18.7	20.1	594	11.78	14.99	11.83
Eucalyptus viminalis	554	18.7	20.2	532	13.01	16.28	12.85
Eucalyptus viminalis [Culburra cult. (P47A)]	460	5.7	10.0	526	20.58	28.24	22.29
Eucalyptus viminalis ssp. cygnetensis	492	9.9	11.1	855	15.02	20.31	16.03
Eucalyptus viminalis ssp. cygnetensis [Tintinara FTI_J_1994.01]	492	9.3	8.6	256	14.84	20.47	16.16
Melaleuca cuticularis [Stirling Range CALM P9088]	492	9.3	3.4	598	0.84	1.75	1.44
Melaleuca cuticularis [Stirling Range CALM P9088]	509	9.4	1.5	598	0.04	0.05	0.05
Melaleuca uncinata [Karoonda GA_1993.03]	348	10.3	1.6	278	0.003	0.004	0.003
Melaleuca uncinata [Keith SFMB_1994.01]	492	9.3	1.5	171	0.003	0.004	0.003

Figure 61 - Plot average annual plant stemwood production rates by annual rainfall for all sites and species observations in the Upper South East region.