10 Native hardwood plantation scenario

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10.1 Summary

This paper estimates the minimum area of plantation forests that would need to be established in the MDB to provide a long-term sustainable supply of 2.25 million tonnes year^{-1} (M t yr^{-1}) of firewood annually from the MDB to replace wholly the supply obtained presently from native forests. The estimates were made for plantations of *Eucalyptus globulus*, a species which is considered appropriate for planting in the MDB, which are managed with silvicultural practices consistent with the normal standards considered appropriate today in Australian plantation forestry and growing on sites with reasonably fertile soils. The estimates were made using a publicly available growth and yield model system for *Eucalyptus globulus* plantations. It was assumed that the plantations are grown exclusively for the production of firewood and would be harvested at an age when 80% of the total stem wood volume of a plantation stand is of a size large enough to produce firewood (that is of logs with a minimum small end diameter under bark of at least 10 cm). It was estimated that if more productive sites, along the eastern and southern boundaries of the MDB, were used for plantations a total of just over 0.2 M ha of plantations would be required, grown on 10 year rotation. If plantations were restricted to less productive areas of lower rainfall (<900 mm yr^{-1}) in the MDB, or to areas where land clearing for agriculture has been particularly intensive, just under 0.35 M ha of plantations would be required, grown on an 11 year rotation. If planting was restricted to the less productive areas of the MDB on soils at high risk of salinisation from agriculture, a total of about 0.6 M ha of plantations would be required, grown on a 20 year rotation. It is considered that the practicalities of plantation establishment in the MDB would make it likely that plantation areas larger than these minima would actually be required to obtain the total firewood supply required from the MDB.

10.2 Introduction

Sections 7 and 8 have considered the sustainable firewood supply available from the privately owned native forests of the MDB. The present paper considers the possibility that plantations might be established in the MDB as an alternative source of supply of the 2-2.5 M t yr^{-1} of firewood[5] it is believed are taken annually from the native forests of the MDB at present (determined from Driscoll et al.2000).

In the past, forest plantations for the commercial production of wood have been established in regions of Australia where the annual rainfall is at least 800 mm yr^{-1} and, to achieve the highest productivity, often above 1000 mm yr^{-1} (Turnbull and Pryor 1978). Because of the generally lower rainfall of the MDB, there has been little incentive in the past to establish plantations there.

More recently, there has been greater appreciation of the benefits that may arise from plantation establishment, other than simply wood production. Particularly important has been the recognition of their role in assisting in the amelioration of the environmental damage that has been occurring in some regions of Australia through increasing soil salinity; this damage has occurred as soil water tables have risen in consequence of the clearing of native forests and their replacement with shallow-rooted agricultural crops (Lambert and Turner 2000). This has been exacerbated in some areas by excessive irrigation of agricultural crops. The establishment of deeper-rooted, plantation forest crops may assist in rehabilitation of the damaged soil by lowering the water table in affected areas (Marcar and Khanna 1997, Lambert and Turner 2000). Other social, economic and environmental benefits that may flow from plantation establishment include the possibility of crop

[5] All firewood weights and plant biomasses referred to here are oven-dry weights.

diversification for struggling agricultural enterprises, enhancement of biodiversity maintenance in the landscape and contributions to regional development (Gerrand et al.2003).

Recognition of all these benefits of plantation forestry has led in part to development of a government policy in Australia which aims to triple the size of the plantation estate of the country, from about 1 M to 3 M ha, over the period 1997-2020 (Stanton 1999). In the application of this policy, emphasis is being placed on plantation development by the private sector at the small-scale, farm level as well as at a larger scale by major industry (Race 1999). In general, the policy intends that new plantations should be established on land which has been cleared previously for agriculture, rather than replacing any existing native forest with plantation forest.

Because this policy requires that a much larger land area be planted, it has led inevitably to interest in the establishment of plantations both in regions of lower rainfall than have previously been considered appropriate for plantations and in regions where other social and environmental benefits may accrue; the MDB is one such region. However, as work has continued to develop the application of the policy, firewood has been little considered as a principal product to be derived from new plantation areas. In a series of papers from a major conference held in 2002 on "Prospects for Australian Forest Plantations" (Issue 1 of Volume 66 of *Australian Forestry*), there is virtually no mention of firewood. One paper (Alexandra and Campbell 2003) deplores the fact that the bulk of the approximately 4 M t of domestic firewood burnt annually in Australia (Driscoll et al.2000) derives from native forests and virtually none from plantations. However, Alexandra and Campbell did not consider the practicalities of using plantations for this purpose.

One reason that firewood has been little considered in the context of plantation forestry is that most land-owners see plantations principally as commercial enterprises. Firewood is a low value product, the costs of establishing and managing plantations are high and the time-span of forestry investments is relatively long; it is often difficult to encourage land-owners to grow plantations even for high value wood products (e.g. Race and Curtis 1997, Schirmer et al.2000) and will be even more difficult for a low value product such as firewood. Some firewood would always be available as residue after harvesting more valuable log products from plantations, but the total amount of such wood would be limited. From a commercial point of view, it appears at present that the prospect is limited for growing plantations commercially for firewood as their principal product, unless growers receive substantial subsidies, either directly or indirectly, through payments for the environmental benefits that accrue through mechanisms such as salinity, biodiversity or carbon credits.

There remains considerable research to be done to establish the practicalities of plantation development in the drier regions of Australia. There have been a number of trials undertaken, often in the context of rehabilitation of saline soils, to investigate the growth rates and/or the physiological attributes of various species which might be appropriate for plantation development in these regions, including the MDB (e.g. Biddiscombe et al.1985, Eastham et al.1993, Greenwood et al.1995, Morris et al.1998, Cramer et al.1999, Mazanec 1999a,b, White et al.2000, Dumbrell and McGrath 2003). Other work has examined the processing of wood from plantations in the MDB, although only in the context of sawn wood products and paper pulp, not firewood (Clark et al.1999, Clark and Rawlins 1999, Washusen et al.2000a,b). Some work has investigated the economic feasibility of plantations in the MDB, although only in the context of irrigated plantations for sawn wood or paper pulp (Clark and Rawlins 1999, Sands et al.1999). Irrigation can be expected to increase wood yields substantially and has been considered also in the context of the disposal of sewage waste water in the MDB (Myers et al.1996, 1998). Much work remains to be done to determine definitively which species will be most appropriate and what silvicultural practices are necessary (see Lambert and Turner 2000, Chapter 8) to provide satisfactory growth, appropriate products and adequate environmental benefits in these drier regions of Australia. As well, issues such as the availability of land on which to establish plantations and the intentions of land-owners towards use of their land will need to be addressed.

It was not the remit of the present project to consider in any detail these practical issues which will need to be addressed before plantations could become major suppliers of firewood from the MDB. Rather, an attempt is made in the present paper to establish a benchmark, by estimating the minimum plantation area wholly dedicated to firewood production, which would be required to supply the amount of firewood it is believed is taken annually at present from the MDB. This benchmark should help to put in context the magnitude of the task that would be faced in replacing wholly the supply of firewood from the native forests of the MDB with plantation grown wood.

10.3 Growth and yield model

Fundamental to determination of the area of plantation forests that would be needed in the MDB to supply firewood from it is an estimate of the firewood yields that might be obtained from plantations. There has been insufficient experience of plantation forestry in the MDB to have available enough measured data from forests to answer this question definitively. Fortunately, one plantation forest growth and yield model system has been developed which allows appropriate yield estimates to be made. This system was developed principally for plantations of *Eucalyptus globulus*, a species which may be appropriate to use for plantations in the MDB as discussed below. The remainder of this Section 10.3 describes this model system.

The system has two parts, a "process-based" model part and an "empirical" model part. Both of these parts will be described briefly below. The "process-based" part is used to predict the productive capacity of a plantation forest, at a particular site, based on the climatic and edaphic characteristics of the site. The measure of productive capacity that the model estimates is the maximum mean annual increment in stem wood volume per unit land area that will occur on the site (mean annual increment is defined as the average annual growth rate to any age). This is very similar to the "net primary productivity index" of Barrett (2000) (Section 4.2.2, Figure 4.1, Section 6, Appendix 4, Map 3 and Appendix 6, Table 7, Dataset 16). The relationship between it and the measure of productive capacity produced by the *Eucalyptus globulus* plantation model will be discussed below.

The process-based model part, named ProMod, was developed by Battaglia and Sands (1997). It requires as its principal input the leaf area index (one-sided area of leaves per unit ground area) of a plantation stand, at a time after the stand has reached canopy closure and its leaf area index has become stable with time. It requires also, as inputs, information about the environment of the site. Daily weather information is required, in particular, incident solar radiation (MJ m^{-2} day^{-1}), the sunlit period of the day (sec), maximum and minimum temperatures (^{o}C), rainfall (mm), pan evaporation (mm) and average vapour pressure deficit for the day (Kpa)[6]. Soil variables required are the soil water storage capacity (mm) between field capacity and wilting point, an indication of whether the soil is well or poorly drained and an index of fertility on five-point scale, 0-4, where 0 represents a fully fertilised site where nutrients do not limit growth and 4 represents low fertility. Battaglia and Sands (1997) discuss in more detail the drainage and soil fertility indices. Subsequently, Battaglia et al.(1998) developed a system which allows prediction of the leaf area index of a stand, for input to ProMod, in relation to the same site environmental factors. The

[6] Where daily weather data are not available for a site they may be estimated using a bioclimatic package such as ANUCLIM (McMahon et al.1996). Often, measured values of daily rainfall (mm) and maximum (T_x) and minimum (T_m) temperatures (^{o}C) are available. The other required daily variables for the site can then be estimated as follows. Daily incident solar radiation anywhere in Australia can be estimated using the monthly daily means given by Hutchinson et al.(1984). These can be interpolated to daily values by assuming a sinusoidal variation of solar radiation over a year. The sunlit period of a day anywhere on earth can be estimated using the method of Barkstrom (1981), the mathematical details of which are too lengthy to give here. Average vapour pressure deficit for a day (D, Kpa), can be estimated using equations of Murray (1967) as follows. Define a function g(T) of temperature (T, ^{o}C) as $g(T)=0.61078\exp[17.269T/(237.3+T)]$, then $D=g(0.606T_x+0.394T_n)[1-g(T_n)/g(T_x/2+T_n/2)]$. Pan evaporation ($E_0$, mm) can be estimated for Australia, using methods of Fitzpatrick (1963), as $E_0=1.24+3.98D$.

efficacy of ProMod as a predictor of plantation growth in Australia has been well tested (e.g. Sands et al.2000, Battaglia et al.2002).

ProMod was developed initially for plantations of *Eucalyptus globulus*, the principal hardwood plantation species which has been planted in temperate southern Australia in recent years. More recently, the model has been developed also for plantations of *E. nitens* (a species suitable for planting at higher altitudes than those at which *Eucalyptus globulus* can be grown) and *Pinus radiata*, the principal softwood plantation species grown in temperate regions of Australia. Neither of those alternative species are particularly relevant to plantation forestry in the MDB, but fortunately *Eucalyptus globulus* may well be an appropriate species for the MDB (Clarke and Rawlins 1999, Washusen et al.2000a,b). Studies have been done of its wood properties and economic potential in the MDB (Clark et al.1999, Clark and Rawlins 1999, Sands et al.1999, Washusen et al.2000a,b), although not in the context of plantations for firewood production. The calorific value of *Eucalyptus globulus* wood, at least at three years of age, has been measured as 19.7 MJ kg^{-1} (Senelwa and Sims 1999).

The process-based model ProMod provides no information about the time-course development of wood production during the life of a plantation stand; it simply provides a measure of the overall productive capacity of the forest. However, the yield of any particular log-size class at any age during the life-span of the plantation can be estimated by combing ProMod with an empirical model system developed by Candy (1997) and Battaglia et al.(1999). Empirical model systems describe growth with functions derived from observed growth behaviour of forests, rather than on the basis of their biological and physiological behaviour, as process-based models attempt to do.

A computer package, called the “Farm Forestry Toolbox”, which incorporates both the process-based and empirical models is available publicly from Private Forests Tasmania, a state government authority concerned with the development of privately owned forests in Tasmania. The package allows prediction of the wood yields of any log-size class specified by the user, at any time during the life of an *Eucalyptus globulus* plantation, on any site for which the user has available the climatic and weather characteristics required by ProMod. This combined process-based and empirical model will be referred to hereafter as the “Toolbox” model.

10.4 Estimating plantation firewood yields in the Murray-Darling Basin

The steps necessary to apply the Toolbox model are described below.

10.4.1 Site productive capacity

Environmental circumstances vary widely across the MDB, particularly as rainfall declines from more than 1000 mm yr^{-1} in the most easterly and southerly parts of the MDB to less than 300 mm yr^{-1} towards the arid interior of the continent. It is to be expected that plantation productive capacity will tend to decline generally in moving from wetter to drier parts of the MDB. This trend in rainfall across the MDB is reflected generally in the value of Barrett’s net primary productivity (NPP) index. Its value varies from about 12 t ha^{-1} yr^{-1} in the wettest parts of the MDB to close to zero in the driest parts (see Map 3, Appendix 4).

The first step in applying the Toolbox model was to attempt to relate the site productive capacity measure used in the Toolbox to Barrett’s net primary productivity index. As mentioned in Sections 4.2.2 and 6, a GIS dataset (Dataset 16) with values of net primary productivity index right across the MDB had been produced. If the net primary productivity index and the Toolbox measure of site productive capacity can be related, it should be possible to use the Toolbox model to predict *Eucalyptus globulus* plantation growth and yields anywhere in the MDB for which values of net primary productivity index are available.

In fact, there are two measures of site productive capacity used in the Toolbox. The first (maximum mean annual increment in stem wood volume per unit land area on a site) is determined using the ProMod part of the Toolbox. The second, a measure known in forestry as “site index” and used by the empirical model part of the Toolbox, can be estimated from the site productive capacity estimated from ProMod using equation (1) of Battaglia et al.(1999). Site index is defined in the Toolbox as the average height of the 50 tallest trees ha^{-1} in a plantation stand at 15 years of age (Candy 1997); the concept of site index as a measure of site productive capacity is described in standard texts on forest measurement (e.g. West 2004).

10.4.2 Relating site index to net primary productivity index

To establish the relationship between net primary productivity index and site index, long-term monthly average weather data were obtained for 19 locations across the MDB; these weather data are available publicly from the Australian Bureau of Meteorology web site (http:// www.bom.gov.au). The 19 locations were chosen arbitrarily to cover a wide range of site productive capacities across the MDB. They are listed in Table 10.1, together with values of net primary productivity index for each from Barrett’s GIS surface for the MDB and with long-term average annual weather data for each site as obtained from the Bureau of Meteorology data. The locations cover the MDB from southern Queensland through to Victoria. The wettest location is Creswick, on the extreme southern edge of the MDB, with 1884 mm rain yr^{-1} and the driest is Kyabram, in northern Victoria, with only 462 mm rain yr^{-1}. The coolest site is Guyra, near the eastern edge of the MDB, in the western slopes of the Great Dividing Range in northern New South Wales (mean annual daily maximum and minimum temperatures of 18 and 5^{o}C respectively), and the warmest is Narrabri, well within the MDB about 150 km west of Guyra (mean annual daily maximum and minimum temperatures of 27 and 12^{o}C respectively). Locations in the generally much drier, more westerly parts of the MDB were not considered for reasons discussed below.

Table 10.1. Location, long-term average annual weather data and NPP index for 19 sites selected arbitrarily in the MDB. The site index of *Eucalyptus globulus* plantations at each site, as predicted by the Toolbox model, is shown also.

Location	Latitude ^{o}S	Longitude ^{o}E	Average annual daily maximum temperature (^{o}C)	Average annual daily minimum temperature (^{o}C)	Annual rainfall (mm)	NPP index (t ha^{-1} yr^{-1})	Site index (m)
Armidale	30.52	151.67	20.3	7.1	790	6.9	28.1
Bundarra	30.17	151.07	23.0	7.5	769	7.9	18.3
Carabost State Forest	35.65	147.72	20.0	6.2	1049	9.7	22.8
Castlemaine	37.10	144.20	20.2	6.7	559	7.5	13.1
Coonabarabran	31.27	149.27	23.7	7.4	751	7.7	14.4
Cootamundra	34.64	148.02	22.3	8.5	626	6.9	12.2
Creswick	37.42	143.88	18.0	6.6	1884	8.5	27.7
Gundagai	35.08	148.10	22.3	8.6	714	7.7	16.7
Guyra	30.22	151.67	18.0	5.3	884	9.5	22.6
Kyabram	36.34	145.06	21.3	8.4	462	5.5	8.3
Mudgee	32.60	149.60	23.0	8.3	676	7.1	14.2
Myrtelford	36.57	146.73	21.6	6.5	905	9.7	20.2
Narrabri	30.34	149.75	26.5	11.7	661	4.9	10.6
Stanthorpe	28.66	151.93	21.6	8.8	770	6.7	27.1
Stawell	37.10	142.80	20.1	8.5	534	5.5	14.1
Tenterfield	35.16	147.46	21.3	8.1	856	7.5	31.6

Location	Latitude °S	Longitude °E	Average annual daily maximum temperature (°C)	Average annual daily minimum temperature (°C)	Annual rainfall (mm)	NPP index (t ha^{-1} yr^{-1})	Site index (m)
Wagga Wagga	32.56	148.95	21.9	9.0	585	6.7	12.5
Wellington	34.83	148.91	24.3	9.3	619	6.3	9.8
Yass	34° 50'	148° 55'	20.6	7.2	651	8.1	16.2

The Toolbox model was applied to these 19 sites to estimate the site index that might be expected of an *Eucalyptus globulus* plantation growing at each. To do so, the monthly average weather data were converted to daily values, as required by the ProMod part of the Toolbox, by interpolation from their annual trends. Other daily data were determined as described in footnote "b" in the Section 10.3. To apply the Toolbox, it was also necessary to make assumptions about the soil properties at each location. Based on information provided by McKenzie and Hook (1992) (see Appendix 3 Section 1.8 and Table 1, Dataset 21; Maps 28 - 30, Appendix 4), it was assumed that the soils at each site had reasonable drainage that their field capacity for water and soil wilting point were 250 and 90 mm, respectively, giving a soil water holding capacity of 160 mm and that their fertility was generally adequate, so there would be no major growth response by the trees to fertilization. This is not to say it should be assumed that the soils at every location have exactly these properties. Rather, they reflect the circumstances that might generally be accepted as appropriate for plantation establishment and appear consistent with soil properties generally in the MDB. Thus, the results obtained here from the Toolbox should be interpreted as reflecting what might be expected in *Eucalyptus globulus* plantations which have been established in the MDB on reasonably fertile soils with good water holding capacity.

It should be borne in mind also that it is assumed implicitly in the Toolbox model that appropriate silvicultural practice is applied in any plantation, practice consistent with the standards applied normally in plantation forestry in Australia today. In particular, this means sites will have had appropriate cultivation before planting, browsing by animals (such as kangaroos or possums) will have been controlled, weeds will have been controlled regularly during the first few years of plantation growth until the trees are large enough to shade them out and that some fertilisation may have been done on particularly infertile sites. Such practices may, in effect, influence some of the soil properties that were assumed in applying the Toolbox model to ensure they are appropriate for a plantation forest. If these silvicultural standards are not maintained, wood yields from plantations may be appreciably lower than those reported ultimately in Section 10.5. As discussed in Section 10.2, there must be some doubt about the financial viability of plantations grown in the MDB for a low value product such as firewood; the costs of maintaining proper silvicultural practice in such plantations may limit the possibilities that land-owners will ever plant such plantations in practice, unless integrated with financial returns from the maintenance of other environmental services, such as carbon sequestration and salinity mitigation.

The values for the site index for *Eucalyptus globulus* plantations, estimated from the Toolbox model, at each of the 19 sites are shown in Table 10.1. Figure10.1 shows a scatter plot of these data against the values of Barrett's net primary productivity index for each site. It is clear that there is only a moderate relationship between the two site productive capacity measures. To ensure homoscedasticity of the data, they were transformed to logarithms and the relationship between them fitted as a straight line with ordinary least-squares regression. The relationship was statistically significant ($p<0.01$), but not strong ($r^2=0.36$). After back transformation from logarithms, the fitted relationship was:

$$S = 1.239P_B^{1.299} \qquad \text{(Model 10.1)}$$

where S is stand site index (m) and P_B is Barrett's net primary productivity index (t ha^{-1} yr^{-1}).

Note that the value 1.239 in Model 10.1 incorporates the value of the correction factor by which it is necessary to multiply estimates made from a regression equation fitted logarithmically when they are back-transformed from logarithms. In this work, the bias correction factor used was that of Snowdon (1991), which is determined as the mean of the site indices determined with the Toolbox model divided by the mean of their predicted values from the logarithmic regression, after back-transformation from logarithms. The fit to the data of Model 10.1 is shown on Figure 10.1.

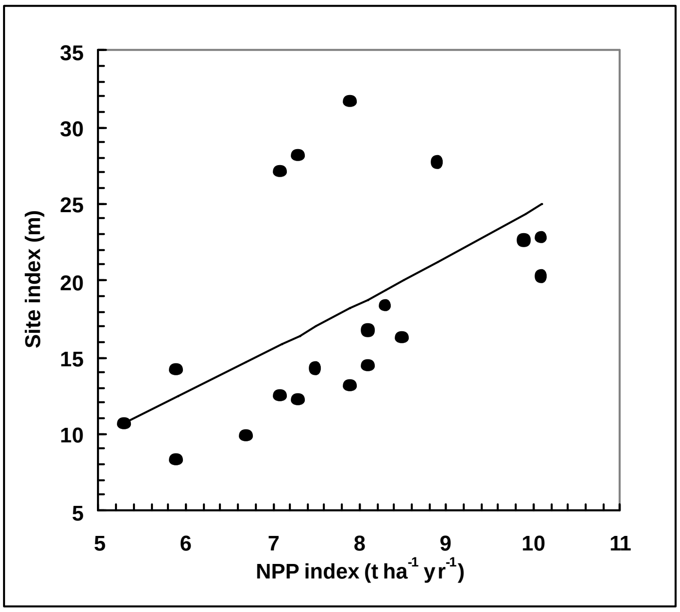

Figure 10.1. Scatter plot of values of site index for *Eucalyptus globulus* plantations, estimated from the Toolbox model, at each of 19 sites in the MDB against the Barrett (2000) NPP index for each site. The solid line shows the fit to the data of Model 10.1.

It is not surprising that the relationship between the Barrett (2000) net primary productivity index and the estimated site index estimated for *Eucalyptus globulus* plantations is not very strong. Whilst both indices are derived from process-based models which have similar formulations, there are considerable differences in the way in which the two models were applied. The net primary productivity index was derived for vegetation generally in Australia, not for *Eucalyptus globulus* plantations specifically, whereas the Toolbox model attempts to describe the specific physiological characteristics of *Eucalyptus globulus*. Values of net primary productivity index were derived for environmental circumstances averaged across gridcells with a size of approximately 5.2 x 5.2 kilometres, and the weather data used for those areas were obtained by Barrett as predicted values from Australia-wide weather data from the Bureau of Meteorology, whereas the values of site index were derived using data from the specific weather data of particular weather stations. Values for the net primary productivity index were derived using estimates of the average leaf area index of the vegetation which actually occurs across 8 km square areas of Australia, estimates derived from interpretation of satellite imagery, whereas values of site index were derived using specific estimates of the leaf area index of *Eucalyptus globulus* plantations, at specific weather station sites, using information in the Toolbox model about the specific physiological characteristics of *Eucalyptus globulus*. Values of net primary productivity index were derived using estimates of soil characteristics at any site obtained as predictions from Australia-wide published data, whereas values of site index were obtained assuming soil at any site was reasonably fertile, well drained and with a water holding capacity of 160 mm. Lastly, in the derivation of net primary productivity index, no assumptions were made about the management practices which have been applied to determine both what vegetation occurs at any site and how that vegetation grew subsequently, whereas values of site index were obtained assuming that a high standard of silvicultural practice had been applied to the *Eucalyptus globulus* plantation at any particular site.

Given all this, it was felt for the present work that Model 10.1 could be used to give a reasonable estimate of the productive capacity of an *Eucalyptus globulus* plantation which might be expected at any site in the MDB for which a value of net primary productivity index is available.

10.4.3 Predicting firewood yields from *Eucalyptus globulus* plantations

Once the site index of an *Eucalyptus globulus* plantation was estimated for a site in the MDB using Model 10.1, the empirical part of the Toolbox model was used to predict the time course of wood yields which might be obtained from the plantation over its life-span.

The empirical part of the Toolbox model requires that the user specify the stocking density at establishment of the plantation. Initial stocking density can be expected to affect both the total production of a stand and the average diameter of the trees at any later age. For the present work, it was assumed that stocking density at establishment was 1,111 stems ha^{-1} (equivalent to a square spacing of about 3 x 3 m). This is a fairly conventional planting density used in forest plantations in Australia. It was chosen here also because it was found that it gave average tree stem diameters at breast height which might be appropriate for firewood plantations at their harvest.

It was assumed also that the diameter under bark at the small end of any firewood log cut from the stem of a tree should be no less than 10 cm; any log with a diameter smaller than this was assumed to be too small for use as firewood. It was assumed also that plantations being grown for firewood would not be thinned at any stage during their life-span; since the value of firewood logs is independent of their diameter (as long as it is above the minimum), it was felt that no advantage would be gained in plantations for firewood through the acceleration of diameter growth rates from thinning. Lastly, it was assumed that the clear-felling harvest of a plantation would occur at the age when at least 80% (a value chosen arbitrarily) of the total stem wood volume of the trees in the plantation was of a size sufficiently large to be used as firewood; in any harvest operation there will be inevitably parts of the stem near the top of the tree have too small a diameter for use as any wood product.

The Toolbox model predicts stem wood volumes. To convert these to weights of firewood, it was assumed that *Eucalyptus globulus* stems have a basic density of 0.51 t m^{-3}, an average value for young plantation grown *Eucalyptus globulus* determined by Raymond and MacDonald (1998), as quoted in Ilic et al.(2000).

Given these assumptions, Figure 10.2 shows predictions from the Toolbox model of the time course of development of total stem wood biomass and firewood biomass from plantations of *Eucalyptus globulus* with site indices of 28.6 and 17.4 m, that is for plantations growing on sites with net primary productivity indices of 11.2 and 7.6 t ha^{-1} yr^{-1}, respectively (as estimated using Model 10.1). In both cases, results are shown to the age at which firewood biomass first exceeded 80% of total stem biomass. Under the assumption that this should determine rotation age, the results suggest a rotation age of 10 years would be appropriate for the stand of higher productivity and 20 years for that of lower productivity. Corresponding firewood yields at those two ages would be 105 and 78 t ha^{-1}, respectively. The Toolbox model does not report the average diameter of the trees at clear-felling, but does report their “quadratic mean diameter”, which is the diameter at breast height over bark of the tree of average cross-sectional area at breast height over bark, a value often not greatly different from average diameter. For the two examples in Figure10.2, the quadratic mean diameters at clear-felling were predicted as 19 and 18 cm for the higher and lower productivity stands respectively.

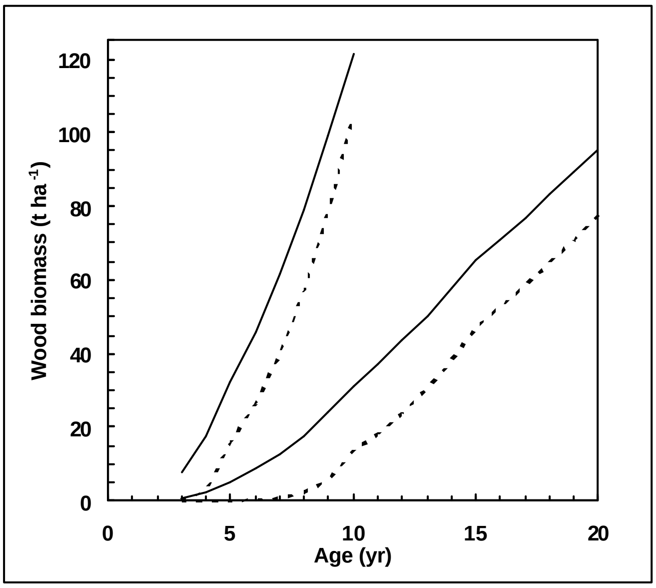

Figure 10.2. Time course of development of stand stem wood total (——) and firewood (- - -) biomass for an *Eucalyptus globulus* plantation of site index 28.6 m (upper two lines) and 17.4 m (lower two lines) as predicted by the Toolbox model.

10.5 Plantation areas required to supply firewood from the Murray-Darling Basin

The application of the firewood yield prediction system developed above now allowed estimates to be made of the minimum areas of *Eucalyptus globulus* plantations which might be required in the MDB to supply wholly the 2-2.5 M t yr^{-1} of firewood it is believed are taken annually from the MDB at present (Driscoll et al.2000).

Only land with an net primary productivity index of at least 5 t ha^{-1} yr^{-1} was considered. This is the productive capacity at which Model 10.1 predicts the site index of *Eucalyptus globulus* plantations would be 10 m. This is the lowest productive capacity for which the Toolbox model is able to predict plantation production reliably; it is considered that sites with a productive capacity lower than this would simply be inappropriate for plantation establishment. This constraint limited the sites chosen in Table 10.1 to establish Model 10.1.

For the predictions, four options were considered for the circumstances under which plantations might be established in the MDB (see also Section 4.3.7 and 4.3.8). These were:

Option 1. Plantations are established only in the most productive regions of the MDB, that is along the more easterly and southerly fringes of the MDB. This option should determine the absolute minimum plantation area which might be required to wholly supply the firewood taken presently from the MDB.

Option 2. Plantations are established only in the most productive regions of the MDB where annual rainfall averages less than 900 mm yr^{-1}. This option reflects a desire that water lost from the MDB through evapotranspiration from plantations should not come from the higher rainfall, most productive regions of the MDB. There is presently little risk of environmental degradation through soil salinisation in the more productive regions. As well, those regions supply relatively large quantities of water as run-off to rivers from cleared farm land, water which will reduce river salinity concentrations and which would then be available for farm irrigation in drier parts of the MDB (Vertessy et al. 2003).

Option 3. Plantations are established only in regions of the MDB where the general woody landscape cover is less than 30% of the land area. This option reflects a desire to establish trees in areas of the MDB which have suffered more extensive land clearing in the past, areas which are more likely to have suffered loss of floral and faunal biodiversity.

Option 4. Plantations should be established only in regions of the MDB which are at higher risk of environmental degradation through soil salinisation. This option reflects the desire to avoid further degradation of the soils and water of the MDB.

The GIS system available to this project (Section 4) was used to produce the data for the plantation scenario. The exploitation criteria for Scenario 3, which define the land deemed suitable for the establishment of plantations are described in Section 3.4. The GIS data and methods employed to produce the modelling data for the 4 options are described in Section 4.3.7. The resulting data for each option of the Scenario are described in Section 4.3.8.

Maps 20, 22, 23 and 24 (Appendix 4) show the location of privately owned, cleared land in the MDB deemed suitable for plantation establishment under plantation Options 1 - 4 respectively. The land area has been stratified by productive capacity, as assessed by net primary productivity index. The total area of the land of the highest productive capacity class would be sufficient to contain the *Eucalyptus globulus* plantation area estimated here as necessary to supply 2.25 m t yr^{-1} of firewood annually from the MDB. Appendix 6, Tables 10, 12, 14 and 16 show the stratified data for Options 1-4 respectively. The stratified data, with a net primary productivity index of at least 5 t ha^{-1} yr^{-1}, can be found in Appendix 6, Tables 11, 13, 15 and 17 for Options 1-4 respectively.

The results of the application of the firewood yield prediction system for the four options are shown in Table 10.2. They show that the smallest possible area of *Eucalyptus globulus* plantations that could be established in the MDB to supply the required 2.25 M t yr^{-1} of firewood annually is 0.21 M ha. As might be expected, this was for plantation Option 1, which assumed the most productive land available in the MDB was used for plantations. Options 2 and 3 gave similar results, 0.33 and 0.35 M ha respectively, but would require larger plantation areas than Option 1 because the land suitable for them is less productive than that for Option 1. Option 4, being on land considerably less productive than the other three, would require by far the largest plantation area (0.58 M ha). The rotation lengths of 10-11 years for Options 1-3 are similar to those generally considered appropriate in Australia for eucalypt plantation forestry for the production of lower value wood products (principally wood chips for paper-making in plantations in southern Australia). The rotation length of 20 years for Option 4 would generally be considered too long to produce a low value forest product; such a rotation length would usually be countenanced only if there were other values, such as environmental benefits, deriving from the plantations.

Table 10.2. For each of the four plantation options, the sixth column shows estimates of the minimum area of *Eucalyptus globulus* plantations required in the MDB to supply annually 2.25 M t yr^{-1} of firewood. The last column shows the area of the most productive regions available for consideration under each option, estimated from the GIS (see Tables 4.18 - 4.21). The weighted average net primary productivity index used to determine these areas is shown, together with the results estimated from the Toolbox model of the rotation age, firewood yield at harvest and the quadratic mean diameter of the trees at harvest.

Plantation option	Weighted average NPP index ($t\ ha^{-1}\ yr^{-1}$)	Rotation length (yr)	Firewood yield ($t\ ha^{-1}$)	Quadratic mean diameter at harvest (cm)	Plantation area needed to supply firewood (M ha)	Area of the most productive regions available for consideration (M ha)
1	11.2	10	105	19	0.21	0.28
2	9.8	11	75	18	0.33	0.59
3	9.7	11	72	18	0.35	0.43
4	7.6	20	78	18	0.58	0.76

Maps 20, 22, 23 and 24 (Appendix 4) show the regions of the MDB deemed suitable for establishment of plantations under each option respectively. From Table 10.2 it can be seen that the areas of each of the most productive regions, estimated from the GIS (see Tables 4.18 - 4.21), are close to the plantation areas shown for each option. If plantations were established outside those regions, on less productive land, larger plantation areas than those shown in Table 10.2 would be needed to achieve the same annual supply of firewood from the MDB.

10.6 Discussion and conclusions

The area of the MDB currently under private hardwood plantation has been estimated by this project at 1,536 ha (Table 4.7). Therefore it would require initiation of a very large plantation program in the MDB, if the firewood supplied presently from native forests is to be replace by plantation grown wood. The results of Table 10.2 suggested that 0.2-0.6 million hectares of plantations would be necessary to achieve this, the final area depending on the choices made as to which of the plantation options 1-4 considered here were preferred.

It should be appreciated that the plantations areas estimated here are the minimum areas necessary for each of the four options. In effect, it was assumed that all the most productive land deemed suitable for plantations under each option would indeed be available for plantation establishment. This is most unlikely to be so. Many land owners will prefer to continue to use their land for its present agricultural purposes. This would mean that some less productive land would have to used for plantations, with concomitant increases in the plantation area required to meet the firewood supply needed from the MDB.

It was assumed also that plantations are established in the MDB wholly for firewood production. Particularly in more productive areas, it is likely that plantation growers would wish to grow plantations on longer rotations to yield larger, more valuable log sizes for solid wood products. Such plantations might be economically more viable than plantations grown wholly for firewood production. Whilst they would yield firewood as well, from smaller logs cut from near the top of tree stems, the total amount of firewood obtained from them would be much smaller than if the plantations were grown specifically for firewood. This would then require an appreciably greater plantation area to achieve the required firewood supply from the MDB. As discussed in Section 10.1, the financial viability of plantations grown wholly for firewood in the MDB may well rely on some sort of direct or indirect subsidy.

If plantations are grown in the MDB for firewood, they would start producing firewood only after the end of their first rotation. The results of Table 10.2 suggest that it would be at least 10 years from the start of the plantation program before plantations could replace the firewood supplied presently from native forests and then only if they were established on the most productive land available in the MDB. If they were established on other than the most productive land, it could be up to 20 years before that supply became available.

The plantation areas shown in Table 10.2 are sufficiently large that their achievement would involve a very major plantation program. Even on the most productive sites (Option 1), 21,000 ha of plantations would have to be established annually for 10 years to reach the final estate size of 0.21 M ha. If planting was restricted to sites at risk of soil salinisation (Option 4), 29,000 ha would have to be established annually for 20 years to achieve the final estate size required. Planting rates of this magnitude constitute an appreciable proportion of the 80,000 ha per year of new plantations required to achieve the objectives of the 2020 vision for Australian forest plantations (see Section 10.1); averaged over 1998-2002, the rate of establishment of new plantation areas has been 87,300 ha per year, most of which has been in the more productive, temperate regions of southern Australia (National Forest Inventory 2003).

To initiate and manage plantation programs of the size required for firewood production across the vast area of the MDB and amongst many private land owners would be a very difficult undertaking, particularly if subsidies were needed to encourage the planting. Perhaps the best that might be hoped for is the establishment of some plantations, across a range of sites represented by the various options considered in this work. This might ultimately achieve a total plantation area sufficient to replace partly the firewood supply taken presently from native forests in the MDB, particularly if firewood was a secondary product i.e. from thinnings.