5 Model review and forest mensuration data for model development and validation

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5.1 Introduction

The key objective of this study was to analyse the long-term sustainability of meeting firewood demand in the Murray-Darling MDB (MDB) from three possible sources: firewood harvested from standing and fallen dead timber (coarse woody debris) termed the "dead-wood scenario" (Section 7), thinning of live trees ("green-wood scenario"; Section 8) and firewood sourced exclusively from plantations ("plantation scenario"; Section 10. Section 3 describes the exploitation criteria for each scenario.

In the previous chapter we described the GIS design and data acquisition, as this was a prerequisite to modelling potential yield of firewood from the three scenarios. In this section we describe the process of searching for appropriate data and models, which had the end result that we were unable to identify an appropriate existing forest growth and yield model or data suitable for predicting long-term firewood supply under the dead-wood and green-wood scenarios in these low rainfall areas. As a consequence we were required to collect suitable forest mensuration data (e.g. basal area, wood volumes and coarse woody debris loads) from known age stands representative of the broad vegetation types subject to harvesting in the MDB, through a specially designed survey process. The methodology for the survey design and field measurements are described in this section.

The results of the stratified surveys were then used to develop a forest growth and yield modelling system which is described in Section 6. A subset of the forest sites surveyed for modelling purposes were also surveyed as case studies for the possible impact of thinning stands under the green-wood scenario and this is described in Section 9.

5.2 Review of existing models and forest data

At the commencement of the project, we conducted a comprehensive review of growth data and existing forest growth and yield models which might have been suitable for modelling the potential supply of firewood from forest and woodlands of the MDB. Appendix 7 summarises the information considered. Most growth and yield models presently available were developed for forest species of high commercial value, most of them growing in high rainfall regions outside the MDB. The productivity of the forests in the MDB is generally much lower than that of the tall forests in the higher rainfall areas of coastal and eastern Australia, and as such provide only 5% of Australia's commercial eucalypt timber (MDBC 2003). There are only four forest types in the MDB which have been used consistently for commercial forest production or firewood:

1. White Cypress Pine (*Callitris glaucophylla*); the species grows in even- or uneven-aged, closed or open forests, often in mixture with various eucalypt species within the MDB;
2. River Red Gum (*Eucalyptus camaldulensis*); widespread over the MDB but confined to riparian areas;
3. Ash forests, usually Alpine Ash (*Eucalyptus delegatensis*); from the higher rainfall and altitude areas of south-east NSW and north-east Victoria; and
4. Mallee woodlands (eg. *Eucalyptus socialis, Eucalyptus gracilis, Eucalyptus oleosa subsp. oleosa* and *Eucalyptus dumosa*), confined to the low rainfall regions in the south-west of the MDB.

Whilst other forest types in the MDB have been used from time to time for firewood or minor wood product production, none has been the subject of a major forest industry and consequently there has been no production model previously developed for these lower rainfall forest types. Of the above four commercially exploited vegetation types that have been modelled in some way, the White Cypress Pine model appeared to have the greatest applicability to the dead-wood and green-wood scenarios, as River Red Gums are a specialised forest type confined to periodically flooded riparian systems along major rivers of the MDB. Its regeneration, growth and yield are dependent on inundation, and hence are not applicable to the vast area of the MDB not on floodplains. Neither was an Alpine Ash model suitable, as this species grows in temperate high rainfall areas which form only a small portion of the south-eastern corner of the MDB. For mallee woodland types, Neagle (1994) published sufficient data to enable us to create a growth and yield model suitable for predicting long-term firewood yield from mallee forests. The mallee model was used in conjunction with estimates from our GIS of the existing areas of mallee in the MDB and is described in Section 8. Initial results suggested that the cypress pine model is inappropriate to predict yields from mallee eucalypts. It is perhaps not surprising that mallee forests display a quite different growth pattern to that of other forest in the MDB as their growth habit differs and they are a more arid species.

As a result of these findings, and because the only forest type within the MDB for which a published and accessible forest growth and yield model has been developed was White Cypress Pine forest (Vanclay 1985), it was felt that the White Cypress Pine model offered the only system available to allow some objective assessment of growth and wood yields from forests of the MDB. It was not known to what extent the growth behaviour of White Cypress Pine forests are typical of the range of forest types that occur in the MDB. Certainly it would be expected that applying a model developed for one species to predict growth and wood yields of the other species in the MDB would lead to at least some bias in estimates of wood yields for the other species. However, no other approach seemed a possibility for the present work without undertaking extensive field work across the MDB.

5.3 White Cypress Pine Model

Testing of the White Cypress Pine model system showed that it was not immediately suitable for the purposes of the present work to predict long-term firewood supplies from non-mallee forests and woodlands, so modifications and further development were made to the model to allow its general application for the prediction of firewood quantities available from forests anywhere within the MDB.

Whilst long term wood yields are not that much different, it became obvious during the modelling process that there is a very different pattern of growth between the lower rainfall eucalypts and White Cypress Pine. Some modelling was available from mallee forests of South Australia which suggested that the White Cypress Pine model was inappropriate to apply to those forests and that the differences appeared to be quite substantial. It was perhaps not surprising that preliminary fieldwork data showed that forest and woodland eucalypt species had a much faster growth in the earlier years than the cypress pine model was showing. The consequences were that much more wood was available at the times of thinning in the green-wood scenario and harvest for the dead wood scenario.

Subsequently, as results from the modelling demonstrated (Figures 5.1 and 5.2), it was seen that the available supply of firewood was being significantly underestimated for both dead-wood and green-wood scenarios. Figure 5.1 demonstrates that, for the dead-wood scenario, supply estimated by the modified White Cypress Pine model could not meet the current firewood demands, with an average of only around one million tonnes being available per annum for harvest. This figure should be compared with the results for the dead-wood scenario, estimated using the final model, shown in Figure 7.3.

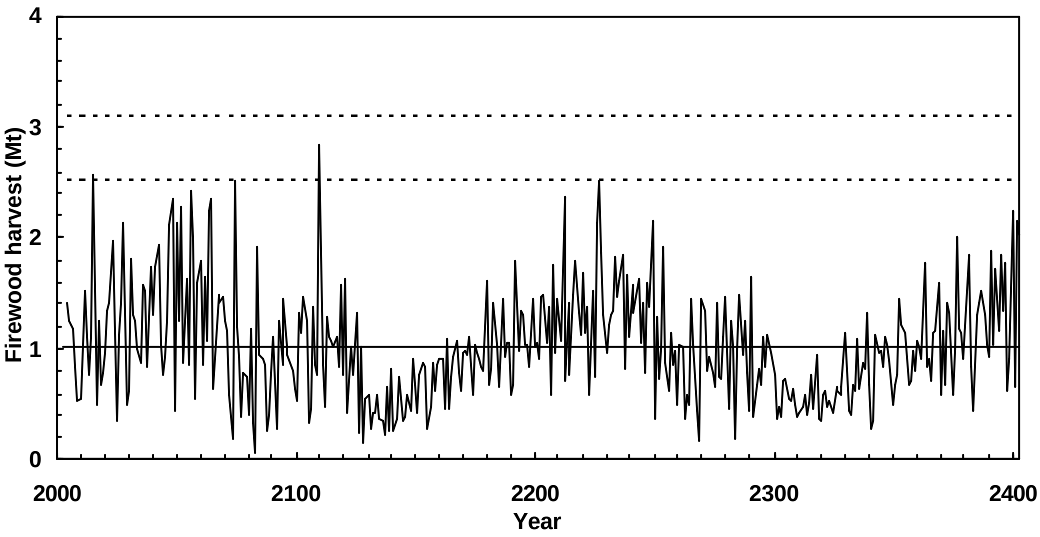

Figure 5.1 Estimates of the annual amounts of firewood which could be harvested from coarse woody debris (dead-wood scenario), based on the modified White Cypress Pine model. The two horizontal dashed lines indicate the range of the amount of firewood within which it is believed the current firewood harvest from the MDB lies. The solid horizontal line is the average of all the annual estimates.

Figure 5.2 shows that, for the green-wood scenario, the modified White Cypress Pine model predicted that only around one and half million tonnes (on average per annum) would be available for harvest, again significantly less than the current demands. These results should be compared with the results for the green-wood scenario, estimated using the final model, shown in Figure 8.2.

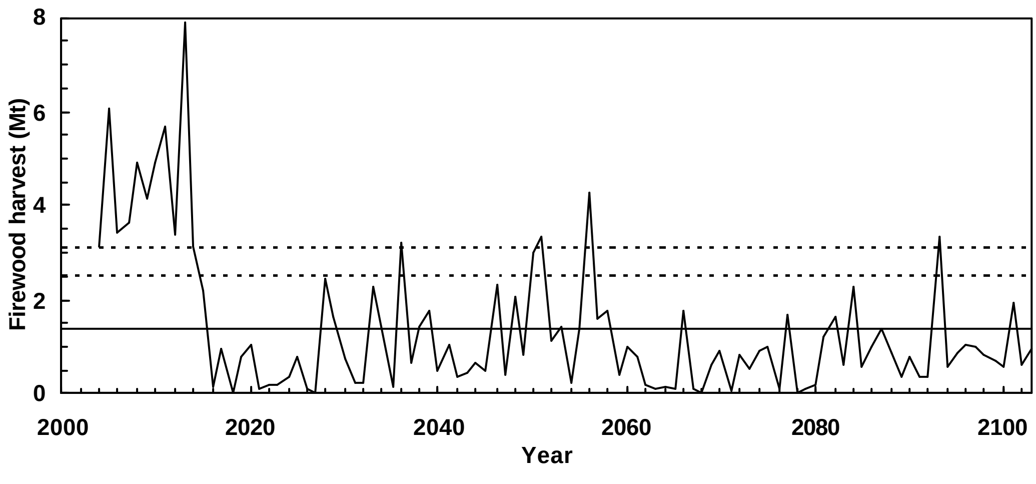

Figure 5.2 Estimates of the annual amounts of firewood which could be harvested in the green-wood scenario (thinning of live trees), based on the modified White Cypress Pine model. The two horizontal dashed lines indicate the range of the amount of firewood within which it is believed the current firewood harvest from the MDB lies. The solid horizontal line is the average of all the annual estimates.

It was therefore necessary to develop our own growth and yield model for the prediction of firewood supply for the dead- and green-wood scenarios.

5.4 Data from known age forests

In order to develop our own model system to predict firewood supply from the dead-wood and green-wood scenarios, ideally we needed forest growth data collected from specific stands in the

MDB over many decades. Alternatively, space can be substituted for time; data from many different sites of many different ages would suffice to develop and verify a forest growth and yield model. At the beginning of the project, we undertook a literature review to establish the extent and status of forest mensuration data available for the woodlands and forests of the MDB. The review included web searches, extensive literature searches, telephone and email enquires to a number of regional branches of State Forests NSW; NSW National Parks and Wildlife Service; Department of Conservation and Land Management, Victoria; NSW Department of Infrastructure, Planning and Natural Resources; Greening Australia; CSIRO Forestry and Forest Products; and a variety of statutory and land management agencies e.g. the NSW Office of Private Forestry and private farm forestry groups, individuals and land holders.

Appendix 7 shows a table of the 39 different potential sources of data and models which we initially short-listed from the results of the literature review as being worth further investigation. The potential data sources were tabulated to provide a framework to evaluate the usefulness of each to the project. Once the table was completed, it provided a comprehensive database on author, data source, the type of forestry sampling or modelling, forest yield outputs, growth rates, forest type, tree species and the potential strengths and limitations of that data.

The review found very little data for the MDB, or even within the more productive areas of eastern Australia, that were either accessible or in published format. Where data did exist, there were either problems with data access, or there were large gaps in data collections, or the sample sizes were too small. It was indicative of the limited nature of commercial forestry operations in the MDB that this literature review found no adequate data for developing growth and yields models for woodlands and forests in the MDB.

The greatest limitation was a lack of information on the ages of the remaining stands of forest and woodland in the MDB, at national, regional or even site scales. The State Forests NSW records for ages of harvested sites in the higher productivity forests were the best documented. However, there is very little documentation for stand age at a stand level in the lower productivity areas for species other than White Cypress Pine and River Red Gum. Some information existed for a number of State Forests and National Parks for which detailed historical records had been kept, or significant survey work been undertaken, however the information was not available across the entire range of net primary productivity classes extant in the MDB. More consistent and specific data was required for this project.

We also investigated the possibility of deriving age information from dendrochronology, air photograph or satellite image comparisons of specific sites over time, or archival records, but the time required to apply these methodologies was beyond the scope of this project. It was therefore necessary to develop a field sampling program for so that a specific set of forest attributes could be measured and recorded in a consistent and relevant format. The primary requirements were that the methodology was exactly replicated across all sites, that the ages of all sampled stand were known, and that the sampling was stratified to sample the range of forest and woodland types, across a range of ages between 15 and =100 years old and across the range of net primary productivity classes present in the MDB.

Data were required for the development and validation of the coarse woody debris component of the forest growth and yield model (Section 6). Thus an additional objective for the field studies was to obtain estimates of the amounts of coarse woody debris which might be expected to be present in a range of forest and woodland ecosystems, in order to model long-term supplies of coarse woody debris, particularly for the dead-wood scenario.

As was the case for other forest mensuration data, data on amounts of coarse woody debris in forests and woodlands are scarce, although over the last decade there has been increased research into the ability of forests to sequester and store carbon under greenhouse scenarios. There have also been a number of studies, albeit primarily outside of Australia, investigating the role of coarse woody debris in ecosystem function. Driscoll et al. (2000) reviewed the Australian scientific literature and found major knowledge gaps in a number of areas, namely the relationships between coarse woody debris levels and vertebrates, invertebrates, fungi and ecosystem processes. The existence of these knowledge gaps has been confirmed by a recent and comprehensive review of coarse woody debris in Australian forest ecosystems (Woldendorp et al. 2002), which concluded that studies addressing the issues of coarse woody debris are rare. See Section 9 for the results of the literature review of coarse woody debris studies in relation to ecological impacts of firewood harvesting.

The field data collected for this project provided the most consistent and available data of forest attributes to characterise many of the forest and woodland types found in the MDB. These attributes include stand basal areas, individual tree as well as stand volumes, number of stems per hectare, species, stand ages, and their associated coarse woody debris loads. The methods used are explicit and readily repeatable.

Data for the majority of the forestry mensuration attributes have not been collected previously in the MDB.

In order to stratify the sample across the range of forest types in the MDB, we first had to define the difference between forests and woodlands, then choose a mapped description of vegetation types that covers all of the MDB. We then broadly sampled at sites of known age across the most relevant vegetation types, stratifying by stand age and net primary productivity..

5.5 Forest and woodland types

This project was constrained to categorise the forests and woodlands of the MDB in a manner compatible with the forest and woodland categories used by the spatial data available to the project. The data used by the model system for each scenario (that is, area of forest type, by age, by net primary productivity class) were to be derived from the spatial dataset (Section 4.2.2). Therefore, the data used to develop the growth and yield model had to be based on compatible forest types, and this had to be taken explicitly into account in the selection of sample sites.

5.5.1 Defining the forests of the MDB

It is important to be aware of the significant differences between the variety of definitions of "forest" and "woodland" used by different Agencies.

The National Forest Inventory 2003 Forest by Tenure dataset (Section 4.2.2 and Appendix 3 Section 1.2) was used for this project to identify areas of forest and woodland in the MDB. The National Forest Inventory (NFI) is a partnership between the Commonwealth and all State and Territory Governments, with the aim of producing a single, authoritative source of data at the national level. 'Forests' and woodlands' are defined by the NFI as:

"an area, incorporating all living and non-living components, that is dominated by trees having usually a single stem and a mature or potentially mature stand height exceeding 2 metres and with existing or potential crown cover of overstorey strata about equal to or greater than 20 per cent. This definition includes Australia's diverse native forests and plantations, regardless of age. It is also sufficiently broad to encompass areas of trees that are sometimes described as woodlands"

Herewith, we use this broad definition that combines both forests and woodlands into one term called 'forests'.

However, the NFT definition of forests is also expressed in three crown cover classes[1]: woodland (tree crowns cover 20-50 percent of the land area when viewed from above);

1. open forest (51-80 percent crown cover); and
2. closed forest (81-100 percent crown cover). These are mainly rainforest and mangroves which were not treated as a source of firewood by this project.

There are two other significant sources of definitions for forests and woodlands. The definitions used by the MDB Commission (2003) differ from those used by the NFI in two main respects:

1. mature stand height is 5m; and
2. crown cover is = 30%.

The AUSLIG 1990 Vegetation Atlas of Australian Resources is designed to be more specific at the structural level, defining eight growth forms and four canopy cover classes:

1. open woodland at 0-10% foliage cover;
2. woodland at 10-30%;
3. and open forest above 30% foliage cover; and
4. and closed forest above 30% foliage cover.

The only available dataset at the scale of the entire the MDB was the NFI 2003 dataset, so we were constrained to adopt the NFI classification and definitions for this project.

5.5.2 Descriptions of the forests and woodlands in the MDB

Table 5.1 summarises the community descriptions which apply to the forest type categories in the NFI 2003 dataset (also see Table 4.4). These forest types and their descriptions provided the general site descriptions used when considering the selection of the field sites for forest mensuration. The table can also be used to interpret the definitions of forest and woodland types used in the GIS modelling and analysis.

Table 5.1 The community descriptions for the forest and woodland types in the MDB, as defined in the NFI 2003 dataset (also see Table 4.4).

Forest Type	**Community description**
Acacia	The most common wattles *Acacia* spp. in the MDB are Mulga (*Acacia aneura*) and Brigalow (*Acacia harpophylla*) woodlands in the drier, north-western areas. Numerous other *Acacia* species are present in varying densities either as understory or canopy.
Callitris	Cypress pines: *Callitris* species include White Cypress Pine (*Callitris glaucophylla*) typically either a common component of the central eucalypt woodlands of the MDB or forming extensive stands.
Casuarina	Sheoaks (*Casuarina* and *Allocasuarina* species) are widely distributed as scattered trees or extensive stands often within the eucalypt forests and woodlands.
Eucalypt Low Open Forest	Most of these forests occur in arid regions in association with *Acacia* species i.e. Poplar Box (*Eucalyptus populnea*) and Blackbox (*Eucalyptus largiflorens*) in western New South Wales, *Eucalyptus populnea* in southern Queensland, with 21-50% crown cover, <10m tall.

[1] Crown cover is determined by estimating or measuring the area of ground covered by tree canopies, ignoring overlap and gaps within individual canopies. A line around the outer edge defines the limits of an individual canopy, and all the area within is treated as “'canopy” irrespective of gaps and overlaps.

Forest Type	Community description
Eucalypt Low Woodland	Most of these forests occur in arid regions in association with *Acacia* species i.e. Poplar Box (*Eucalyptus populnea*) and Blackbox (*Eucalyptus largiflorens*) in western New South Wales, *Eucalyptus populnea* in southern Queensland, with 50-80% crown cover, <10m tall.
Eucalypt Mallee Open Forest	The more than 100 species of eucalypts with a multistemmed habitat and a vegetation dominated by them, with 51-80% crown cover
Eucalypt Mallee Woodland	The more than 100 species of eucalypts with a multistemmed habitat and a vegetation dominated by them, with 20-50% crown cover
Eucalypt Medium Open Forest	These include dry sclerophyll forests such as those described in detail in Section 9, Murray River Red Gum (*Eucalyptus camaldulensis*) forests with 50-80% crown cover 11-30m tall.
Eucalypt Medium Woodland	Typical communities include box woodlands with grassy understorey e.g. White Box (*Eucalyptus albens*) and Yellow Box (*Eucalyptus melliodora*) woodlands on fertile western slopes of southern New South Wales and Victoria, with 21-50% crown cover, 11-30m tall.
Eucalypt Tall Open Forest	Often referred to as “wet sclerophyll forests”: “wet” occurring only in very south eastern parts of the MDB where rainfall exceeds 1000 mm a year eg. Alpine Ash (*Eucalyptus delegatensis*) communities, with 50-80% crown cover and >30m tall.
Eucalypt Tall Woodland	Eucalypt forests, with 21-50% crown cover and >30m tall.
Hardwood Plantation	Typically eucalypt species suitable for low rainfall areas eg. Spotted Gum (*Eucalyptus maculata*), Sugar Gum (*Eucalyptus cladocalyx*), Red Ironbark (*Eucalyptus sideroxylon*) and Blue Gum (*Eucalyptus globulus*).
Softwood Plantation	Typically *Pinus spp*. *Pinus radiata* in higher rainfall areas, other *Pinus spp*. are being trialled in lower rainfall areas.
Unknown Plantation	Unknown Plantation.

5.6 Field sampling design

For any particular forest type, a forest growth and yield model predicts how a stand in the forest grows with time and hence the amount of wood available for harvest from it at any stage of its lifetime. Such models take account also of the fact that the productivity of a forest, hence the amount of wood it can yield at any age, depends on the characteristics of the site on which it is growing. The description of the development of the growth and yield model used for the dead-wood and green-wood scenarios is detailed in Section 6. Therefore, it was necessary that the field data collected by this project sampled the range of site productivity capacities and extant in the MDB, and the range of forest age classes.

Consequently, the first step in the design of the sampling strategy was to stratify the MDB into broad primary productivity sub-classes. The second was to stratify by stand age class. The third step was to stratify sites with stands of known age by position on slope, selecting plots and identifying the forest type. Once this had been undertaken, the following data items were collected from the plots for the yield model: stand basal areas, individual tree volumes, stand volumes, number of stems per hectare, species, stand ages, and coarse woody debris loads.

The net primary productivity stratification was carried out using the GIS system (Section 4) to produce maps which could be used in the field to locate areas where sites could be located. The age and position on slope stratifications were conducted in the field during the process of site selection.

5.6.1 Net primary productivity

Four broad net primary productivity classes were chosen for the stratification. Table 4.1 presents these classes in terms of their general geographic area. Map 25 (Appendix 4) shows the geographic distribution of these classes.

Table 4.1 The 4 net primary productivity subclasses used to initially stratify the MDB for field site selection.

Net Primary Productivity (NPP) Class	Net Primary Productivity and oven dry biomass/ha/year	Area of the MDB
1	10.6 – 14	Eastern highlands
2	7.2 – 10.6	Eastern tablelands and slopes
3	4.0 – 7.2	Central slopes and plains
4	0.2 – 4.0	Western plains

5.6.2 Stand age

After defining an area of the MDB in terms of net primary productivity the next step was to travel into the forest area to specifically locate stands of forest or woodland of known age. Stand “age” in this context is defined as the time since a stand regenerated from bare ground following clearing, destructive wildfire or other natural calamity.

We relied substantially on oral history for the age of the stands selected for sampling. At the stand level i.e. a specific stand of trees which could be sampled, the best source of were private landowners who had a long-term historical connection with the land e.g. a family property, an interest in history or were involved in private farm forestry.

The lack of hard data on age classes meant there is some uncertainty on the ages we have assigned to the stands. If the stand was younger than 70-80 years, we believe that the age is accurate to within year or two. However as stand ages increases, so does the associated degree of uncertainty, increasing to a maximum of 10 years or so. Further, where trees had developed significant hollows and circumference there were no oral or written records to verify ages, so the stand was assigned an age of 100+ years.

Suitability of even aged versus mixed aged stands

A potential sampling site was then assessed further for species composition and its history of disturbance i.e. ringbarking, grazing, fire, fertilising, and harvesting. There were very few sites found to be in a “pristine” condition. The primary disturbances were ringbarking or bulldozing to create cleared pasture, and harvesting for a variety of timber uses, including building, fence posts, mine props and firewood.

The age structure of the dominant overstorey trees was then assessed. For collection of data for the forest growth and yield model an ideal site would consist of an even age stand resulting from one major disturbance event. These conditions were most frequently found in sites less than 30 years old and cleared by bulldozer or clear-felled rather than selectively logged. As a stand age increased, so did the frequency of disturbance events and subsequently there could be up to 1 or 2 other age cohorts present. Potential sampling sites were frequently rejected because disturbance history had resulted in very mixed aged stands.

5.6.3 Position on slope

Topographic position (i.e. position on a slope) is an important explanatory variable for species presence in the landscape but it is also important variable for within species variation as a result of differences in soil characteristics and water availability. Sites on upper slopes tend to have drier shallower soils than those on the lower parts of the slopes. These can influence forest attributes such as tree diameter, volume and height and stand basal area and stocking density as a result of these differences in resource availability. For the initial fieldwork in net primary productivity Class 2, three plots were randomly selected within each site, one each on upper slope, mid slope and lower slope, in order to capture any stand variation characteristics across the slope due to changes. However within net primary productivity Classes 1, 3 and 4 each of these subsequent sites had only 1 plot per site due to time limitations.

5.7 Field sampling methods

Forest mensuration is part of the forest inventory process which may be defined as the systematic collection, evaluation and presentation of specific information on forest areas. Generally, detailed observations are only made of a small part of the area and techniques are applied to extrapolate from these limited observation to the whole area of interest (Brack 2000, West 2004). The selection of which measurements and individuals to choose are a fundamental part of forest mensuration. Measurements are made on individual trees, stands (small groups of trees) and forests (groups of stands) and for this report, a unique forest survey method was designed to measure both stand characteristics and individual tree bole taper and volume.

Suitable forest and woodland stands were found on 57 sites and forest mensuration and ecological impact data was collected from a total of 79 stands within the sites. Site ages ranged from 10-150+ years. Each of the four net primary productivity classes contained approximately fifteen sites ranging across these age classes. Sites were located between Tumut/Tumbarumba in the east, to the Bourke/Cobar area in the west on private properties, Travelling Stock Reserves, National Parks and State Forests. Two staff undertook reconnaissance and data collection in the field for approximately 50 days between April and August 2003.

5.7.1 Live tree measurements

Once the forest or woodland site of known age had been selected a series of forest mensuration data was collected in order to calculate potential yield of firewood. The stand and forest measurements are summaries derived from specific measurements taken on selected individual trees. So for each forest stand a "point sample" was taken so that the basal area (over bark) of the stand could be determined from a single point, rather than having to establish a plot of known area in which all trees are measured. In most stands, the stem wood volume under bark from ground to tree top was measured for three individual trees included in the point sample. The principles of point sampling underpin the methodology described here and can be found in standards texts on forest measurement practice (e.g. West 2004). Stocking density of the trees can determined also from the point sample. The results from these stand basal areas over bark and stand stocking density of the live trees in each stand are shown in Appendix 8.

In order to calculate stem volume the individual tree height, basal area, tree shape and bark thickness are needed. We used a combination of a Spiegel Relaskop, digital hypsometer (Forestor vertex), transponder and diameter tape. The relaskop was selected because it could be used in the estimation of tree diameter at any point up the tree bole to assist in measuring stem wood volume through centroid sampling technique. The vertex and transponder was used for individual tree heights and distances.

The relaskop was then used to determine basal area (m^2 ha^{-1}) and stocking density (tree stems ha^{-1}) for the stand level. Firstly a basal area factor was chosen and the relaskop used to select an average of 15 to 20 trees within the plot to measure their diameter and height. An Excel spreadsheet function was used in cases of uncertainty to determine if the tree was in the sample by using the distance to the tree and its diameter at breast height over bark (DBHOB). If the tree was in the sample its height was determined using the vertex and transponder and its diameter measured at breast height (1.3m) by using a diameter tape. The tree species was recorded and whether it was live or dead. The woody biomass of dead trees were considered part of the coarse woody debris of the stand (see section 5.5.2). Using a hand-held computer, data were entered directly into an Excel spreadsheet with functions which calculated live tree and dead tree stand basal area and stocking density

These standard tables providing known stem volume functions are available from more highly productive forests however these have not yet been developed for these lower rainfall forests. Measurements were therefore taken of individual tree stem wood volumes to develop a volume function for these forests. This was undertaken by selecting three trees per plot, with the aim of sampling a wide range of tree sizes and species over all the stands measured. Their stem wood volumes were measured using the "centroid method" (West 2004). This involves measuring the bark thickness at breast height of the tree concerned with a bark gauge and the diameter over bark of the stemat a point high up on the stem, is measured; as prescribed by the centroid method. The Relaskop was used to take such diameter measurements from the ground. Despite its relative simplicity of application, the centroid method generally gives quite precise estimates of stem wood volume of standing trees, with little bias (West 2004). The volume function developed is described in Appendix 9. This function is used to estimate volumes of other trees measured in the point sample from their diameters at breast height over bark and their total heights. Wood densities are included in Appendix 8.

5.7.2 Coarse woody debris

Coarse woody debris was defined as all dead standing trees = 5cm DBH and any fallen woody material = 10cm at its mid-point and = 50cm in length. The length and diameter at mid-point of any piece of wood on the ground that fell into this category was measured using a 25x50m plot. The plot was established within the area at which the forestry point sample was made. This is a standard method used for assessing amounts of coarse woody debris in Australian forests (McKenzie *et al.*2000). As it was measured, each piece of woody debris was assigned to one of three classes:- Class 1 (wood was solid when kicked and lacked cavities, cracks or a hollow pipe), Class 2 (mostly solid when kicked but contained cavities, cracks or a hollow pipe or Class 3 (gave or crushed when kicked).

The volume of any piece of fallen woody debris measured in a ground plot was determined as that of a cylinder, with cross-sectional area determined by the measured diameter of the piece and length equal to the measured length (known as Huber's formula). This is a standard method used in forestry science to determine volumes of sections of tree stems or branches (West 2004).

To convert those volumes to biomasses, it was assumed that woody debris pieces categorised as Class 1 had suffered negligible decay and their basic density was the same as that used for estimating the live tree stem wood biomass in that stand. Pieces of Class 2 were assumed to have suffered some decay and to have a density equal to 75% of that of undecayed wood. Those of Class 3 were assumed to have a density of 30% of that of undecayed wood. The stand biomasses of each of those classes of woody debris in each stand measured are shown in Appendix 8.

Where standing dead trees were present, they were measured in a point sample and their stand stem wood biomasses estimated from their heights and diameters at breast height in the same way as was done for the live trees. The stand stem wood biomasses determined in this way are listed as part of the coarse woody debris of the stand in Appendix 8.

5.7.3 Ecological data

In addition to the forest mensuration data, site characteristic data for assessment of ecological impacts e.g. location, aspect, altitude, soil type and depth, slope, geological substrate, vegetation community, topography and site history were recorded for each plot. The ecological data and methods are described in detail in Section 9.

5.8 Summary Data

Using the survey design and methodology described here we were able to collect completely new kinds of forestry data for the low rainfall areas in a scientifically rigorous format across carefully stratified sites in the MDB, so that the non-mallee forest model system described in the next section could be based on the most current, consistent and accurate data available. The summary data , for each point sample taken are provided in Appendix 8 tables.

Shown in the table are:

1. location, including latitudes and longitudes
2. tree species present
3. wood density of the priciple tree species in the point sampe (based on Ilic et al 2000)
4. stand age
5. net primary productivity index (tonnes ha-1 yr-1), derived from the GIS dataset
6. Basal area over bark (m2 ha-1)
7. Stocking density (stems ha-1)
8. Stem wood biomass (tonnes ha-1)
9. Coarse woody debris (tonnes ha-1) of standing dead trees
10. Coarse woody debris (tonnes ha-1) Decay Class 1 ground debris (solid)
11. Coarse woody debris (tonnes ha-1) Decay Class 2 ground debris (mostly solid)
12. Coarse woody debris (tonnes ha-1) Decay Class 3 ground debris (decayed)

The data are available also in unprocessed form. They have not been documented here due to the large size of the dataset. The raw data provide the detailed measurements of tree heights, tree diameters, species sampled, site description and individual coarse woody debris measurements for each plot. Those data will be made available on request.

The forestry mensuration data were used in the development of the growth and yield model, which is described in Section 6.