11 Management and Policy Implications

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11.1 Objectives revisited

The aim of this research project was to "Improve the information base", which is Strategy 1 of the *National Approach to Firewood Collection and Use in Australia* (ANZECC 2001). Specifically our research addressed the following key information gaps identified in the *National Approach* document:

1. What are the amounts, availability, and economics of alternative firewood sources?
2. What are the rates of accumulation of fallen timber, and sustainable rates at which to harvest it?
3. What are the ecological impacts of alternative firewood harvesting regimes?

The project focused on the Murray Darling MDB (MDB) because the majority of firewood supplying the population centres near or within the MDB comes from privately owned forests, in low rainfall areas, which are harvested in a generally unregulated manner (Section 2.5; Driscoll et al. 2000). The communities comprising these forests were identified as being the most threatened because they consist of the most heavily utilised firewood species, they are slower growing than traditionally harvested higher productivity forest communities and have been extensively cleared.

We analysed alternative firewood harvesting regimes by identifying three plausible future sources: continued reliance on dead timber (dead-wood scenario), firewood sourced exclusively from live timber from managed native forests (green-wood scenario), and firewood sourced from plantations of eucalypts grown exclusively for firewood (plantations scenario). We had neither the time nor the resources to consider properly what management regimes are the most appropriate to apply for the green-wood scenario in the various forest types in the MDB; we were able to consider only general management regimes.

The long term quantity and location of firewood harvested under these plausible scenarios were predicted by constructing a forest yield and growth model for low rainfall eucalypts linked to a GIS with the best available coverage of vegetation for the entire MDB. We limited our economic analysis to the broad constraint that it is uneconomic to source firewood beyond 500 kilometres from major markets (eg. capital cities). Our detailed and spatially explicit yield modelling can be used in future for detailed analysis of economic feasibility.

We examined the possible ecological impacts of alternative harvesting regimes, firstly by updating the literature review of Driscoll et al. (2000), then by developing field survey methodology and testing it on 19 sites with a history of different timber harvesting regimes. The case studies allowed us to hypothesise probable impacts of different harvesting regimes under the dead-wood and green-wood scenarios. A scientifically rigorous long term experiment, specifically designed to examine the ecological impacts of different firewood harvesting regimes, was beyond the time and resources of this study. Such an analysis would require harvesting regimes to be carefully replicated, with sufficient pre- and post-treatment data to quantify the differences between seasonal variation and treatment effects. The ecological impacts of plantation forestry were also beyond the resources and time of this two-year project.

11.2 Outcomes of scenario analysis

The following sections review and discuss the implications of each of the three scenarios. This is by no means an exhaustive discussion, but rather raises issues that require further deliberation by the wide range of stakeholders involved in the large but highly dispersed firewood harvesting industry in the MDB.

11.2.1 The dead-wood scenario

Our model of sustainable yield, based on spatial data from the project GIS (Section 4), predicted that a continued reliance on dead standing and fallen timber (coarse woody debris) from private native forests and woodlands is entirely feasible. Our model predicted that a long term average annual sustained yield of 10 million tonnes of coarse woody debris and dead standing trees can be harvested from 12.3 million hectares of non-mallee forests within 500 kilometres of the capital cities within or near the MDB. This is about four times the current 2-2.5 million tonnes estimated to be annually harvested from these forests.

However, an exclusive reliance on firewood from coarse woody debris would continue to deplete the residual loads of woody debris left after harvest, which could be done at 5-10 yearly intervals. If the maximum 10 million tonnes per year of firewood was harvested from coarse woody debris, the long-term average amount of woody debris remaining in the forest after harvesting would be 3 tonnes per hectare, far less than the average 20 tonnes per hectare which would remain if there was no harvesting of woody debris.

Our model system assumed implicitly that present loads of coarse woody debris have not been seriously depleted by firewood harvesting in the past. We estimated that there is currently a large surplus of standing and fallen dead timber within the MDB (Fig. 7.3). However, for our forest mensuration studies (Section 5), it was a difficult and time-consuming process to locate forest stands that had little evidence of timber removal. We suggest that coarse woody debris loads are actually well below maximum potential levels in forest stands close to population centres, near roads, on shallow slopes and with forest types that are preferred by firewood markets such as the Yellow Box (*Eucalyptus melliodora*) woodlands. Forest stands within the MDB with high loads of coarse woody debris are likely to be furthest from population centres, in areas with difficult access and comprised of tree species subject to little demand from firewood markets (e.g. many eucalypt species in dry sclerophyll forests).

If the maximum sustained yield from the MDB private forests approximates our estimate i.e. is about four times greater than current demand, then there exists some flexibility for the management of the intensity of harvest from coarse woody debris. There are at least two broad options; the intensity of harvest can be reduced from any one stand, and/or large areas can be excluded from any harvesting of coarse woody debris. For any given stand, the harvesting rotation can be lengthened to allow for greater accumulation of coarse woody debris before harvesting. Alternatively, the proportion of coarse woody debris harvested at each rotation can be reduced, or a combination of longer rotations and less removal of woody debris at each harvest could be practiced.

Rather than focusing on the management of individual stands, which will be difficult to regulate due to the dispersed nature of firewood harvest on private land, the areas from which firewood can be harvested could be regulated. We modelled the maximum sustained yield of firewood from coarse woody debris from the entire National Forest Inventory (2003) dataset (Appendix 3 Section 1.2) for non-mallee forests and woodlands under private tenure, within 500 kilometres of the capital cities in or near the MDB (12.3 million hectares). One means of regulating the harvest of coarse woody debris would be to apply exploitation criteria such as those we developed for the green-wood scenario (Section 3.3 and 11.2.2).

Another option would be for firewood harvesting to focus on the more productive forests in the MDB. For example, we found that the current demand of 2.5 million tonnes per year could be obtained by harvesting only the 3.1 million hectares of the most productive forests in the MDB (as defined in Table 7.1). This is 9.2 million hectares less than the entire area of the MDB with a cover of non-mallee native forests within the commercially feasible limit of 500 kilometres from capital cities. There is clearly plenty of scope to better manage the harvest of dead timber within the vast area of the MDB with its large variation in potential productivity. There is a need to delineate those regions where harvest of fallen and standing timber can continue, and those regions that it should be highly restricted or proscribed.

Recommendation 1. Commercial harvesting of firewood from fallen and standing dead timber should be phased out in those regions of the MDB where coarse woody debris is highly depleted, particularly in the cropping zone.

Our modelling suggests that if the harvest of coarse woody debris continues, it can be restricted to the most productive forests above a net primary productivity of = 7-14 tonnes biomass/ha/annum.

This project has developed the modelling capability to analyse the yield of firewood and residual levels of coarse woody debris from any combination of management regimes. Modelling firewood yield and loads of residual coarse woody debris left after a wide range of different management regimes or exploitation criteria was beyond the scope of this project. Additional options for regimes and rules need to be developed by land managers, particularly state agencies responsible for legislation that regulates timber harvesting.

11.2.2 The green-wood scenario

The green-wood scenario modelled sustained yields by rotationally harvesting live timber, leaving all dead timber to accumulate as coarse woody debris. For mallee forests this involved clear-fell harvesting on a 50 year rotation, with regeneration by coppice. For non-mallee, it involved “flexible selection” management, with two or three thinnings over the life-time of a stand and with 50% of the standing tree basal area being removed at each thinning. Such management should encourage maintenance of forest stands which contain a wide range of tree sizes and ages, consistent with contemporary community attitudes to native forest management.

Rather than modelling sustained yields from all the privately held MDB forests within a commercially feasible distance of 500 kilometres from capital cities (13.5 M ha), we first applied a series of rules or exploitation criteria to exclude areas of forests deemed particularly sensitive to harvesting disturbances. We excluded harvesting from all forests within 50 metres of rivers which only excluded 16,770 ha of forest, or just 0.05% of the forest cover of the MDB with potential firewood (Table 4.8). In addition, forest cover on slopes greater than 15° were excluded from harvest; our GIS analysis determined that this only excluded 118,000 hectares of forest cover on private tenures (Table 4.9). We then applied the exploitation criteria with the greatest impact: exclusion from harvesting of all forest stands which did not have at least a 30% cover of native forests (the 30% cover rule). This rule excluded 3.4 million hectares of forest, or 25.2% of the total forest cover within 500 kilometres of capital cities. Surprisingly, only an additional 0.17 million hectares of forest was excluded when forest stands < 100 hectares in size were removed from the analyses (the 100 hectare rule); that is the 30% cover rule excluded most patches less than 100 hectares in size before the application of the 100 hectare rule.

Even though our ecologically based exploitation criteria eliminated 3.7 million hectares (or 27%) of the privately managed forests in the MDB within 500 kilometres of capital cities, the remaining 9.8 million hectares of forests on private land appears to be enough to meet current demand of 2-2.5 million tonnes of firewood per year. Our model system estimated that, over the next 100 years, the maximum annual sustainable supply of firewood from the MDB under the green-wood scenario would average 2.3 million tonnes per year, with a deviation no more than 0.2 million tonnes in any year. About 22% of this supply would come from mallee forests and the remainder from non-mallee. Because the green-wood scenario does not involve removal of woody debris from the forests, it was considered that this approach to firewood harvest management in the MDB may have benefits for the conservation of biodiversity and maintenance of landscape function (see Section 11.3).

We suggest that it is feasible to meet a long term demand for firewood exclusively by thinning live trees from only those forests away from major water courses, on shallow slopes less than 15°, and from forests patches at least 100 hectares in size that have at least a 30% forest cover. An exclusive regulated harvest of live trees would eventually create mixed age stands and allow for substantial accumulation of coarse woody debris. Averaged across the entire modelled area, loads of woody debris would vary between 15-20 tonnes per hectare over the next 100 years. This would result in 5-7 times greater post-harvesting loads of coarse woody debris than under the dead-wood scenario, which on average left only 3 tonnes per hectare of woody debris after harvest of dead standing and fallen timber.

Recommendation 2. Firewood could be sourced from thinnings of live trees in densely stocked regrowth forest if harvesting was done under defined exploitation criteria and improved harvesting guidelines (see Recommendation 7).

There is clearly sufficient yield potential to sustainably harvest live trees to meet the current demand for firewood from the MDB, but there are few stand-based guidelines for managing the thinning of live trees from low rainfall forests within the MDB. Most guidelines have been developed for stands with high timber values, grown in high rainfall areas, on highly productive soils (eg. coastal Spotted Gum forests). There are guidelines for managing low rainfall single species *Callitris* forests on private property and State Forests (Lacey 1973, Knott 1995, Nicholson 1997) but limited guidelines for management of the diverse range of non-mallee eucalypts that dominate the forest cover on private land in the MDB. Guidelines that do exist for dry sclerophyll forest types (Forestry Commission of NSW 1983, Kellas and Hateley 1987, Hamilton and Cowley 1987) are broadly descriptive and, excepting the higher productivity ash forests which have been continually harvested, focused on characterising basic forest processes.

The exploitation criteria developed for the green-wood scenario are a possible basis for regional guidelines. The simple rotation and retention rules built into the growth and yield modelling for the green-wood scenario (2 or 3 thinnings and 50% of the stand basal area removed at each thinning) could also form the basis for stand-scale management guidelines. However, the appropriate scale over which thinning could be feasibly applied with minimal environmental impact needs to be determined. For example should thinning of half the basal area mean that every other tree should be harvested, or should 50% thinning allow for every other 1 hectare block to be clear-felled? In the context used so far it means clearfelling in small blocks. Section 9 of this report examines possible ecological consequences of various thinning regimes practiced by a few private landholders with dry sclerophyll forests on the Southern Tablelands of NSW. There is clearly a need to extend this analysis.

Sustainable harvesting of live trees for firewood is constrained by a few stand based management guidelines. It is also constrained by market acceptance of firewood comprised of thinnings. The traditional firewood market is based on the consumption of slow-growing box species such as iron bark, white box, yellow box and red gums. Market barriers to consumption of other species from more productive forests with a much greater cover (e.g. dry sclerophyll species) need to be reduced.

Recommendation 3. Active and sustained marketing of firewood from densely stocked regrowth forests (e.g. stringy barks) is required if the demand for firewood from coarse woody debris (dead-wood) from traditionally preferred species (e.g. Red Gum/Box mix) is to be reduced.

11.2.3 The plantation scenario

A third scenario for meeting the current demand for firewood is to source it from native eucalypt forests. We did not model potential supply from softwood forests as domestic firewood heaters sold in Australia are not licensed to burn softwoods, such as *Pinus* species.

Our model system estimated 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 of firewood annually from the MDB to replace wholly the supply obtained presently from native forests. We estimated that if the most productive regions along the eastern and southern boundaries of the MDB were used for plantations, a total of just over 200,000 hectares of plantations would be required, grown exclusively for firewood on 10 year rotations. 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 350,000 hectares of plantations would be required, grown on an 11 year rotation. If plantings were restricted to the less productive areas of the MDB on soils at high risk of salinisation from agriculture, a total of about 600,000 hectares of plantations would be required, grown on a 20 year rotation (Section 10).

These estimates were made with models based on plantations of *Eucalyptus globulus*, a species which is considered appropriate for planting in the higher rainfall regions of the MDB, using a publicly available growth and yield model system for *Eucalyptus globulus*. It was assumed that the plantations would be 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, i.e. logs with a minimum small end diameter under bark of at least 10 cm.

It is unlikely that extensive plantations will be established exclusively for firewood because it is a low value timber product. Commercially viable eucalypt plantations are more likely to need to produce a range of products, including high value saw logs. Firewood may be a commercially viable by-product from plantation thinnings and off-cuts. If firewood becomes a secondary product from plantations, then a much greater area of plantations would be required than our estimates of 0.2-0.6 million hectares grown exclusively for firewood.

Our estimates are also minima because we assumed that trees would be grown on the most productive soils within each of the four options analysed for the plantations scenario (Section 10.5). This is most unlikely to be the case. Many land-owners will prefer to continue to use their best land for its present agricultural purposes. This would mean that some less productive land would have to be used for plantations, with concomitant increases in the plantation area required to meet the firewood supply needed from the MDB.

Even on the most productive sites for plantation forestry in the MDB, 21,000 hectares of plantations would have to be established annually for 10 years to reach the final estate size of 0.21 million hectares. If planting was restricted to sites at risk of soil salinisation, 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 hectares per year of new plantations required to achieve the objectives of the 2020 vision for Australian forest plantations (see Section 10.1). High rates of plantation establishment are feasible. The recent rate of establishment of new plantation areas has been 87,300 ha per year, averaged over 1998-2002, 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 achieved over the next ten years is the establishment of some plantations, across a range of sites represented by the various options considered in this work. Current low rainfall tree breeding programs such as ARTLIG (The Australian Low Rainfall Tree Improvement Group) are focusing on the breeding of hardwoods for low rainfall zones of southern Australia and making the appropriate species as available as possible in the short term. This might ultimately achieve a total plantation area sufficient to partly replace the firewood supply presently taken from native forests in the MDB, particularly if firewood was a secondary product, i.e. from thinnings.

The issue of combining farm forestry plantations and biodiversity conservation is rapidly being promoted as an opportunity for a "win-win" situation for landholders and the environment. Plantation programs which are designed to integrate biodiversity management guidelines have been reasonably well researched and there are a number of accepted farm forestry designs which provide guidelines which address issues such as plantation location in the landscape, tree and shrub diversity and composition, physical complexity and patchiness, and incorporating forestry with remnant vegetation (Dames and Moore 1999, New and England 2002, Salt et al 2003, Race and Freudenberger 2003).

Probably the biggest barrier to sourcing firewood from plantations is lack of market demand for plantation timber. Households have traditionally demanded firewood that is clearly coarse woody debris from slow growing eucalypt species sourced from low rainfall regions of the MDB. A substantial proportion of the firewood sourced from the MDB is harvested by householders themselves, or small semi-commercial harvesters working on a seasonal or casual basis. Shifting demand away from traditionally sourced coarse woody debris in favour of firewood from fast growing plantations is a major challenge. The "Draft Code of Practice for Firewood Merchants" (DEH 2003) which promotes the use of firewood sourced from plantations is a small initial step in developing a significant demand for firewood from plantations.

Recommendation 4. Active and sustained marketing of firewood sourced from plantations is required to assist in the reduction of demand for firewood from coarse woody debris (dead wood).

There is a role for State and Commonwealth agencies to support the marketing of plantation firewood. The commercial firewood industry is too dispersed, informal and poorly coordinated to manage this aspect without support.

11.3 Environmental impacts

There is limited data on the potential environmental impact of any of the three harvesting scenarios. Our field work associated with the primary aim of modelling the amounts and locations of alternative supply options did provide some insights into possible impacts and these are summarised below.

11.3.1 The dead-wood scenario

The harvesting of coarse woody debris has recently been declared a "threatening process" under the NSW Threatened Species Act. It is our opinion that this listing was based on limited information. We are aware of only a few studies that have directly manipulated (added or removed) levels of coarse woody debris in low rainfall forests in the MDB. In the case of the Mac Nally et al. (2000; 2002) studies, some wildlife species increased in abundance with the addition of coarse woody debris in a flooded Red Gum forest and other species did not. There are very few other studies that have examined the impact of manipulating levels of coarse woody debris across a range of low rainfall forest types.

The research of Mac Nally et al. (2000; 2002), needs to be extended to other vegetation types such as Box and Ironbark woodlands and dry sclerophyll forests. The impact of manipulating levels of coarse woody debris needs to include consideration of the dynamics of the insects dependent on woody debris. In turn, these insects appear to provide critical food resources for many wildlife species, including some woodland birds and reptiles.

Recommendation 5.Long term and rigorous research is needed that experimentally manipulates levels of coarse woody debris in a diversity of vegetation types in order to quantify the environmental impacts of commercial scale removal of fallen and standing dead timber on a range of taxa and ecosystem processes.

From an evolutionary and food-web perspective, there are likely to be many species that are dependent on coarse woody debris for all or part of their life cycles, since woody debris has been a component of forest ecosystems for millions of years. However, many species dependent on woody debris are likely to have survived numerous periods of low coarse woody debris loads, since any stand of eucalypt forest has inevitably been burned on many occasions over evolutionary time periods. We know from the effects of contemporary fires that coarse woody debris can be highly depleted after intense burns, but also act as an island for remnant fauna and micro flora which can recolonise an area after low intensity fires (Tolhurst and Flinn 1992)

Thus the issue is not the removal of woody debris at any one small patch or forest stand (e.g. <1 ha), rather the impact of broad scale removal and the duration between removal events. What is clear from even the most superficial examination of forest cover in the MDB, is that the loss of coarse woody debris has been enormous because of the extensive land clearing throughout the most fertile and well-watered regions of the MDB. The current removal of 2-2.5 million tonnes of woody debris per year for firewood pales into insignificance compared to the amount of coarse woody debris lost due to 150 years of clearing. We calculated that there are 74.5 million hectares of non-native forest cover, such as pasture, agricultural land, areas of no forest or no data in the MDB (Table 4.13). Assuming that most of this non-native cover was once primarily forest with some grassland which has since been cleared, and that the average level of coarse woody debris in the absence of removal could be 20 tonnes per hectare (Fig 8.4), then as much as 1.5 billion tonnes of coarse woody debris has been lost due to clearing.

Fallen and dead timber is a renewable resource as long as the forest remains. Much of it is gone, particularly in the most productive areas of the MDB with the most fertile soils and sufficient rainfall for cropping and exotic pasture development. Clearly there is a need to conserve what little coarse woody debris is left in these highly cleared regions of the MDB. Thus the load of coarse woody debris is of secondary importance in any one particular stand within these regions.

We argue that there is scope for continuing the firewood harvest of coarse woody debris in those regions with an extensive forest cover, but not in those regions where clearing as well as firewood removal has greatly reduced this important component of forests and woodlands.

Our model system together with the GIS (which provides the natural resource data layers used by the model system to calculate forest growth and yield), can be used to provide assistance in delineating those regions where continued harvesting of coarse woody debris may be sustainable, and those regions where it is not.

It is proposed that of guidelines are developed that provide an indication of the level of coarse woody debris left after a harvesting rotation, but only in those regions with sufficient forest cover to withstand harvesting. Our field mensuration data (Section 5) provide some preliminary information on the maximum values of coarse woody debris to be expected in forest stands exposed to low levels of disturbance over the past 100 or so years. We found evidence, in the absence of harvesting or other human influences, a linear relationship between live tree biomass and coarse woody debris biomass (Fig. 6.3). This relationship allowed us to predict that there should be about 0.4 tonnes of coarse woody debris for every tonne of live stem wood in those forest stands that have been little disturbed by fire or harvesting. There will inevitably be less coarse woody debris in young stands and in slow-growing stands. In the absence of disturbance, there should be more coarse woody debris in older stands and more productive stands with greater volumes of live trees.

What we don't yet know is what proportion of the expected load of coarse woody debris can be removed without adverse environmental impacts. Nor do we know at what scale woody debris can be harvested within a region of high forest cover. We need to know if all commercially-useful coarse woody debris should be removed from a 1 hectare stand, 10 hectare stand, or 100 hectare stand, or whether it would be preferable to harvest only half of the available coarse woody debris in any one stand. Maximal harvesting in any one stand and banning harvesting from other stands is probably more practicable for both commercial harvesting and regulation. We suggest that coarse woody debris "refugia" (no harvesting) are required within a hierarchy of scales, such as one hectare refugia within 10 hectare harvested blocks, 10 hectare refugia within 100 hectare blocks, and 100 hectare refugia within 1000 hectare blocks. A range of different sizes and numbers of blocks free from harvesting should provide refugia for a wide range of organisms that require both small, medium and large size patches with high levels of coarse woody debris.

Recommendation 6. Within regions where harvest of dead timber could continue, guidelines and regulations are needed to create "refugia" free of dead timber harvesting.

11.3.2 The green-wood scenario

We conducted a number of case studies to assess the potential environmental impacts of thinning of live trees in dry sclerophyll forests. We focused on dry sclerophyll forest because it still remains in extensive stands and much of it is under private ownership. We used a case study approach, because each study site had a unique history of disturbance including harvesting of live trees by a range of different means. Our analysis of the survey data can only suggest some of the potential impacts of forest thinning because none of the sites had adequate pre- and post-treatment data.

The insights we gained from these case studies can be summarised as follows: thinning of live trees can enhance biologically diverse habitat if the thinning is done in a way which increases forest structure, stimulates regeneration and maintains essential ecosystem function.

Our surveys, and many others, have quantified much greater habitat values in dry sclerophyll forests and woodlands which have mixed ages of trees, old trees with hollows, and an understorey of shrubs, tussock grasses, fallen timber and litter, i.e. with high structural complexity. Our case studies, and many others, have shown that there are more species across a range of taxa in structurally complex forest stands compared to structurally simple forests. Our studies and others have also shown that structurally complex forests "leak" less water, nutrients and soil than structurally simple forests with little ground cover.

We suggest that the impacts of thinning of forests for firewood can be minimised if the thinning operation leads to greater structural complexity. Thinning of forests can increase forest structure if it leads to tree regeneration which, in time, will create mixed age stands. Thinning can also increase structure if it leads to greater loads of coarse woody debris left after the thinning operation. Thinning can increase structure if opening of the forest canopy stimulates the establishment of a greater density and diversity of shrubs, grasses, forbs and orchids.

Thinning of live trees for firewood will have adverse environmental impacts if it perpetuates even aged stands with few old trees with hollows. Thinning will also have adverse impacts if coarse woody debris is also harvested or burned. Finally, thinning will have adverse effects if it exposes the soil surface to excessive rainfall erosion and prevents the regeneration of trees, shrubs and grasses.

The challenge is to develop thinning regimes that enhance forest structure and landscape functionality, rather than reduce it. Our case studies provide some insights into how thinning operations can improve forest structure, diversity and landscape functionality. We suggest that thinning operations need to achieve three outcomes:

1. Profitable products including firewood are harvested;
2. Significant soil disturbance occurs in the short term;
3. The landscape recovers rapidly from the soil disturbance.

To achieve the first outcome, the scale of harvesting operations needs to be large enough to make efficient use of large scale harvesting equipment. Thinning of individual high value saw logs may be commercially viable, but thinning of individual trees for low value firewood is unlikely to be profitable. Pulling down belts of trees with a chain between two bulldozers ("pulling/chaining") appears to achieve outcomes 1 and 2. Pulling/chaining is a rapid and inexpensive means of getting trees down onto the ground. We and others have hypothesised that soil disturbance is necessary to stimulate regeneration. If this hypothesis proves correct, then pulling/chaining provides the necessary widespread soil surface disturbance.

Outcome 3 can be achieved if the timber is pulled across the slope and if the timber is cured *in situ.* This is a successful method used at the Bredbo case study site (Section 9). Pulling/chaining at right angles to the slope causes trees to lie across the slope enhancing the capture of litter, fine soil material and seed. Trees that fall down the slope provide much less surface obstruction for capture of fine materials and propagules. Our case study evidence suggests that curing trees in place promotes rapid recovery from soil disturbance. Once cured (a minimum of 2-3 years; P. Davey, personal communication), there will be additional disturbance in sectioning and removing logs, but there appears to be sufficient off cuts remaining (coarse woody debris) to provide the necessary surface obstructions to trap soil and litter material. Our case studies were consistent in showing that if substantial loads of unharvested material are left in place, then outcomes 2 and 3 can be achieved. Bulldozing post-harvest "debris" into windrows appears to be counter-productive as our surveys suggest this practice increases the risk of soil and nutrient loss and retards regeneration, particularly on steep slopes.

Rather than being "debris", post-harvest coarse woody material is a critical resource for maintaining landscape function and providing "safe" sites for the germination of trees, shrubs and other herbaceous species. Our surveys and others have shown that this post harvest "debris" is also habitat for a wide range of invertebrates and vertebrates.

Again, the question is what is the appropriate scale over which a pulling/chaining style harvest should take place. We need to know the appropriate width of pulled/chained belts and the optimum width of unchained belts left after any one harvesting rotation. The principle of landscape heterogeneity needs to be applied. At some scale, patches of old-growth forest need to remain unharvested to maintain those species dependent on the habitat and resources found only in old-growth stands. At some scale, harvested belts may be beneficial to those species dependent on the dense cover and resources provided where the harvesting regime promotes regeneration.

Recommendation 7. Scientifically-defensible harvesting guidelines need to be developed which promote regeneration, improve forest structure and maintains landscape function, in order to improve the management of low rainfall forest stands.

Our case studies provide some insights for the development of such guidelines that need to be under-pinned by adaptive management research. That is, draft guidelines should be developed and applied and their impact monitored and assessed in a replicated manner.

11.3.3 The plantation scenario

The environmental impact of shifting firewood harvesting to plantations is hard to quantity at this point in time. We do anticipate, however, that one of the primary benefits of this shift would be to reduce impacts of harvesting live and dead timber from native remnant forests and woodlands. Secondarily, the difficulties of regulating the highly dispersed harvest of firewood from native forests would be eliminated if all firewood came from plantations. Even if it was economically feasible to exclusively source firewood from plantations, harvests from native forests would need to continue for at least another 20 years. We estimate that there are currently only 1600 hectares of hardwood plantations in the MDB (Table 4.4), far less than the 200-600,000 ha that would be needed to exclusively supply firewood to meet current demand (Section 10).

The conservation values and environmental impacts of plantations themselves are beyond the scope of this report. Again, values and impacts are scale-dependent. If plantations are extensive enough, they can have both positive and negative impacts on catchment hydrology. Plantations can reduce the yield of fresh water from high rainfall catchments (Vertessy et al. 2003). Lower water yields may exacerbate down stream salinity because less fresh water is available to dilute saline flows from other sub-catchments. In lower rainfall catchments, plantations have potential to reduce ground water recharge and lower saline water tables (Turner and Lambert 2000). At the scale of an individual stand, *Eucalyptus globulus* plantations in Western Australia can have greater habitat values than surrounding wheat paddocks, but have fewer habitats and support fewer native species of wildlife than nearby native remnant woodland vegetation (Hobbs et al. 2003)

11.4 Combination of strategies

A practical way to reduce the environmental impact of firewood harvesting would be to adopt a combination of strategies. Our research suggests that the current impact of a firewood harvesting regime, which is entirely reliant on dead wood, could be reduced by:

1. The exclusion of dead wood harvesting from highly depleted areas (e.g. extensively cleared regions);
2. Promotion of harvest of live trees from well managed native forests in regions with a high forest cover;
3. Promotion of sourcing of firewood from expanded hardwood plantations.

Our modelling suggests that large areas of fragmented woodlands and forests could be excluded from dead wood harvesting because the current yield of dead wood across the entire forest cover within 500 kilometres of capital cities far exceeds current demand. Some areas have been highly depleted of coarse woody debris, whilst others areas are probably under-exploited. Results from the model suggest that the thinning of live trees can produce large tonnages of firewood, particularly over the next 20 years or so, as there appears to be a significant "backlog" of unthinned forests. Our case studies indicate that thinning can enhance forest structure, landscape function and species diversity if harvesting regimes promote regeneration of trees, shrubs and other herbaceous species. Our model predicts all demand for firewood from the MDB could be met from as little as 200,000 hectares, but this extent of hardwood plantations does not exist, nor is the establishment of plantations exclusively for firewood likely to be economic under current conditions.

Recommendation 8. A combination of strategies should be modeled, then adopted, to reduce the impact of firewood harvesting. A combined strategy includes excluding the harvest of coarse woody debris from areas where such a harvest is deemed to be ecologically unsustainable; thinning live trees from regions with extensive regrowth; and investing from hardwood plantations which supply firewood as a secondary product.

11.5 Achievements against objectives

This research project aimed to explore a range of sources and harvesting regimes for the 2-2.5 million tonnes of firewood consumed each year from the MDB. We succeeded in initiating this exploration. We have developed a GIS with sufficient resolution and data layers to provide data for a growth and yield model appropriate for low rainfall forests in the MDB. We have also developed a model system that can explore both the spatial and temporal implications of a variety of harvesting strategies at landscape and regional scales. These are significant accomplishments, particularly given that the forests and woodlands in the MDB are neither static in time nor across space. Our model system was explicitly designed to address the vast spatial and temporal dynamics of the woody cover in the MDB.

Our model system is not precise as it was parameterised on a limited field data set. Even though further validation is required we consider that the outputs from the model system are sufficiently accurate for the analysis of strategic options. Rather than using our system for estimating the growth and yield of any one forest stand it should be used to further explore options to reduce the impact of firewood harvesting in the MDB. We have modelled only a selection of possible options; these being harvests exclusively from dead wood, thinnings of live trees and plantations. There is sufficient scope to use our model system to examine the yield and location of harvests from any combination of strategies.