EFFECTS OF LIVESTOCK ON RIPARIAN ZONE VEGETATION IN AN AUSTRALIAN DRYLAND RIVER

A.I. ROBERTSON* AND R.W. ROWLING
The Johnstone Centre, School of Science and Technology, Charles Sturt University, Locked Bag 588, Wagga Wagga, NSW 2678, Australia

ABSTRACT
Vegetation structure and composition and the mass of components of organic detritus were assessed in paired areas, with and without stock access, at six sites. The study revealed that grazing has altered and continues to alter the structure and function of the riparian landscape in the Murrumbidgee River and its tributaries in southeastern Australia. Seedlings and saplings of the dominant *Eucalyptus* tree species were up to three orders of magnitude more abundant in areas with no stock access, and the biomass of groundcover plants was an order of magnitude greater in areas with no stock access at all sites. Plant species richness did not differ between areas with and without stock access when the ameliorating effect of canopy tree density was taken into account, but plant community composition differed significantly between areas at all sites. Coarse particulate organic matter and terrestrial fine woody debris were consistently more abundant in areas without stock. In-stream fine and coarse woody debris was more abundant in areas without stock at mainstream sites, but not in tributaries. The percentage of bare soil was greater in areas with stock access at all sites. Differences between areas with and without stock access were generally most pronounced at sites where the riparian zone had been excluded from stock access for more than 50 years. The effects of livestock on vegetation and components of detritus have a significant influence on the function of riparian zones. Efforts to restore river health that focus solely on reducing the impact of regulated flows may be nullified if livestock grazing is not considered as part of river ecosystem management. Copyright © 2000 John Wiley & Sons, Ltd.

KEY WORDS: livestock; organic detritus; riparian zone; river restoration; vegetation

INTRODUCTION
The structures and functions of riparian habitats are the result of processes operating at a hierarchy of scales (Salo, 1990). Our current understanding of river ecosystems suggests that variations in flow control the physical framework for ecological processes at large scales (e.g. across catchments over hundreds to thousands of years). At smaller scales (e.g. within reaches and over years), biological interactions may control species abundance patterns and material cycles (Power et al., 1988). An understanding of those processes that are important at different levels of organization will help to explain some of the variability observed in floodplain rivers (Johnson et al., 1995), thus providing the basis for appropriate management strategies for rehabilitating riparian zones (Naiman and Decamps, 1997).

Dryland floodplain rivers, such as those in the Murray–Darling Basin, Australia, have spatial and temporal flow variations that are more extreme and less predictable than those in more humid regions of the world (Puckridge et al., 1998). The consequences of such variability are complex, and include varied channel shapes and floodplain geomorphology, and a biota which has evolved to recruit in response to floods and to endure lengthy periods of low flows (Lake, 1995). These rivers have been modified significantly since European settlement (e.g. Crabb, 1997). The storage and subsequent release of high percentages of mean annual runoff in headwater dams, the reduction of flows by weirs, and the extraction of water to obtain reliable water supplies for agriculture have resulted in highly regulated river flows (e.g. Maheshwari et al., 1995). The more obvious ecological impacts of flow regulation have been more
frequent cyanobacterial blooms, the establishment of populations of exotic fish adapted to more homogeneous flows, and altered hydrology of floodplain wetlands, with subsequent changes to the distribution and abundance of aquatic biota, and disruption to the breeding cues of fish and waterbirds (Walker, 1985; Gehrke et al., 1995). Flow regulation has also severely disrupted material cycles within these river systems (Robertson et al., 1996).

Current ecosystem management to restore river health in most of the Murray–Darling Basin focuses on providing ‘environmental flows’ from water storages at the expense of irrigation supplies (e.g. EPA, 1997). Such a management strategy clearly reflects current ecological thinking on rehabilitating large rivers (Sparks, 1995). However, it is questionable whether restoration of flows alone will result in any measurable improvement in ecological functioning in the rivers of the Murray–Darling Basin (Robertson, 1997). While more natural flows can restore physical links between river channels and adjacent habitats, the catchments and floodplains of these systems have been, and continue to be, affected by a number of other factors that alter the quantities and quality of materials available for transport and transformation during floods. Past and present agricultural and grazing practices and the introduction of exotic aquatic biota, such as carp (*Cyprinus carpio*), have all contributed to significant changes in the structures of floodplain habitats (e.g. Chesterfield, 1986; King et al., 1997) and their functions in relation to their adjacent river channels in the Murray–Darling Basin (Robertson et al., 1996; Robertson, 1997).

Several reviews have identified grazing by domestic stock to be a major cause of disturbance to Australian riparian habitats (Smith and Smith, 1990; Walker, 1993; Bacon et al., 1994). However, surprisingly little empirical information is available on the relationship between grazing and the structures and functions of the riparian zone in Australian dryland rivers (Walker, 1993).

The introduction of European grazing animals on to the floodplains of the Murray–Darling Basin began in the 1830s (Bacon et al., 1994), and by the 1860s and thereafter, there was noticeable damage to the vegetation on heavily grazed regions of floodplains of the Riverina region (Gammage, 1986). In the 1890s, cattle replaced sheep as the major grazers in the wetter areas of the Murray–Darling Basin floodplains, and rabbits became abundant (Bacon et al., 1994). The relative importance of native, domestic and feral grazers in degrading riparian habitats in the Murray–Darling Basin has not been assessed, nor is it clear how the alteration of flooding regimes resulting from river regulation (e.g. Maheshwari et al., 1995) has interacted with grazing to influence riparian zones. These are key issues in the management of riparian vegetation in the Murray–Darling Basin (Bacon et al., 1994).

Livestock concentrate in the riparian zones of dryland rivers because of the availability of water and the high levels of primary production relative to adjacent rangelands. The riparian zone is, thus, particularly susceptible to damage by domestic and other grazing animals (Robertson, 1997, 1998).

In this paper, we compare vegetation structure and composition, the abundance of woody debris and leaf litter, and the percentage of bare soil in areas with and without livestock access at several sites. We show how important livestock are in controlling the structure and function of the riparian landscape of the mid-Murrumbidgee River and its tributary streams in southeastern Australia.

**STUDY REGION AND SITES**

Sites chosen for investigation of the impact of livestock on riparian areas were situated on the Murrumbidgee River and its tributaries, the Tarcutta and Billabong Creeks, and the Yass River, between Wagga Wagga and Yass in southern New South Wales (Figure 1). The region’s climate is characterized by hot, dry summers and cool, wetter winters. The average maximum and minimum air temperatures at Wagga Wagga are 31.3°C in January, and 2.6°C in July, respectively. The average annual precipitation is 573 mm.

The Murrumbidgee floodplain consists of grey clay soils developed on alluvial deposits dominated by fine sand, silt and clay. The soils surrounding the floodplain vary considerably; however, the major soil types are red podzolics and red earths. The soils along Tarcutta Creek are dominated by yellow solonetz and red podzolics (Tuckson, 1995). The red earths, red podzolics and the black earth soils of the
Figure 1. Location of study sites in the riparian zone of the mainstream and tributaries of the Murrumbidgee River, Australia

Murrumbidgee floodplain are also the characteristic soils of Billabong Creek (Soil Conservation Service of NSW, 1974). The hillslopes surrounding Yass are comprised of podzolic soils, while the steeper ridge and slope terrains are characterized by lithosols (Nicholl and Scown, 1993). The footslopes and drainage lines of the Yass region are dominated by soloth–solodic soils, with minor areas of layered alluvial soils along active floodplains (Nicholl and Scown, 1993).

In the study region, river red gums (Eucalyptus camaldulensis) dominate the riparian zone of the Murrumbidgee River, while white box (Eucalyptus albens), grey box (Eucalyptus wooliiana), river she-oaks (Casuarina cunninghamiana) and several introduced willow species (Salix spp.) are also present on the floodplain. Dominant perennial pasture species occupying the riparian zone include Danthonia and Stipa spp. The area immediately surrounding the Yass site is dominated by a yellow box–red gum (Eucalyptus melliodora–Eucalyptus blakelyi) community, combined with a Stipa spp. grassland.

European settlement of the region took place during the 1820s and 1830s. The alluvial areas surrounding the riparian zone offered ideal conditions for grazing and cultivation, making these areas particularly attractive to settlers (Kirkpatrick, 1994). The entire area surrounding Wagga Wagga had been taken up by pastoralists by the early 1840s.

By the 1870s, sheep and cattle had removed virtually all the original native kangaroo grass, tall spike rush and oat grass from around Narrandera (Gammage, 1986). Livestock had also exposed bare earth, allowing winter annuals and weeds to colonize. The impact and spread of weeds were evident as early as 1880, when many properties reported barley grass, speargrass, corkscrew and silver grass as common (Gammage, 1986). Cultivation of many riparian and floodplain lands began in the region during the 1830s and 1840s, and soon expanded along the entire Murrumbidgee River catchment. Much of the riparian area used for cropping was cleared using a mixture of ringbarking and burning in the late 19th century (Grant, 1989).

At present, the floodplain of the river around Wagga Wagga supports intensive livestock grazing and some mixed cropping. Stocking rates in this region of the Murrumbidgee floodplain range from 1 to 26 dry sheep equivalents (DSE) ha$^{-1}$ year$^{-1}$, with a mean of approx. 12 DSE (Jansen, 1998).

Six sites were used in the study (Figure 1). The choice of sites was governed by the location in the region of areas where stock access has been eliminated (hereafter called NO STOCK areas). At each of the study sites, an area with stock access (hereafter called STOCK areas) was established near the fenced
areas to be used for investigation of the impact of livestock on vegetation, detritus and soil variables (see below). The positions of all STOCK areas were chosen to minimize the effect of covariates on comparisons of paired areas. Care was taken to ensure that paired areas at any site were as similar as possible in geomorphic settings (erosional, depositional or straight banks), bankslope (within at least four degrees) and densities of large mature trees. However, because of the degree of clearance of large trees at some sites, the density of large trees was included as a covariate in the analysis of some data (see below). The NO STOCK areas ranged in size from 1 to 6 ha.

All surveys were performed between April and June 1997, i.e. at the end of the austral autumn. Rainfall during the period of January–June 1997 was 184 mm, compared with the long-term average of 270 mm. Mean maximum temperatures during this period were higher than long-term averages, and mean minimum temperatures were lower.

The paired areas on Tarcutta Creek were situated on private property used for cattle and sheep grazing. Both areas were located on depositional bends and were within 1 km of each other. The NO STOCK area had been fenced off from livestock for more than 50 years. The STOCK area on Billabong Creek was situated in a travelling stock reserve, which is used by drovers to house high numbers of livestock over short periods of time. The adjacent NO STOCK area had been fenced off for 4 years. The Yass River site was situated on a privately owned cattle-grazing property. The paired areas were adjacent to one another, and the NO STOCK area had been fenced off from livestock for 5 years. Limited stock access is granted in the NO STOCK area at Yass during times of severe drought, but this had not occurred for 2 years prior to this project.

There were three sites on the mainstream of the Murrumbidgee River within 45 km upstream of Wagga Wagga. The scarcity of the ungrazed floodplain on the Murrumbidgee River meant that two islands were used as NO STOCK areas. At Oura, the NO STOCK area was located on the erosional bank of an island, while the adjacent STOCK area was located on a grazing property on the erosional bank of the river. Even in periods of very low flow, the island cannot be reached by livestock. Both the STOCK and NO STOCK areas at the Borambola site were located on a cattle-grazing property. Livestock had been excluded from the NO STOCK area for 4 years. The two areas were 700 m apart and located on straight sections of the river. At the Eringoarrah site, the areas were situated on a privately owned cattle-grazing property. The NO STOCK area was located on an island, with limited stock access occurring only during periods of extremely low flows. The STOCK area was located 1 km upstream of the NO STOCK area and both were on erosional banks of the river.

Kangaroos and wallabies graze on the floodplain and along tributary streams in the region, but the fences used to exclude livestock present no barrier to these native herbivores. Introduced rabbits occur across the region, but none of the six exclusion areas employed rabbit-proof fencing.

METHODS

For this project, we studied stream banks, i.e. that part of the riparian zone between the land–water interface at natural base flow and the bank-full discharge level. This was necessary because most areas that had been fenced off from stock were restricted to only a narrow region of the floodplain at the river’s edge.

Because riparian vegetation provides a vital habitat for aquatic and terrestrial fauna and flora, influences material fluxes across the land–water interface and contributes to foodchains within both systems (Naiman and Decamps, 1997), we measured a variety of vegetation and related parameters (see below) in the paired areas to determine the influence of livestock. With the exception of in-stream woody debris (see below), all variables were measured in three transects within each area. Transects were orientated perpendicular to the water’s edge, so as to cover the length of the riparian zone at each area, and were placed randomly along the riverbank. All transects were 7.5 m wide but were of variable length, depending on the slope of the bank in each area.
Tree density (stems ha\(^{-1}\)) and size structure data were based on measurement of the diameter at breast height (dbh) of all overstorey species occupying the area within each transect. For the major species, size classes included large trees > 32 cm dbh, medium trees 6.5–32 cm dbh, saplings 1.5–6.5 cm dbh, and seedlings < 1.5 cm dbh.

The biomass of groundcover vegetation and litter (leaves, bark and twigs < 1 cm diameter) was measured in each transect. At 5 or 10 m intervals (depending on transect length), along each transect, we sampled all groundcover vegetation and litter within a 0.25 m\(^2\) quadrat. The material was sorted, oven-dried for 4 days at 80°C and weighed.

To determine the degree to which riparian areas would be subject to erosion during periods of high rainfall and high flows, we estimated the percentage of bare ground in each plot. For each transect in each plot, we recorded the presence or absence of bare soil at 1 m intervals.

We recorded the length and average diameter of all pieces of terrestrial woody debris within each transect so that the volume of wood could be estimated. All pieces of wood were classified either as coarse woody debris (CWD > 10 cm diameter), or as fine woody debris (FWD > 1 cm and < 10 cm diameter).

Because in-stream woody debris was often submerged, we used a different approach to estimate abundance (France, 1995). A tape measure was placed along the length of each river or tributary in each area, 15 cm out from the bank, and we recorded the diameter of all woody debris intercepted by the tape. Data were summarized as the frequency of occurrence of coarse woody debris and fine woody debris along 100 m of the stream or river within each area.

To determine plant species richness, we recorded the total number of species encountered in the first 20 m of each transect in 20 min. We then estimated the percent cover of each species by eye. Percent cover data were used in the comparison of plant community composition.

For most variables, we used a two factor (sites: six levels; livestock access: two levels) analysis of covariance (ANCOVA) to compare means. Site was a random factor, while grazing was fixed. The covariate in all cases was the stem density of *Eucalyptus* spp. trees (> 6.5 cm dbh) (Table I) in each transect, because tree density may affect regeneration, understorey vegetation, litter, mass of woody debris and the degree of use of the site by livestock for shade. The approach taken with the analyses was to determine if covariates or the interactions they contributed to explained significant proportions of the variance in the models. If interaction terms were not significant, they were removed from the model and simplified models were used to investigate the sources of variance. For all variables, no interaction terms were significant and only main factors and the covariate explained significant proportions of the variance. Thus, only the main factors and covariate are presented in the results. With the exception of the variable percent bare ground, which was transformed (arcsin√p), raw data were used in analyses. In all cases, data were homoscedastic (Levene’s test). For in-stream fine and coarse woody debris, frequency of occurrence data in areas at each site were compared using heterogeneity chi-squared analyses.

### Table I. Mean (± 1 S.E.) stem density of *Eucalyptus* spp. (all individuals > 6.5 cm dbh) in STOCK and NO STOCK areas at all sites

<table>
<thead>
<tr>
<th>Site</th>
<th>STOCK area (number ha(^{-1}))</th>
<th>NO STOCK area (number ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tarcutta</td>
<td>179 ± 22</td>
<td>489 ± 59</td>
</tr>
<tr>
<td>Billabong</td>
<td>111 ± 22</td>
<td>311 ± 44</td>
</tr>
<tr>
<td>Yass</td>
<td>311 ± 80</td>
<td>600 ± 102</td>
</tr>
<tr>
<td>Borambola</td>
<td>222 ± 22</td>
<td>600 ± 168</td>
</tr>
<tr>
<td>Eringoarrah</td>
<td>245 ± 59</td>
<td>667</td>
</tr>
<tr>
<td>Oura</td>
<td>511 ± 111</td>
<td>1045 ± 182</td>
</tr>
</tbody>
</table>

Note that the same number of trees were located in each transect in the NO STOCK area at Borambola.
Plant community composition was analysed using non-metric multidimensional scaling (MDS). Percent cover data for each transect were transformed (double square root) before analysis to reduce the impact of a few dominant taxa on subsequent analyses (Clarke and Warwick, 1994). The Bray–Curtis similarity coefficient was used to generate the similarity matrix. To determine if plant community composition differed between areas and sites, a two-way, crossed analysis of similarity (ANOSIM) was performed on similarity data (Clarke and Warwick, 1994). To simplify the presentation of data, we separated mainstream and tributary sites in the analyses.

**RESULTS**

The mean density of seedlings of *Eucalyptus* spp. was significantly greater in NO STOCK areas at all sites, and the livestock treatment accounted for 11% of the total variation in the ANCOVA model (Figure 2, Table II). No seedlings were recorded in the STOCK area at the Tarcutta and Billabong tributary sites, nor at the Eringoarrah mainstream site. The greatest differences between areas occurred at the Tarcutta and Oura sites, where livestock had been excluded for the longest periods (Figure 2). The pattern for *Eucalyptus* saplings was similar to that for seedlings (Figure 2, Table II), with the exception that mature trees also had a significant effect on sapling densities (Table II).

Mean live groundcover biomass was consistently an order of magnitude greater in NO STOCK areas (Figure 2, Table II) and overall mean biomass, based on all sites was 209 and 27 g m\(^{-2}\) in NO STOCK and STOCK areas, respectively. Variation at the livestock treatment level accounted for 42% of the total variation in the ANCOVA model (Table II).

Although plant species richness was often greater in NO STOCK areas (Figure 2), such differences were explained more by the density of the major canopy-forming tree species in areas than by the effect of fencing out livestock (Table II). We arrived at the same result for the total richness of native (ANCOVA, livestock treatment, \(p = 0.64\); covariate trees, \(p = 0.001\)) and exotic plant species (ANCOVA, livestock treatment, \(p = 0.79\); covariate trees, \(p < 0.01\)). Although the exclusion of livestock did not appear to influence richness of exotic plant species, individual weed species were often more abundant in NO STOCK areas. For instance, at the five sites where it was recorded, the percentage cover of blackberry (*Rubus fruticosus*) was always significantly greater in NO STOCK areas (ANCOVA, livestock treatment, \(p < 0.001\)). Overall means of percent cover for blackberry, based on these five sites, were 16% and 0.5% in NO STOCK and STOCK areas, respectively.

The mass of litter (leaves, bark and twigs) was generally greater in NO STOCK areas, and there was significantly more litter in mainstream sites (Figure 3, Table II). Surprisingly, litter mass was not related to the stem density of trees (Table II). The mean volume of terrestrial fine woody debris was greatest in many of the NO STOCK areas (Figure 3), but high levels of variation within areas meant that no terms in the ANCOVA model were significant (Table II). The volumes of terrestrial coarse woody debris were highly variable within areas, and there was no consistent pattern in coarse woody debris among areas and sites (Figure 3, Table II). STOCK areas always had far greater proportions of bare ground (Figure 3), and variation at the livestock treatment level accounted for 36% of the total variation in the ANCOVA model (Table II).

There were significant differences between sites in the frequency of occurrence of in-stream fine woody debris (heterogeneity chi-squared, \(p < 0.001\)) and coarse woody debris (heterogeneity chi-squared, \(p < 0.001\)) across areas. The frequency of occurrence of fine woody debris and coarse woody debris was consistently greater in NO STOCK areas at sites on the mainstream of the river, but not at tributary sites (Figure 4).

We recorded a total of 119 plant species in all areas and sites. There were significant differences in plant community composition between sites and between STOCK and NO STOCK areas for tributary sites (ANOSIM, site \(R = 0.996, p < 0.001\); livestock treatment \(R = 0.963, p < 0.001\)) and for mainstream sites (ANOSIM; site \(R = 0.947, p < 0.001\); livestock treatment \(R = 1, p < 0.001\)). For tributary
Figure 2. Mean (±1 S.E.) densities of seedlings and saplings of *Eucalyptus* spp., biomass of groundcover plants, and total plant species richness within NO STOCK (black bars) and STOCK (open bars) areas in three tributary and three mainstream sites of the Murrumbidgee River; Tar = Tarcutta Creek, Bill = Billabong Creek, Yass = Yass, Bor = Borambola, Erin = Eringaarrah, Oura = Oura; all trees were *Eucalyptus camaldulensis*, with the exception of those at Yass that were *Eucalyptus blakelyi*.

sites (Figure 5), the magnitude of difference in plant community composition between STOCK and NO STOCK areas increased with time since exclusion of livestock (Tarcutta, 50 years; Billabong, >4 years; Yass, 2 years). There was no such pattern for mainstream sites, where the magnitude of difference between areas was similar for all sites (Figure 5), although the NO STOCK island area at Oura has had livestock excluded for much longer (>50 years) than at the other sites. In tributary and mainstream sites, areas with greater mean stem densities of mature eucalypt trees separated clearly from areas with lower densities of trees (Figure 5).
Table II. Summary of two factor (site, livestock treatment) analyses of covariance (as $F$-ratio values) for vegetation and litter variables where the covariate was the stem density of red gum trees

<table>
<thead>
<tr>
<th>Variable</th>
<th>Site ($F_{5,28}$)</th>
<th>Livestock ($F_{1,28}$)</th>
<th>Trees ($F_{1,28}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedling density</td>
<td>1.19 (ns)</td>
<td>4.50* (11)</td>
<td>0.83 (ns)</td>
</tr>
<tr>
<td>Sapling density</td>
<td>0.98 (ns)</td>
<td>4.36* (5)</td>
<td>4.29* (5)</td>
</tr>
<tr>
<td>Groundcover biomass</td>
<td>3.17* (7)</td>
<td>92.64*** (42)</td>
<td>3.08 (ns)</td>
</tr>
<tr>
<td>Species richness</td>
<td>12.21*** (52)</td>
<td>0.12 (ns)</td>
<td>7.85** (7)</td>
</tr>
<tr>
<td>Litter</td>
<td>6.65*** (29)</td>
<td>14.69*** (13)</td>
<td>0.02 (ns)</td>
</tr>
<tr>
<td>Fine woody debris</td>
<td>1.90 (ns)</td>
<td>2.92 (ns)</td>
<td>0.34 (ns)</td>
</tr>
<tr>
<td>Coarse woody debris</td>
<td>0.89 (ns)</td>
<td>0.06 (ns)</td>
<td>0.03 (ns)</td>
</tr>
<tr>
<td>Percent bare soil</td>
<td>2.01 (ns)</td>
<td>47.08*** (36)</td>
<td>1.56 (ns)</td>
</tr>
</tbody>
</table>

Numbers in parentheses are the percentages of the total variance in the model accounted for by each significant factor.

* $p<0.05$, ** $p<0.01$, *** $p<0.001$, ns = not significant.

DISCUSSION

Riparian vegetation and dead organic matter

Comparisons of paired areas without pre-impact data are classic ‘natural experiments’, from which it is difficult to derive conclusive cause and effect relationships. However, as Kirkpatrick (1997) argued for a similar situation with grazing exclusion areas in the Australian highlands, it is extremely unlikely that all of the NO STOCK areas we were able to find in the mid-Murrumbidgee region were established by chance in parts of the riparian zone whose vegetation communities differed fundamentally from adjacent portions of the same habitat. As far as covariates were concerned, we took great care to minimize the differences between areas in geomorphic setting, soil type and slope—all factors that interact with flow regimes to determine plant community structure in riparian habitats (Naiman and Decamps, 1997). In addition to grazing by livestock, the degree of tree clearance on floodplains and river banks is potentially the most significant factor that influences the structure of riparian vegetation communities in the region.

To control for this, we included the density of the dominant overstorey species, Eucalyptus camaldulensis (E. blakelyi at the Yass site) in each area as a covariate in most of our formal data analyses.

Our data indicate that livestock have had a major impact on the structure of vegetation in the riparian zone in the sites we studied. Recruitment of seedlings into the population of the canopy dominant Eucalyptus camaldulensis (E. blakelyi at the Yass site) was greater in NO STOCK areas at all sites. At most sites, seedlings were almost absent from STOCK areas, while at the two sites in areas where livestock had been excluded for the longest time (Tarcutta, 50 years; Oura, > 50 years), densities were $>10^3$ seedlings ha$^{-1}$.

As recruitment of E. camaldulensis is strongly dependent on flooding (Bren, 1988, 1992), it may be that our surveys, which were conducted in a drought year and 6 years after the last major flood in the region, reflected poor overall recruitment. However, we recorded the same pattern for saplings as we did for seedlings, indicating that, at the high stocking rates in the region, livestock currently play a major role in controlling the recruitment of red gum populations. Previous work on the relationships between cattle and river red gums indicated that cattle did not have a major negative impact on seedling survival (Dexter, 1970). However, that work was performed in forestry reserves, where cattle are stocked at very low densities (equivalent to < 1 DSE ha$^{-1}$) to reduce understorey fire fuel loads. Our surveys over greater spatial scales than reported here show that along 600 km of the riparian zone of the Murrumbidgee River between Gundagai and Hay, the impact of livestock on recruitment of red gum also appears to decrease as stocking rates decrease in the lower rainfall regions of the western end of the catchment (Jansen and Robertson, in press).
Figure 3. Mean (±1 S.E.) mass of coarse particulate organic matter (CPOM)—litter, fine woody debris (FWD), coarse woody debris (CWD), and the percentage of bare ground within NO STOCK (black bars) and STOCK (open bars) areas in three tributary and three mainstream sites of the Murrumbidgee River; site names as in Figure 2

Tree density (as a covariate) explained significant amounts of variation in the density of saplings at our study sites. It is likely that this reflects the long-term (years) use of riparian areas with tree cover as shelter sites by cattle during dry summer and autumn periods (Robertson, 1998). When camped under mature trees, cattle kill seedlings by trampling, as well as by consuming their leaves.

The biomass of groundcover was also generally an order of magnitude greater in areas from which livestock were excluded. It is likely that our data represent an extreme seasonal view of the differences in groundcover biomass. Our surveys were performed at the end of a very dry autumn. In wetter years, and during wetter parts of the year (i.e. between July and October), groundcover biomass can be much greater.
in grazed portions of the riparian zone. Nevertheless, our observations over larger spatial scales and at
different times of the year in the Murrumbidgee catchment indicate that livestock generally have a major
negative impact on riparian groundcover biomass (e.g. Jansen and Robertson, in press).

Differences in the density of canopy-forming eucalypts were more responsible for differences in plant
species richness between STOCK and NO STOCK areas than livestock, with species richness lowest where
tree densities were highest. It is likely that differences in tree density influence the microclimate of
riverbanks via shading and through allelopathic impacts, thus altering growing conditions for other plant
species.

We recorded significant differences in plant community composition between STOCK and NO STOCK
areas at all sites. This occurred even in areas that had been fenced off for less than 5 years. A variety of
physical and biotic factors can influence riparian plant community composition, including soil type,
hydrology and geomorphic factors (Tabbachi et al., 1996; Naiman and Decamps, 1997). These probably
accounted for differences in vegetation communities between sites. However, the significant differences
between areas at each site indicate that livestock have had major impacts on vegetation composition
across the riparian landscape, as has been suggested for other regions in Australia (Smith and Smith,
1990), and observed elsewhere (e.g. Platts and Raeleigh, 1984; Fleischner, 1994). It was apparent from our
data that the stem density of mature trees also influenced the overall plant community composition.

Taken together with the finding that understorey species richness is controlled more by the density of
canopy-forming eucalypts, it is clear that livestock may ultimately control understorey plant species
richness and composition through their negative impacts on recruitment to the populations of canopy-
forming trees.

Previous studies of dead organic matter (litter and woody debris) in riparian areas of dryland rivers in
parts of the Murray–Darling Basin that are managed for forestry (Robinson, 1997; Glazebrook and
Robertson, 1999) indicate that alterations to flood regimes and wood harvest practices have changed
forest floor detrital mass. Our data on components of dead organic matter in the riparian zone of the
Murrumbidgee indicate that livestock may also have a very significant direct (via trampling) or indirect (via impacts on live vegetation structure and biomass) impact on detrital mass. The quantities of leaves and bark of eucalypt species and dead groundcover vegetation, and to a lesser extent, fine woody debris on the river banks, were much greater in NO STOCK areas at all sites.

It is difficult to know the degree to which livestock influence the quantities of in-stream woody debris. Although we recorded greater frequencies of fine woody debris and coarse woody debris in NO STOCK areas at mainstream sites, this was not true of tributary sites. In addition, although livestock may influence quantities of woody debris indirectly by altering live plant biomass, fine woody debris and
coarse woody debris are transported in floods. Thus, quantities of in-stream fine woody debris and coarse woody debris are more likely to be controlled by physical processes operating at spatial and temporal scales outside those considered in this study.

Some of the between-site variation in the variables we measured may be attributed to the period of exclusion of livestock. Areas had stock excluded for different lengths of time, resulting in riparian patches which were at different stages of recovery (e.g. Platts and Wagstaff, 1984). Because the effects of livestock on riparian systems vary with soil type, geomorphology, topography and grazing intensity, the ability of each site to recover was also highly variable (Clary and Webster, 1989).

The most significant differences between STOCK and NO STOCK areas (density of *Eucalyptus* seedling and saplings, groundcover biomass, plant community composition) generally occurred at the Oura and Tarcutta sites, where livestock had been excluded for the longest periods of time (> 50 years). These differences indicate that while improvements in riparian structure and function (see below) may occur within 5 years of livestock exclusion, full recovery from the impact of livestock may take decades.

**Livestock and riparian function**

In their recent review of the ecology of riparian zones, Naiman and Decamps (1997) recognized three broad categories of ecological functions of riparian zones: as sources of nourishment, as nutrient filters, and as habitat. Our data indicate that all these functions have been significantly altered by livestock at our study sites.

Organic matter produced by riparian vegetation can be a significant contributor to riverine food chains, entering rivers either directly (Thorpe and Delong, 1994) or during flood pulses (Junk et al., 1989). By reducing the densities of seedlings and saplings belonging to the dominant overstorey tree species, and decreasing the mass of live and dead vegetation components on riverbanks, livestock will affect the quantities of allochthonous detritus entering the Murrumbidgee River and its tributaries. Because livestock concentrate their activities in riparian zones (Robertson, 1997), the densities of their faecal material are often greatest in these ecotones (authors’ personal observations). They will, therefore, also affect the quality of organic matter entering riverine food chains.

Riparian vegetation acts as a physical and biological buffer to non-point sources of particulate and dissolved nutrients. Grassy riparian zones may trap more than 50% of sediments from adjacent agricultural areas (e.g. MacKenzie and Hairsine, 1996; Karssies and Prosser, 1999), and plants can take up significant quantities of nutrients in transport (Peterjohn and Correll, 1984; Wassens, 1999). Variations in plant biomass can indirectly affect microbial communities in soils by altering microclimates and organic matter loads, thus further affecting nutrient transformations (Naiman and Decamps, 1997). The significant impacts that livestock have on groundcover biomass and detrital mass in the riparian zone of the Murrumbidgee River will clearly have negative impacts on its nutrient filtering function. The degree to which livestock expose bare soil on the banks of the river and its tributaries will also increase sediment input to the river during periods of high flow.

Most riparian zones are covered by a variety of herbaceous and woody materials, which, together with the ready access to water, make these ecotones important habitats for terrestrial and aquatic fauna (Naiman and Decamps, 1997). Our data show that at high stocking rates, livestock may ultimately control the density of overstorey trees through their impact on seedlings and saplings. Livestock also control groundcover biomass, as well as influencing the quantities of woody debris on riverbanks and in the river channel. The reduction in the quality and quantity of riparian habitat by livestock has influenced the composition of amphibian (Healey et al., 1997), littoral invertebrate (Nye, 1997) and woodland bird (A. Jansen, personal communication) communities in the region.

Finally, relatively small geomorphic features in the lower riparian zone in dryland rivers, such as concave benches, are sites of accumulation and transformation of organic matter, and can promote invertebrate colonization and productivity (Thoms and Sheldon, 1997). Our data show that trampling
Livestock and the riparian zone

and grazing by livestock results in significant increases in the percentage of bare ground, and livestock trampling destroys the micro- and meso-structure of soils in riparian zones (Robertson, 1997). Such severe disturbance by the hooves of livestock is likely to have a major direct impact on small geomorphic features, and, thus, on ecological and erosional processes in the riparian zone.

River restoration

Severe alterations to the flow regimes of dryland rivers in southeastern Australia have had disastrous effects on the biota and ecological processes in these rivers, and their associated riparian and floodplain habitats (Walker, 1985; Robertson et al., 1996). Not surprisingly, efforts at river restoration have focused on establishing more natural flow connections between river channels, riverbanks and floodplain wetlands (EPA, 1997). However, southeastern Australia has been the focus of agricultural activities since just after European colonization, and represents some of the most altered of Australian rural landscapes. Vegetation clearance was severe in most catchments in the period of 1830–1930, fire regimes were altered dramatically following the cessation in burning activities by Aboriginal people in the mid-19th century, and rabbit plagues had a major impact on the regeneration of riparian vegetation (Chesterfield, 1986). One major source of landscape change that has increased in intensity since European settlement, and continues today, is grazing by domestic livestock. At present, there are 67 million sheep and 7 million cattle in the Murray–Darling Basin (Crabb, 1997). Their activities are often concentrated around riverbanks and wetlands, which are still used as major watering and resting sites, particularly during droughts and dry periods of the year (Robertson, 1998).

Our data indicate that livestock have a major impact on the structure and function of the riparian landscape of the mid-Murrumbidgee River. As we have argued elsewhere with regard to floodplain wetlands (Robertson, 1997), it is possible that, owing to the high stocking rates employed in the region, the impacts of livestock may override any beneficial impact of ‘environmental flow’ allocations in the river.

The effects of livestock on riparian ecotones depend on stocking rate, stock management practices, stock behaviour, access to alternative water and shade, and climate (Elmore, 1992; Robertson, 1998). Variation in these factors will determine the degree to which our findings relate to other regions of the Murray–Darling Basin.

While fenced off plots have enabled us to determine the impacts of livestock on the riparian zone, it is clear that fencing the entire riparian zone is not possible, nor socially realistic. Increases in the percent cover of exotic plant species, such as blackberries in livestock exclusion plots, are clearly not valued by farmers or by those interested in conserving native flora. However, exotic plants can contribute to the habitat and nutritional and filtering functions of riparian zones (e.g. Wassens, 1999). To determine the degree to which exotic taxa play a role in river restoration projects will clearly be as much a social as a scientific challenge (Robertson and Roshier, 1999). Rehabilitation of riparian areas is possible without fencing, using prescribed grazing practices which have been devised for particular situations (Elmore, 1992). We are currently investigating such grazing practices for the riparian zone of the Murrumbidgee catchment.

Acknowledgements

We thank Michael Healey and Nigel Anthony for help with field sampling and data processing, Phil Eberbach for statistical advice, and Rod Rumbuchs and Michael Healey for help with the preparation of figures. Special thanks go to the landowners on whose properties we worked. Two referees made valuable comments on the paper. The work was supported by ARC Collaborative Grant C29700044 to A. Robertson.


Robinson R. 1997. Dynamics of coarse woody debris in floodplain forests: impact of forest management and flood frequency, BAppSc (Hons) Thesis, Charles Sturt University, Wagga Wagga, NSW.


