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Edges define the stream! Restoring the integrity of riparian zones beginning with coarse woody debris (CWD) on the Murray-Darling floodplains

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SUMMARY: By using a variety of methods, we estimate that the total amount of coarse woody debris (CWD) on the floodplains of the southern Murray-Darling basin is in the order of 4.2 million tonnes, or the equivalent of about 600,000 River Red Gums of 1.0 m girth. Preliminary estimates suggest that this may be only about 15% of the levels before European settlement. Restoration of CWD to those levels would require the equivalent of clear-felling 115,000 ha of current standing crops of floodplain timber! Our work is continuing on improving these estimates and also attempting to determine relationships between levels of CWD and biodiversity.

THE MAIN POINTS OF THIS PAPER

- Fallen timber, or coarse woody debris (CWD), on floodplains is rarely considered to be an important management issue, yet in-stream woody debris is. In reality, these are closely related issues that would be best considered in a unified fashion.
- Existing levels on the lower Murray-Darling basin may be only 15% of pre-European-settlement levels.
- Ecological restoration of riverine systems must address the CWD question because of its importance to biodiversity and to ecological function. Appropriate levels of CWD are crucial for the ecological 'health' of floodplains

1. INTRODUCTION

Ecological problems have become increasingly evident in the lowland rivers of the Murray-Darling basin of eastern Australia (Dexter *et al.* 1986). Regulation and amelioration of water flow throughout the basin has reduced flushing and flow variability (Close 1990; Lake 1995). Flooding frequency (% years) in some areas has dropped 40-50%, inundation duration by 60% and duration of dry periods increased by factors of 2 to 5 (Leitch 1989). These aspects seem to favour irruptions of some exotic fishes and the spread of weeds (Chesterfield 1986), and impede the germination of flood-reliant flora (Bren 1988; Dexter *et al.* 1986). Regulation has reduced the complexity of the rivers, which has been implicated in the decline in many native aquatic species. The isolation of rivers from floodplains probably has caused calamitous effects on many species using temporary wetlands and billabongs (Parkinson 1995), as well as significantly altering the origins of sources of energy for aquatic ecosystems (Robertson *et al.* 1997).

In the riparian zone of floodplains, one of the most striking impacts has been the general reduction of structural variety, especially the loss of mature trees, shrubs and natural litter or 'debris'. In particular, coarse (or large) woody debris (CWD) has been stripped from rivers and floodplains. On the latter, CWD is thought to be ecologically significant because it: (1) yields structural habitat for riparian fauna during both dry periods (invertebrates, non-fish vertebrates, Hawkins *et al.* 1983; Stanhope *et al.* 1987) and inundated phases (e.g. fish, aquatic invertebrates and micro-organisms, Bryant 1983; Fausch & Northcote 1992; O'Connor 1991; Thorp *et al.* 1985); (2) is a nutrient source for invertebrates and for flora (Bilby 1981; Culp *et al.* 1996); and (3) provides retentive structures for trapping finer debris, in-flowing nutrients and sediment, producing much more complex local microhabitats for animals (Andrus *et al.* 1988; Aumen 1990; Harmon *et al.* 1986). Thus, CWD is home and a provider of food and nutrients to many invertebrates (especially insects), reptiles, small-mammals and fishes. Birds are known to depend upon CWD for foraging and for cover.

Although the rôles of woody debris have been extensively studied in North America (Harmon *et al.* 1986; Maser & Sedell 1994), the importance of woody debris in the control of diversity in forested systems has not been fully appreciated and certainly has not been evaluated intensively within Australia (although see (Brown 1996), especially in floodplain forests. Woody debris generally has been viewed with disfavour (wildfire fuel) by managers and as an exploitable resource (firewood or 'forest waste') by local inhabitants. From a management perspective, floodplain CWD has not attracted much attention at all.

The growing appreciation of the impact of habitat and structural simplification on riparian-zone diversity has led to the establishment of several priority research areas in natural resource management funding programs aimed at assessing the condition of the inland riparian zones. The Land and Water Resources Research and Development Corporation (LWRRDC) has formed a Rehabilitation and Management of Riparian Lands program, one theme of which is Program B: *Ecological Issues* (Bunn 1994). Also, the Natural Resource Management Strategy Investigations and Education (NRMS) program of the Murray-Darling Basin Commission (MDBC) issued a call for Riverine Environment Priority Project Areas 1996/97. We have secured funding under the Project Brief R1: *Woody debris on floodplains* to conduct a broad-scale review of the ecological significance of CWD on floodplains. This NRMS project has several objectives that are designed to provide a general picture of CWD status and probable ecological consequences. The main ones are to provide: (1) information on the current levels at broad scales; (2) an historical estimate of CWD

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availability; and (3) data on terrestrial faunal association with CWD availability at selected, contrasting sites during the dry phase. The NRMS project therefore involves attempting to construct a broad picture of CWD in the floodplains of the southern Murray-Darling basin. The ultimate objective is to assess what measures need to be put into place to help restore the ecological functions associated with CWD in floodplain forests, which will relate mainly to impacts on biodiversity.

2. METHODS

2.1 Historical survey: Pre-European settlement levels of CWD on floodplains

Potentially useable data on the nature of floodplain environments was produced by five major groups of people during the 19th century: explorers, squatters and selectors, government surveyors, scientists and naturalists, and foresters. Relevant records include journals, river charts, lease applications, plans of pre-emptive rights, 'improvement' files, river surveys, parish plans, parliamentary reports and forestry records. All of these sources were exhaustively searched during this work; a preliminary report detailing the extent of this survey is available upon request.

2.2 Aerial survey

Aerial surveys were conducted along the floodplains of the Murray (Albury to Murray Bridge, 914 km surveyed of 1074 km), Murrumbidgee (Wagga Wagga to Murray, 408/485), lower Darling (Menindee to Murray, 232/270), Lachlan (Hillston to Murrumbidgee, 178/220), Wakool (Edward to Murray, 178/200), Edward (Deniliquin to Wakool, 120/166), Darling Anabranch (Populta to Murray, 102/150), lower Goulburn (Nagambie to Murray, 72/150), Loddon (Bridgewater to Little Murray, 96/130), Campaspe (Lake Eppalock to Murray, 74/95) and Avoca (Charlton to Murray, 68/80) rivers. A light aircraft flew along the mid-path of the river, and so, smoothed serpentine curves in some places. A geographical positioning system (Ensign XL, Trimble Navigation Systems, Sunnyvale CA, USA) was mounted on the aircraft and connected with a microcomputer system running the Automated Real-time Mapping Software system (Cipher Systems, Tyabb, Australia). The latter keeps track of the flight path of the aircraft and allows the user to record 'events' such as, in this case, counts of piles of woody debris. The aircraft flew at a constant elevation above the ground and marks on the wing-struts were used to estimate a fixed distance (200 m) from the course of the aircraft. Thus, each km traversed amounted to 40 ha (1000 m × 400 m). Visible piles of woody debris were continuously registered by using the event recorder. Data were loaded into a Geographic Information System (GIS) to allow inspection and some data analyses.

Some 2442 km of the 2987 km (82%) of the reaches were surveyed in this way, with much of the residual 18% being too thickly forested (Gunbower Island, Barmah/Millewa forests, lower Goulburn, lower Ovens floodplain) to survey from the air. The continuous aerial survey data was divided into 2 km stretches for subsequent analyses and ground truthing. The total numbers of sightings of debris piles was tallied for each 2 km stretch, which we call 'sites', and is regarded as an *index* of woody debris availability. Our aim was then to relate index measures to actual amounts of timber through ground truthing.

2.3 Ground truthing

2.3.1 General approach

Calibration of the aerial surveys by ground truthing involves selecting a series of 2 km stretches for detailed, on-the-ground measurements. We conducted pilot measurements involving strip transects of different dimensions and numbers at a site near Robinvale in Victoria. These measurements suggested that estimates derived by using 18 (200 m × 25 m) transects per 2 km stretch would be optimal in terms of accuracy/effort trade-offs. Thus, for ground truthing, nine transects of these dimensions were conducted on the left and right banks of the floodplain at selected sites. Mid-points and orientations of transects were randomly determined prior to visits, with the provisions that the transects had to be within 200 m of the rivers and that transects did not overlap or intersect. All woody debris at least 10 cm in diameter within the transects were measured. Pilot measurements indicated that the measurement of mid-point diameters and lengths of debris pieces, when treated as cylinders, was sufficiently accurate compared with measuring end diameters and lengths.

2.3.2 Site selection

We divided the southern Murray-Darling basin into three regions: the 'west', involving the Darling, Anabranch and western Murray reaches, the 'north', comprising the Lachlan, Wakool, Edward, and Murrumbidgee reaches, and the 'south', with the Goulburn, Loddon, Campaspe and eastern Murray reaches. To select sites for ground truthing, we randomly selected one site per region in each of the index classes 0–5. Because of the patchy availability of sites with indices above 5, we randomly selected only one site per region in the index-classes of 6–9 (the maximum). Thus, initially there were 18 sites for measuring on-the-ground levels of woody debris, although only 10 have so far been completed.

2.4 Amounts of CWD forested blocks

Five main areas could not be surveyed by using aircraft due to dense canopy cover and their extension beyond 200 from the river. These were: Gunbower Island (21,000 ha), Barmah (30,000 ha), Millewa (33,600 ha), lower Goulburn floodplain (7000 ha) and the lower Ovens floodplain (10,000 ha). In each of these areas, a number of randomly positioned transects of the same character as described above were measured on the ground. There were 30 such transects in Barmah, Millewa and Gunbower Island, 36 at Goulburn and 60 on the Ovens floodplain.

2.5 Estimating CWD on the southern Murray-Darling basin floodplain

We used resampling methods to compute means and confidence intervals for each forest block and for the ground-truthed aerial surveys. For each block, the data were examined to see whether they could be reasonably modelled by a statistical distribution (e.g.

lognormal, normal, exponential). If so, sets of appropriate numbers (e.g. 30 for Barmah, 36 for Goulburn) of values drawn randomly from these distributions can be viewed as 'possible' measurements for the block in question. If not (e.g. Ovens), the existing data were 'bootstrapped' to produce variance estimates. We used the *Resampling Stats* software package (Simon 1990) to do these calculations. There were 1000 resampling episodes per forest block, which yield estimates of the 95% confidence intervals (i.e. excluding the smallest 25 values and the greatest 25 values).

Estimating total floodplain CWD from aerial surveys is more complicated. First, ground-truthing regression relationships are needed to convert index measurements to CWD volumes, as measured on the ground. However, the regression relationships confer an uncertainty on the computed first estimate that must be taken into account. This was done by generating the variance in the estimate for CWD for each index measure (i.e. 0–9) and adding a value to the first estimate randomly drawn from a normal distribution with zero mean and the computed variance, to produce the second estimate. We also took into account variance due to within-site variability estimated from the 18 transects within sites. This variance was modelled as a function of the mean for sites because the variance was found to increase as the mean increases. Once this variance was computed, a randomly sampled value from a normal distribution with zero mean and the appropriate variance was added to the second estimate to produce the final estimate. This process is repeated for all 1221 'sites' and the mean and confidence interval computed for 1000 resampling episodes.

2.6 Conversion factors

Fallen timber was measured as volumes (m^3). However, Robinson's (1997) measurements of the density of woody debris from River Red Gum *Eucalyptus camaldulensis* of known age showed a remarkable constancy irrespective of decay status, allowing the useful relationship of 0.6 tonne/m^3. (Note: this density implies that River Red Gums float, which is true until they become 'water-logged'). Thus, volumetric measurements could be easily converted into mass measures. Also, for River Red Gums, A. I. Robertson (cited in Robinson 1997) found a tight (R^2 = 0.989) regression relationship between tree mass and tree diameter at breast height (DBH): $\log_{10}$(mass in kg) = 2.2842 $\log_{10}$(diameter in cm) – 0.7200. Thus, a 100 cm diameter River Red Gum is close to 7 tonne, which can be used to convert fallen timber in 'whole-tree equivalents'.

3. RESULTS

3.1 Historical survey: Pre-European levels of CWD on floodplains

A thorough search of the potential sources of information listed above yielded little data on pre-settlement abundances of fallen timber. Land 'improvement' files were the only documents that provided any information on woody debris. These files detailed the costs claimed by land-holders for clearing their land of fallen timber. Unfortunately, it is not possible to determine CWD densities from this information as the rate of payment is unknown.

3.2 Aerial survey

Index values derived from the aerial surveys were right-skewed, with most (1085) of the 1221 values between 0 and 4 and only one 2 km 'site' having an index of 9. Based on these values, there is more fallen timber per km in the southern floodplains (mean index 1.47) than the northern (1.22) or western regions (1.05).

3.3 Ground truthing

This aspect of the research is on-going and more data will provide better information for relating indices to mass densities. For 10 sites, the regression relationship between measured volume density (m^3/ha) and index value was: volume = 12 + 21 × index, R^2 = 0.87.

Variances among transects within sites were linearly related to means, which implies a non-linear relationship between the standard deviation and the mean. A model of standard deviation (SD) as a function of the mean (μ) was fitted by using the non-linear regression routine of *SYSTAT* (Version 7; Wilkinson 1989). For the 10 sites referred to above and another four for which we had no aerial indices, the non-linear model was: $SD = 67 \times \mu / (\mu + 55)$; R^2 = 0.93. This degree of statistical fit indicates that the SD can be well estimated once the mean has been determined.

3.4 CWD in the major forest blocks

Barmah houses the greatest mass of woody debris on the southern Murray-Darling floodplain, averaging over 24 tonne/ha (Table 1). The average in the lower Goulburn area is about one-half of the Barmah value, and the other areas lie between (Table 1). The estimated amount of CWD at Barmah is about 741,900 tonnes, but may be as little as 565,700 tonne or as much as 957,700 tonne (Table 1). In the five forest-block areas, comprising 101,600 ha, there is 1,912,200 tonne of CWD (Table 1). The outside limits (in the very unlikely event that values for all blocks are at the confidence limits) are 1,483,300 tonne and 2,393,500 tonne (Table 1).

3.5 CWD estimates from the aerial survey

More than half of the surveyed area was estimated from aerial-survey data (119,480 ha). By using the estimation procedures outlined above, the most probable mass-density was 18.94 ± 0.83 tonne/ha (Table 1). This value is consistent with the mean of the ground-truthed sites, which was 21.85 tonne. Given these two relationships, the total amount of CWD on the floodplain outside of the forest blocks is about 2,262,900 tonne, or 54% (Table 1). The relatively narrow limits to the estimates from the aerial survey (± 100,000 tonne, or 4.4% of the mean) is due to having information (indices) from a large number of 'sites' (1221) in the aerial survey, while the fractions of forest blocks actually measured ranged between about 0.1% in Barmah and Millewa (hence confidence limits of about 25% of the mean) to at most 0.6% on the Ovens floodplain (Table 1).

3.6 Total CWD estimates

Combining results from the blocks and aerial survey, the total CWD on the southern Murray-Darling floodplain is about 4,175,100 tonne, with confidence limits of 3,645,000 to 4,753,600. In terms of large River Red Gums, these figures amount to 596,400 tree-equivalents (520,700–679,100).

4. DISCUSSION

4.1 Historical survey: Pre-European levels of CWD on floodplains

The density of CWD on a floodplain at any time depends on the rates of production and loss from the system. Production varies primarily with the age structure and tree density of a forest (which, in turn, varies with management practices such as burning, forestry and river regulation; see Robinson 1997). Processes contributing to the loss of debris include physical breakdown, microbial and fungal decomposition, transport by flood waters, fire and wood collection. Investigation of how these factors have varied over the last two centuries allows inferences to be made about how CWD loads have changed.

An examination of plans, forestry records and historical literature suggests that the structure of River Red Rum communities has changed considerably. It appears that in the past, these communities were more open with a lower stocking of trees overall, but more importantly, may have had a significantly greater number of large, veteran trees. These trees produce the greatest volumes of debris (Jacobs 1955), so it is probable that the rate of production of debris in these woodlands was greater before settlement.

Rates of debris loss cannot be determined with any certainty. The greatest change would have been the vast quantities of fallen timber that have been removed from floodplains for firewood since settlement by Europeans. Conversely, the amount of debris moved off the floodplain during floods may have decreased over the last century due to changes in the frequency and especially magnitude of floods and the density of trees. A lack of research on the role of flood waters in moving floodplain timber makes this difficult to ascertain. It is difficult to assess how rates of decomposition and consumption by wildfire have changed since European settlement.

Thus, it is very difficult to make quantitative, or even qualitative, estimates of past levels of CWD. There is a scarcity of early historical data pertaining to River Red Gum forests, and relatively little is known of the dynamics of woody debris in these environments. It seems, however, that in most areas, the amount of debris on the ground is probably much less than in the past due to the younger age structure of contemporary red gum communities and the impact of firewood collection. Some areas managed for forestry purposes may have locally high levels of CWD in the form of logging debris. However, should the debris be claimed for other purpose, as is proposed, then CWD levels may drop drastically.

In *lieu* of historical approaches, we have identified a number of sites at which modifications by European settlement is thought to have been marginal. Once surveyed, these sites may yield a better picture of CWD loads prior to settlement. Robinson (1997) found that standing crops of live trees, CWD and stags all were significantly higher in old-growth areas than in managed areas in a limited number of sites at Millewa. Levels of CWD were about five-fold higher in old-growth areas, while the values for managed areas were comparable to those reported here (ca 20–30 tonne/ha).

4.2 Existing levels and restoration targets

Our estimates of existing levels of CWD depend upon certain assumptions, especially the regression relationship between volume-density and index-values. Work is continuing with the aim to increase the sample size from ten to something nearer thirty (i.e. $30 \times 18 = 540$ transects) to have greater confidence in the regression statistics. Moreover, we wish to measure sites with indices exceeding 5, which has not been achieved yet. Nevertheless, most of the data are internally consistent, with mean mass-densities (tonne/ha) similar to estimates from the resampling procedure and to the means of ground-truth sites.

There are several other limitations. First, we surveyed only the 200 m on either side of the rivers and in some places this is less than the width of wooded floodplain. And second, we have not covered all of the possible major rivers of the system (e.g. Kiewa and Broken Rivers). Nevertheless, the coverage has been extensive and the total estimates should be reasonably close to the actual levels,

There are two main avenues to approaching restoration from an ecological point of view. The first is to restore a system to its pre-impact state, which, as illustrated here, we know little about. However, if the old-growth data of Robinson's (1997) study are representative of pre-impact levels, then a mass-density of about 125 tonne/ha may be a reasonable figure. Such a density implies a restoration target of 27,635,000 tonne for the 221,080 ha considered here. This means restoring between about 23,000,000 and 24,000,000 tonne or the equivalent of 3.3 to 3.4 million River Red Gums of 1.0 DBH in the form of CWD (Table 1). In terms of area, such a program would require clear-felling almost 40,000 ha of mature, old-growth River Red Gum forest given the figure of 600 tonne/ha (Robinson 1997: Fig. 4.1). Both Robinson's and other estimates (e.g. Cuddy *et al.* 1993) suggest that a more representative figure in managed forests now is between 200 and 300 tonne/ha, which translates into 115,000 ha, or over half of the area considered in this project!

Another approach is to attempt to determine the relationships between levels of CWD and the diversity of animals, such as birds, reptiles, mammals and terrestrial invertebrates. To this end, we have established a program involving repeated surveys of 21 sites in Barmah, Gunbower Island and the Ovens floodplain where CWD levels vary from virtually nothing up to 60 tonne/ha. It will take several years to establish strong data sets, but hopefully this work will allow us to determine critical levels of floodplain CWD in relation to the diversity of animals. These levels may be more tractable targets, at least in the foreseeable future, for restoration of CWD on floodplains.

Restoring the ecological integrity of the lowlands of the Murray-Darling Basin must involve the return of the rivers and riverine environments to something closer to their pre-European-settlement condition. It is clear from our study that one of the main components of the structural complexity of riparian zones— fallen timber—is effectively missing over vast areas. It is also clear that a meaningful restoration is a monumental task for many reasons, but especially due to the lack of replacement timber. Thus, not only does CWD need to be reinstated, but there needs to be a massive expansion of forested habitat on the floodplains to service the floodplains. In the shorter term, there needs to be much thought on developing a management strategy for restoring CWD. For example, given a limited amount of material, how can it be best placed to begin the long road to recovery? Are flood runners good candidate areas? How specific are animals in their use of CWD in terms of its location on the floodplain? Is it best to add to existing accumulations or is it more effective to more widely (and thinly) distribute the CWD? The woody debris story is only at the beginnings of its rudimentary course, but this study has established that the task is a huge one because of the severity of the changes that have occurred since settlement by Europeans.

5. CONCLUSIONS

Our results suggest that the southern Murray-Darling basin floodplains have probably been as denuded of woody debris as the in-stream, which has attracted much more attention. However, it is incorrect to think of the rivers and riparian zones as distinct entities that need to be managed separately. Any stream restoration involving woody debris necessarily requires a source of debris, and this can only come from the floodplain itself. The reasons for the massive loss of woody debris in riparian systems are different for the streams and the floodplains. Streams have been stripped under apparently misguided attempts to 'improve' rivers, to reduce floods and enhance navigation. On floodplains, the debris appears to have been lost principally for firewood and timber harvesting. The increasing isolation of rivers from their floodplains (Robertson *et al.* 1997) is particularly crucial for the dynamics of CWD, which once would have been readily washed from floodplains into drainage channels and then to the rivers. Any serious attempts to restore lowland rivers must be linked closely with efforts to restore CWD of floodplains and there are clear links with the provision of environmental flows.

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Table 1: Data on estimates of woody debris on the southern Murray-Darling floodplain. Data are expressed in tonne. CL means confidence limit (upper or lower 2.5%).

Unit	Area	Trans-ects	Transect mean	Unit totals (summed over entire area)		
	Ha	No	tonne/ha	Lower CL	Mean	Upper CL
Barmah	30,000	30	24.36	565,700	741,900	957,700
Gunbower	21,000	30	15.99	272,700	335,900	392,200
Goulburn	7,000	36	11.78	58,400	83,800	112,900
Millewa	33,600	30	16.78	432,300	562,600	710,300
Ovens	10,000	60	18.72	154,200	188,000	220,400
Aerial	119,480	—	18.94	2,161,700	2,262,900	2,360,100
Total (tonne)	221,080	—	18.88	3,645,000	4,175,100	4,753,600
Tree equivalents*	—	—	—	520,700	596,400	679,100
‘Old-growth’ target †	221,080	—	125	—	27,635,000	—
Restoration needed	221,080	—	—	23,990,000	23,459,900	22,881,400
Tree equivalents*	—	—	—	3,427,100	3,351,400	3,268,800

* River Red Gums of 1.0 m DBH; † from Robinson (1997): Fig. 4.1.