The Effect of Changing Irrigation Strategies on Biodiversity

Final Report to the National Program for Sustainable Irrigation – November 2011.

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Introduction

The irrigation industry is facing substantial change that is likely to affect the quantity and timing of water supply, as well as the infrastructure involved in water delivery and use. Effective adaptation to this change while ensuring environmental sustainability requires knowledge of the effects of irrigation practices and landscapes upon local and regional biodiversity, and the potential implications of predicted policy, supplier and farm changes. Here we report on a three year project conducted by CSIRO in collaboration with the Ricegrowers Association who have been conducting an Environmental Champions Program since 2005. This program aims to assist landholders to improve environmental and economic returns of their farm businesses and also allows them to be recognised for their past, current and future environmental stewardship at an industry level.

Irrigated agriculture in Australia's Riverina consists of a variety of industries - rice, cereal, pulse and oilseed production, as well as livestock. Rice is the dominant crop, and is reliant on irrigation water supply from the Murray and Murrumbidgee Rivers, supplemented in some cases by underground water. Riverina irrigators are currently experiencing unprecedented restrictions on production due to water shortages. The current drought, together with the ramifications of the NSW environmental flow legislation of 1997, has resulted in irrigators receiving only a fraction of their water allocations. The Riverina's irrigation industries have significantly improved water use efficiency over the past 20 years through research and improved irrigation layouts. Given recent climate change projections, and increasing pressure on water supplies, the need for even more efficient use of irrigation water in the future is certain. Options for reducing water use are being implemented or canvassed at both the enterprise and supply scales. Examples include changes in the cropping mix at an enterprise level, reduction or cessation of flooding of rice crops, fewer crops and more efficient water use. At the regional scale, changes to the nature of supply channels are possible, while the application of more efficient techniques may result in less drainage being received in regional wetlands.

Water is as significant a resource for native plants and animals as it is for people. Before irrigation development the Riverina was semi-arid plain, with a range of shrubland, grassland, woodland, forest and wetland vegetation. With the advent of the Snowy River Scheme, and the resulting establishment of the Murrumbidgee, Coleambally and Murray Irrigation Areas, new landscapes have been created incorporating irrigation infrastructure, intensive farming in the form of broad-acre crops and horticulture, and significantly, a large change in the temporal availability of water. The removal of native vegetation has adversely impacted some of the original ecosystems, but it has also created opportunities locally for wetland species and regionally for some wetland birds. In addition, some terrestrial biota may well benefit from the extra resources associated with irrigation waters, despite some losses of habitat vegetation (e.g. some species of birds). Interest in biodiversity was not part of the original irrigation development agenda, and overall impacts are not well understood.

In recent times there has been more of a focus on protecting and enhancing remaining biodiversity through Landcare, Land and Water Management Plans and industry initiatives such as the Rice Industry's Biodiversity Strategy and Plan. However the concern now is that future changes in farming and water management practices do not further compound any impacts that have already occurred.

The overall aim of this project was to assess the possible impacts of changed irrigation practices on native biodiversity at local and regional scales, using the irrigation districts of the New South Wales Riverina as a case study.

More specifically, the objectives were to:

a) Identify likely changes to irrigation practices and patterns of water use through consultation with practitioners and stakeholders;

b) Review the available information (including published literature) on the biodiversity of the natural and managed ecosystems of the Riverina;

c) Predict the local and regional implications of changed irrigation practices for biodiversity persistence by integrating and synthesising the results from a) and b);

d) Collect, collate and analyse new and existing information on biodiversity responses to irrigation practices;

e) Predict the local and regional implications of changed irrigation practices for biodiversity persistence based on c and d;

f) Identify strategies which may help ameliorate any negative impacts for biodiversity that may occur.

Likely changes to irrigation practices and their potential effects on biodiversity

Likely changes to irrigation practices and their potential effects on biodiversity were discussed in detail in the publication: McIntyre, S., McGinness, H. M., Gaydon, D. & Arthur, A. D. (2011) Introducing irrigation efficiencies: prospects for water-dependent biodiversity in a rice agro-ecosystem. *Environmental Conservation*, 38, 353-365. That publication is appended (Appendix 1) and the main results are summarised here. References are contained in the publication.

Future changes in irrigation practices will be driven by reduced availability of water. This will lead to the development of water conservation strategies and fewer areas under irrigated, broad acre crops. Projected changes include:

1. A general reduction in the total volume of water available in rivers. Climate change is expected to result in reductions in Murray-Darling stream-flows of 16-25 % by 2050 and 16-48 % by 2100.
2. Changes in water regimes for some natural habitats, associated with changes in management of drainage and surplus irrigation water.
3. Reductions in the frequency and area under irrigated agriculture, including reductions in flood irrigation of paddy rice.

4. The adoption of farming methods that reduce water use, including increased adoption of efficient lateral move, centre pivot and drip irrigation practices on lighter soils, and reductions and increased efficiency in the use of flood irrigation techniques.
5. Changes in the methods of delivering water to reduce leakage and evaporative losses.
6. Possible increases in herbicide use, because ponded water has been the primary method for controlling weeds in rice crops in the past.
7. Likely changes to farm layouts to increase the potential for on-farm storage of water.

Overall these changes will result in a reduction in the amount of water in irrigated landscapes available in most constructed wetland habitats, which we define as irrigation channels, impoundments and flooded crop-growing areas such as flooded rice bays. These habitats have provided significant resources to some wetland plants and animals, such as various species of frog, a tortoise and waterbird species and hence these reductions may have some negative consequences for these species locally. However, these species tend to be common, generalist and tolerant of human disturbance and they also occur in natural wetland habitats. Hence, it is likely that changes to irrigation practices will not have large regional effects on these species.

A more significant issue in the irrigated landscapes is likely to be how future changes to irrigation practices will affect the remaining native vegetation, particularly woodlands, because many of the terrestrial fauna species in these regions are associated with this vegetation. Hence, we suggest that the landscape should be managed to provide the best conditions for biodiversity in these remnant woodlands. Some of the changes that could impact on this vegetation and responses to them include:

1. The deliberate clearing of mature trees in paddocks to allow increased use of lateral move and centre pivot irrigation. Isolated mature trees can provide significant and potentially irreplaceable benefits to wildlife in the landscape, including food, shelter and connectivity, and their removal should be minimised.
2. Changes in the patterns of surface flooding away from natural regimes for a particular vegetation community. In the past some of these communities received more water than normal, but in the future they are likely to receive less water unless management specifically targets watering. Identifying opportunities to integrate on-farm watering of remnants with irrigation practices would be useful.
3. Increased herbicide use in crops due to reduced flood irrigation controlling weeds, leading to impacts on surrounding native vegetation if not managed carefully.

In addition to these management considerations driven by changes to irrigation practices, we also suggest that conservation strategies at the landscape and patch scale in irrigated regions should be the same as those recommended for other intensively managed landscapes, namely to improve natural vegetation condition and where possible increase its total area and connectivity.

Biodiversity patterns in irrigated regions of the Australian Riverina and links to water availability

In the field component of our study we focussed on how black box communities function in irrigated landscapes based on our understanding that:

1. Black box communities comprise a large percentage of the remaining remnant vegetation in Riverina irrigated landscapes.
2. Black box woodlands are generally the major remnant vegetation type on irrigated farms in the Riverina.
3. These woodlands have a natural surface flooding regime of once every three – ten years and hence would be impacted by changes to surface flooding.
4. Much of the native terrestrial faunal biodiversity in irrigated regions is associated with remnant native vegetation.

We were particularly interested in how the vegetation and fauna were responding to water availability in the landscape. To address this we collected data from 33 sites of at least 10 hectares in area, 17 from the Murrumbidgee Irrigation area (hereafter referred to as the Midbidgee) and 16 from the Lower Murrumbidgee Floodplain (referred to as the Lowbidgee in this report). Data from the latter were collected from a separate CSIRO internally funded project, but results are presented here because they aid interpretation of the Midbidgee results. Sites of at least 10 hectares were chosen to reduce negative effects of small patch size on the likely presence of fauna. Sites were also chosen so that they had some of the key attributes known to be important for fauna species, e.g. hollows for hollow nesting species. We focussed on woodland birds, because they are relatively numerous, diverse, easily surveyed and responsive to change, and because prior surveys by other research groups indicated that threatened and declining woodland bird species occurred in the region. In contrast, preliminary surveys indicated extremely low abundance of small native mammals across the Midbidgee.

Our sites in the Midbidgee were chosen to span three levels of irrigation intensity, which we defined as high, medium and low. These classes were based on the area and frequency of irrigation surrounding the site, the density of irrigation channels and other agricultural and urban landuses, and the relative isolation of each site from other woodlands. Our sites in the Lowbidgee were all classed as very low irrigation intensity. Our sites were also selected to sample a range of surface water histories. Using information provided by landholders, we described the sites in terms of prior wetting frequency (approximate return period of significant surface wetting over 30 years); time since the site was last wetted; and time since the adjacent land area was last wetted (Table 1). While the veracity of the water management histories undoubtedly varied between landholders, this was the most accurate information available to us at the time.

Vegetation patterns and responses

A detailed description of the vegetation patterns and responses observed in the study are provided in an appended draft publication to be submitted to *Ecohydrology* (Appendix 2). The main results are summarised here.

Shrub and ground layer

Large shrubs including lignum *Muehlenbeckia florulenta* and nitre goosefoot *Chenopodium nitrariaceum*, were at much higher densities in the Lowbidgee sites compared with the Midbidgee sites (Figure 1a). Barley grass (*Hordeum spp.*), which can be an indicator of high grazing pressure and higher soil salinity followed the opposite pattern, being much more common in the Midbidgee sites compared with the Lowbidgee sites (Figure 1b). *Sclerolaena spp* (usually the native *Sclerolaena muricata* ‘black roly poly’), which is also indicative of higher grazing pressure and is intolerant of frequent inundation, was more common in sites in the low and medium irrigation areas (Figure 2a). In the Lowbidgee it was absent from the sites with a more frequent wetting frequency and most common in the driest sites (Figure 2b). Together these results probably reflect (1) landuse differences between the regions, with past clearing practices and more intensive grazing in the Midbidgee resulting in fewer large shrubs and higher prevalence of plant species that indicate high grazing pressure; and (2) a reduction in significant and frequent surface flooding in the sites in the Midbidgee and on parts of the Lowbidgee floodplain.

Shrubs are particularly important structural components of woodlands for fauna, providing nesting and foraging habitat, protection from predators, and increasing the number of niches available within a given area. It is widely recognized that woodlands with multiple vegetation layers including shrubs support greater fauna diversity and abundance than woodlands without such layers. For example, complex vegetation structure is usually associated with greater bird species richness, diversity and abundance (Watson *et al.* 2001; Seddon *et al.* 2003; Briggs *et al.* 2007). Sympathetic grazing management of black box remnants known to have supported shrubs in the past, or that host shrubs in the present, could produce significant benefits for biodiversity. Such management would be enhanced by judicious use of environmental water to encourage shrub growth and reproduction – especially for lignum.

Table 1. Summary of irrigation landuse intensity and site inundation characteristics of the 33 sites sampled across the two regions.

Region	**Surrounding irrigation landuse intensity**	**Site**	**Prior wetting frequency**	**Time since wet within (years)**	**Time since wet adjacent (years)**
Midbidgee	High	4	1 in 10 years	>20	2-10
		3	1 in 5 years	10-20	2-10
		11	1 in 5 years	10-20	2-10
		2	Yearly or alternate	10-20	2-10
		12	Yearly or alternate	10-20	2-10
		1	Yearly or alternate	10-20	2-10
	Medium	6	1 in 5 years	>20	>20
		7	1 in 5 years	2-10	2-10
		10	1 in 5 years	2-10	2-10
		8	Yearly or alternate	0-2	2-10
		9	Yearly or alternate	0-2	2-10
		5	Yearly or alternate	10-20	2-10
	Low	15	1 in 10 years	2-10	2-10
		13	1 in 10 years	2-10	0-2
		16	1 in 5 years	0-2	2-10
		17	1 in 5 years	0-2	0-2
		14	Yearly or alternate	0-2	0-2
Lowbidgee	Very low	33	< 1 in 10 years	>20	0-2
		32	< 1 in 10 years	0-2	0-2
		29	1 in 10 years	10-20	2-10
		22	1 in 10 years	2-10	0-2
		24	1 in 10 years	2-10	0-2
		23	1 in 10 years	2-10	0-2
		28	1 in 10 years	2-10	0-2
		26	1 in 5 years	>20	2-10
		21	1 in 5 years	10-20	10-20
		20	1 in 5 years	10-20	10-20
		19	1 in 5 years	10-20	0-2
		25	1 in 5 years	2-10	0-2
		34	Yearly or alternate	0-2	0-2
		18	Yearly or alternate	0-2	0-2
		31	Yearly or alternate	2-10	0-2
		27	Yearly or alternate	2-10	2-10

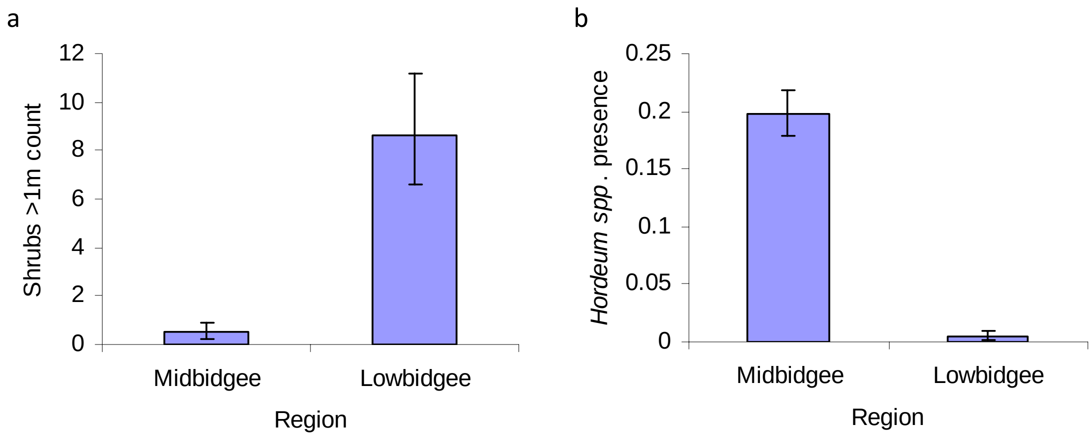

Figure 1 (a) Number of shrubs >1 m tall per photo. (b) Proportion of ground photos with *Hordeum spp.* present (see Appendix 2 for methods, McGinness et al.). Error bars show ± standard error.

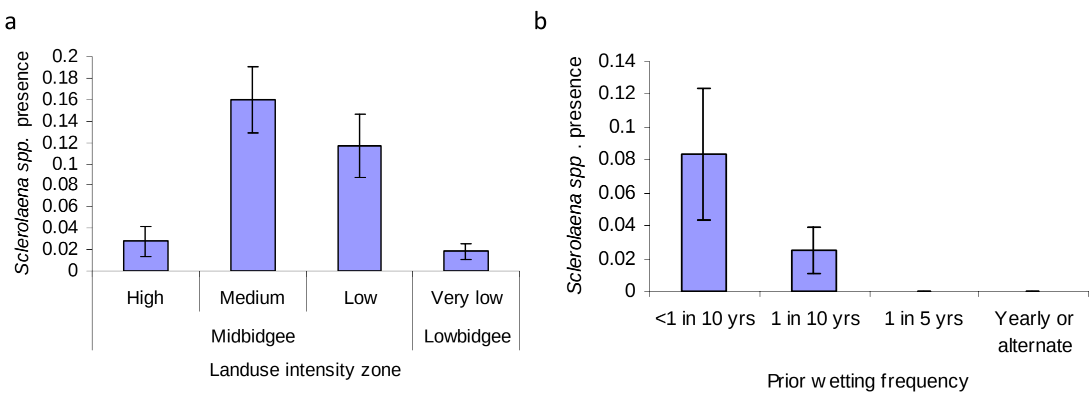

Figure 2 (a) Proportion of ground photos with *Sclerolaena spp*. present (see Appendix 2) in (a) Landuse intensity zones, and (b) Prior wetting frequency categories in the Lowbidgee. Error bars show ± standard error.

Black box tree health

Black box trees in the Lowbidgee region were in significantly worse health than trees in the Midbidgee, with more tree crown death and lower leaf density present in the remaining live branches. There were also more dead trees in the Lowbidgee region than in the Midbidgee (Figure 3). In the Lowbidgee, trees in sites with the most frequent prior wetting frequency (yearly or alternate) had similar crown death and crown density values to those in the Midbidgee, with significantly worse crown death and crown density scores in sites with less frequent prior wetting (Figure 4).

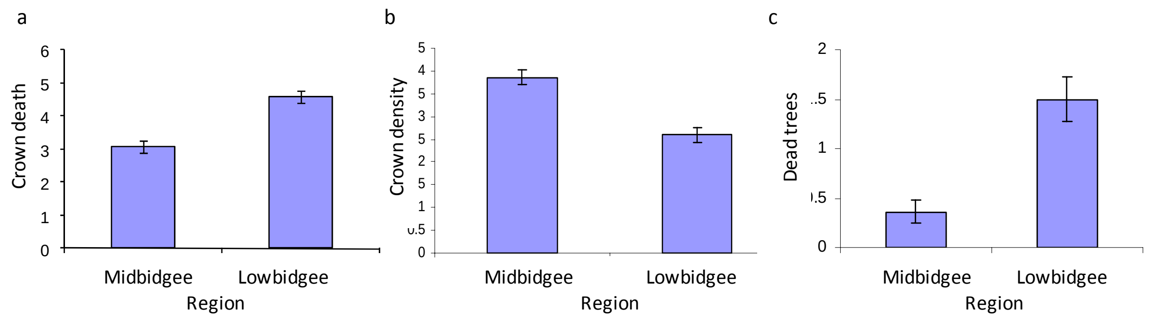

Figure 3. Regional differences in sites for (a) Crown death score (higher is more crown death), (b) Crown density score where leaves were present, and (c) the number of dead trees per photo (see Appendix 2 for methods,). Error bars show ± standard error.

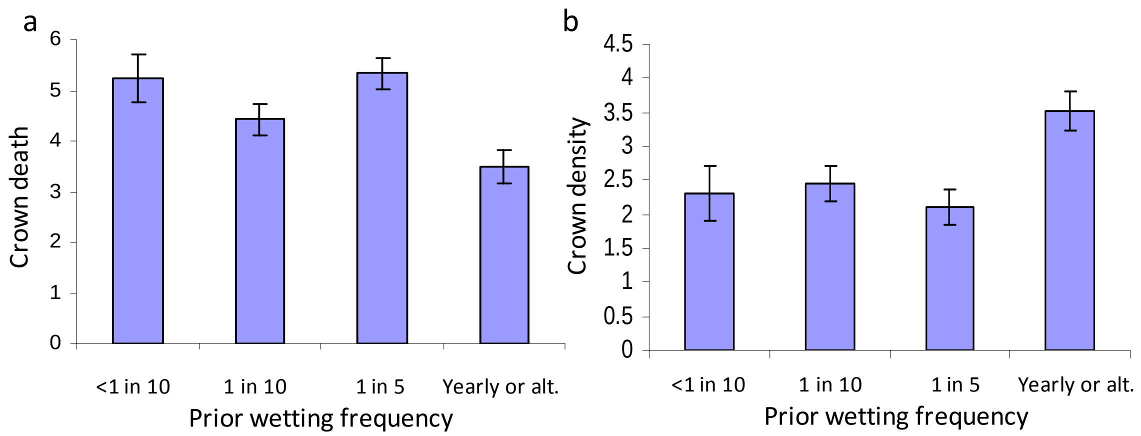

Figure 4. Differences in the amount of (a) crown death (higher is more crown death), and (b) crown density where leaves were present, in Lowbidgee sites based on the prior wetting frequency category. Error bars show ± standard error.

Although the Lowbidgee has lower mean and median annual rainfall than the Midbidgee over the long term (86 and 75 mm lower respectively), during the millennium drought (2000-2009) rainfall was similar between the two regions; with the Midbidgee suffering approximately 100 mm p.a. rainfall deficits and the Lowbidgee relatively smaller reductions (mean 24 mm and median 53mm). During this period trees in the Midbidgee were probably buffered against the drought by continued access to elevated water tables, and in some areas relieved of significant stress by lowering of excessively high water tables. Before the introduction of irrigated rice farming, the watertable in most of the Midbidgee was about 20 m below the surface. In 2001 the watertable for around 85 percent of the mid-Murrumbidgee irrigation area was within two metres of the surface, and some areas were experiencing waterlogged soils (Singh *et al.* 2005). These problems increased every winter and whenever rainfall was higher than usual. However the 10-year drought through the 2000's reduced watertables by 1-3 metres (CSIRO 2008) – keeping groundwater well within the reach of black box trees through the drought, but reducing the problems associated with waterlogging and salinity. Simulations suggest that the growth response of black box to a long term lowering of watertable depth by 1 m will be greater than that induced by small increases in flooding frequency (Slavich *et al.* 1999), so it may be expected that such changes in the Midbidgee would improve tree condition more and across a broader scale than increases in flooding frequency. In addition, unseasonal high river flows in summer may have increased the buffering effect by recharging local Midbidgee aquifers during the summer months, the period of highest evapotranspiration.

In contrast, recovery of aquifers in the Lowbidgee has been impaired by increased groundwater extraction and river regulation over the same drought period. Most groundwater bores have not been metered or licensed, and water tables in the Lowbidgee have dropped significantly since 1980, reducing access to groundwater for trees. The last major flood to reach Lowbidgee black box communities was in 1989, and only a few areas received supplementary managed water prior to 2009. This lack of surface flooding would also have reduced replenishment of shallow groundwater in the Lowbidgee, exacerbating the situation (CSIRO 2008). The effects of irrigation water delivery upon river seasonality and groundwater recharge are also much reduced in the Lowbidgee compared to the Midbidgee. Consequently the condition of black box communities in the Lowbidgee has been adversely affected to a greater degree by the recent drought than that seen in the Midbidgee, as the Lowbidgee has had no equivalent buffers.

In the absence of readily accessible groundwater, flooding for vegetation condition becomes more important, hence the clear vegetation responses to wetting in the Lowbidgee, but few relationships in the Midbidgee. In particular, the significantly greater responses recorded for Lowbidgee sites receiving regular wetting (yearly or alternate years) indicate that in the absence of sufficient rainfall and groundwater, more frequent flooding is required to maintain black box in good condition (less crown death and greater crown density) than would normally be required. For example, modelling of 80 sites at Chowilla on the lower Murray River floodplain showed that black box tree health was significantly greater where flooding occurred more frequently than 1 in 10 years (Taylor *et al.* 1996). Flood frequency is even more important in areas where salinity is a problem, because flooding flushes salts away from the root zone, reducing salt stress in trees. Infiltration of floodwater around black box can be 2-17 times faster than on adjacent bare ground (Akeroyd *et al.* 1998; Bramley *et al.* 2003). In the lower River Murray floodplain, low-salinity soil water overlying highly saline groundwater is the water source used by Black box at most sites (Jolly and Walker 1996; Holland *et al.* 2006). Recharge of this low-salinity deep soil water via floodwaters and vertical infiltration of rainfall is important for trees growing in depressions and on extended floodplains (Jolly and Walker 1996; Akeroyd *et al.* 1998; Holland *et al.* 2006).

Another factor that may have contributed to better tree health in the Midbidgee compared to the Lowbidgee is greater flood duration and depth when using drainage or excess water. Surface watering of black box woodland remnants in the Midbidgee is now almost entirely under management control, and natural flooding is rare. Black box remnants in this region were historically often used to collect irrigation runoff or as storages for unwanted water. In some cases inundation was brief and shallow, rapidly providing stock feed through groundcover response to flooding. In other cases, inundation was deeper and of longer duration. In contrast, flooding of Lowbidgee black box woodlands has generally been shallow and of relatively short duration, except for woodlands lining distinct creeks used for water transferral and some small 'managed' sites. Greater inundation depth and duration in the Midbidgee will have raised the elevation and reduced the salinity of shallow groundwater, benefiting vegetation up to thresholds of tolerance, over which it will have reduced tree health or killed trees and affected species presence in the groundlayer and shrublayer (and hence affected woodland structure).

Tree flowering also appeared to respond to surface wetting in the Lowbidgee, with a higher frequency of flowering adult trees in sites with more recent flooding (Figure 5). In the Midbidgee tree flowering was not associated with surface flooding, consistent with the results for tree condition. The presence of significantly greater numbers of flowering trees in sites wet within the previous two years in the Lowbidgee indicates the importance of flooding for maximising reproduction, particularly where trees do not have access to groundwater. Flowering of black box is known to occur in response to flooding or rainfall

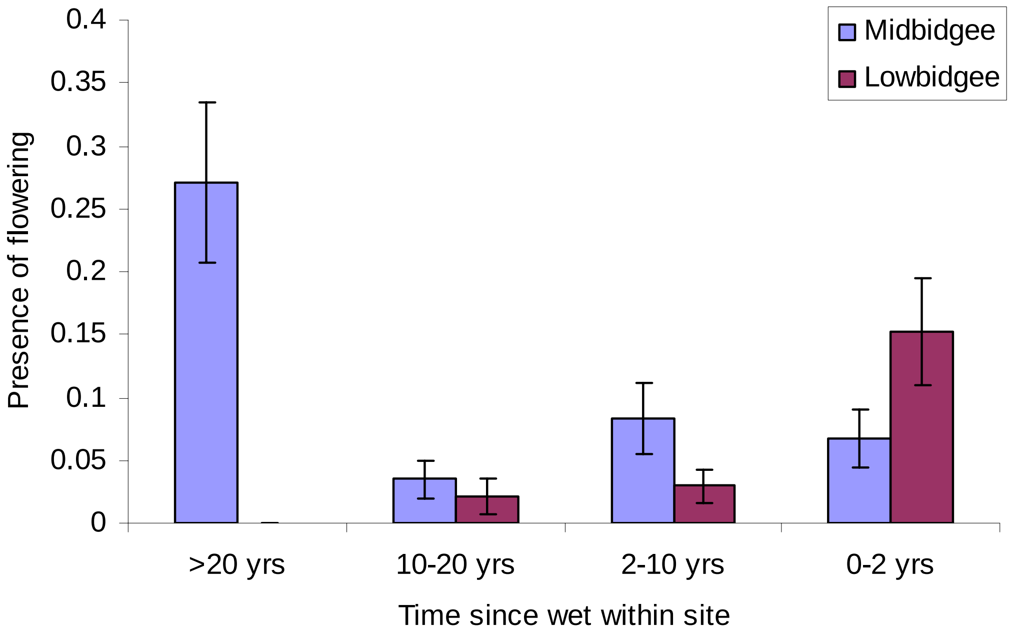

Figure 5. The proportion of photos with flowering trees based on the time a site was last wet (see Appendix 2 for methods). Error bars show ± standard error.

regardless of the time of year, with the quantity of buds, flowers and seed produced and retained determined by both the condition of the parent trees and water availability in the previous year (Jensen *et al.* 2008). Seedfall coincides with the natural flood season, presumably to aid dispersal, and seedlings rely on local rainfall and flooding for survival (Jensen *et al.* 2008). Because trees in the Lowbidgee are in generally worse condition overall, they are likely to produce less flowers, buds and seed than trees in the Midbidgee. This together with insufficient rainfall and surface flooding during the summer months is probably a major restriction on black box recruitment and persistence in the Lowbidgee. Also, while groundwater may allow trees to flower in the Midbidgee, an absence of surface flooding may stop seedlings from recruiting to adult stages. Certainly we found low proportions of young trees in parts of the Lowbidgee and the Midbidgee (Figure 6), and it is possible that some sites currently lack sufficient regeneration to compensate for adult mortality, as has been found for black box sites in Murray River floodplains downstream (George *et al.* 2005). If this is the case then Black box is unlikely to persist in the long term without intervention at these sites.

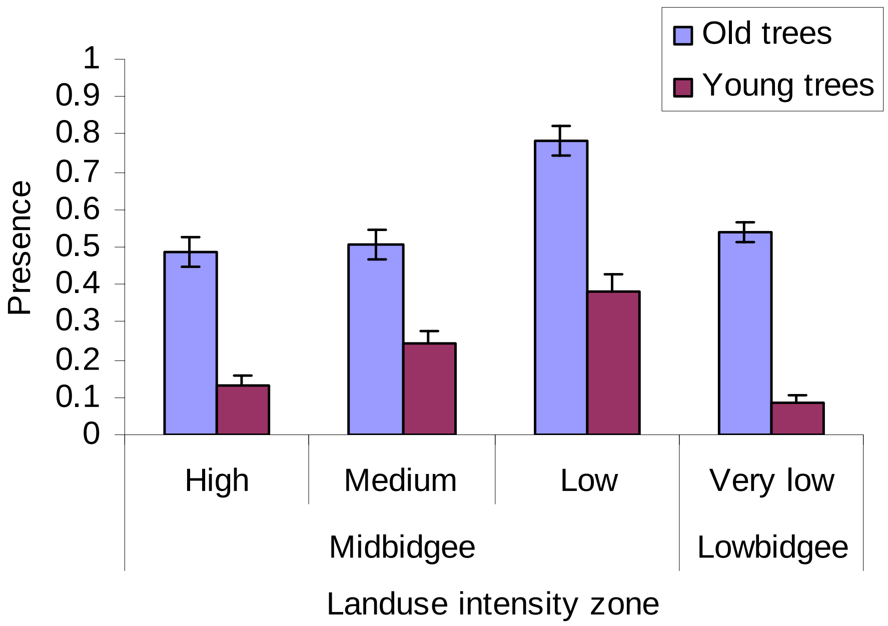

Figure 6. The proportion of photos with old or young trees based on the surrounding irrigation intensity (see Appendix 2 for methods). Error bars show ± standard error.

Overall, it is to be expected that floodplain woodlands with flood histories closer to 'natural' or pre-development regimes will be in better condition and will have greater structural complexity than other floodplain woodlands. Our study has confirmed this, however it has also demonstrated that for black box woodlands this depends on the availability of groundwater, and is more the case for tree condition than for structure. Where groundwater is abundant, of good quality, and easily accessed, flooding frequency is less important for trees. Where groundwater is less available, thresholds exist in flood frequency within black box communities that affect both tree and understorey structure and condition. Specifically, flooding less than once every 10 years leads to decline, and regular flooding of approximately every one to two years may be necessary during drought where extraction of groundwater is leading to falling watertables. These results emphasise the importance of maintaining healthy black box remnants in irrigation areas for biodiversity persistence, and suggest that rehabilitation of black box communities using managed flooding could bring significant biodiversity benefits.

Woodland bird patterns and responses

A detailed description of the woodland bird patterns and responses observed in the study will appear in a scientific paper which is still in early draft stage. Here we provide the main methods and results from the study.

We were particularly interested in how the abundance and breeding activity of selected woodland bird species was influenced by the productivity of our sites. Our underlying hypotheses were that sites with a less frequent wetting history would (1) have lower densities of our selected woodland birds; and (2) have lower rates of breeding. In our analyses we considered this based on the possible wetting histories we had established for our sites (Table 1), and the landuse context (surrounding irrigation intensity and region). We also considered a range of habitat variables which are known from other studies to influence the distribution and abundance of woodland birds, but we point out our study was not designed with the aim of conducting a comprehensive analysis looking at all the possible drivers of woodland bird abundance and diversity. Many more sites would have been required than were possible in our study.

Thirteen selected woodland bird species were considered: Australian magpie, brown treecreeper, apostlebird, white-winged chough, striated pardalote, willy wagtail, noisy miner, yellow throated miner, rufous whistler, grey butcherbird, pied butcherbird, grey-crowned babbler and magpie lark. We chose these as being insectivorous birds that with the exception of the rufous whistler are generally resident species. They are therefore considered to have strong reliance on the condition of the sites, and their surrounds, and hence should be reliable indicators of factors driving local population dynamics. The species range from common species to some that are considered threatened or declining in New South Wales (Table 2). Previous surveys by other researchers in the Midbidgee (Rick Webster, unpublished) indicated that these species comprised the most common resident species in the region and this was concordant with our results. We also counted starlings (*Sturnus vulgaris*), which are an introduced pest species that could compete with native woodland species.

Birds were counted on transects of approximately 2km per site in early and late spring 2009. During these surveys we also recorded breeding behaviour, which included: mating; the number of nestling, fledgling and immature birds; feeding of young; nest building and adults present at a nest. Data were analysed using generalised linear models, taking into account effects of observer and time of day where necessary.

Table 2. Woodland bird species selected for observation in the study, their conservation status and ecological characteristics

Species	Matrix/ Patch[1]	Status [2]	Habit[3]	Diet	Feeding habitat[4]
Grey-crowned babbler *Pomatostomus temporalis*	Patch	Vulnerable, declining	Sedentary, resident	Insectivorous; also seeds	Ground – leaf litter, Large Woody Debris (LWD), bark
Brown treecreeper *Climacteris picumnus*	Patch	Vulnerable, declining	Sedentary, resident	Insectivorous; also nectar, sap	Tree trunks, branches, bark, LWD
Striated pardalote *Pardalotus striatus*	Patch	Secure, stable	Sedentary, resident	Insectivorous	Foliage
White-winged Chough *Corcorax melanorhamphos*	Patch	Secure, increasing	Sedentary, resident	Insectivorous, also seeds	Ground – mostly leaf litter
Apostlebird *Struthidea cinerea*	Patch	Secure, stable	Sedentary, seasonally nomadic	Insectivorous + seeds, small vertebrates	Ground
Yellow-throated Miner *Manorina flavigula*	Patch	Secure, increasing	Sedentary, resident	Insects, nectar, berries, fruit	Foliage and ground
Noisy Miner *Manorina melancephala*	Patch	Secure, increasing	Sedentary, resident	Insects, nectar, berries, fruit, reptiles, frogs	Foliage and ground
Pied Butcherbird *Cracticus nigrogularis*	Matrix	Secure, increasing	Sedentary, resident	Insects, reptiles, frogs, mammals, birds	Ground
Grey butcherbird *Cracticus torquatus*	Patch?	Secure, stable	Sedentary, resident	Insects, reptiles, frogs, mammals, birds	Ground
Australian Magpie *Gymnorhina tibicen*	Matrix	Secure, increasing?	Sedentary, resident	Insectivorous	Ground
Willie Wagtail *Rhipidura leucophrys*	Matrix	Secure, increasing	Sedentary, resident, Winter flocks	Insectivorous	Aerial, ground
Magpie lark *Grallina cyanoleuca*	Matrix	Secure, increasing	Sedentary, resident breeders. Seasonally migratory young	Insectivorous	Ground
Rufous whistler *Pachycephala rufiventris*	Patch	Secure, declining	Seasonally migratory	Insectivorous, also seeds, fruits, leaves	Foliage

[1]Refers to the bird's use of habitat in an agricultural landscape. While most birds rely on trees, some are largely restricted to patches of woodland (patch). Others are able to use the open pasture and crop environment (matrix).
[2]Based on NSW threatened species legislation and analyses conducted by Reid which indicated whether species were showing population declines, were increasing or were stable.
[3]Sedentary, resident species tend to be associated with a particular local patch of habitat throughout their adult life.
[4]Describes which component of the local habitat a species derives the majority of its food from.
(Barker and Vestjens 1989a; Barker and Vestjens 1989b; Reid 1999; Reid 2000; Seddon *et al.* 2003; Antos and Bennett 2005; Antos and Bennett 2006; Briggs *et al.* 2007).

The total abundance of our selected species was best explained by regional differences between sites (LR test, χ^2_1=13.97, P<0.001; Figure 7a). We also show differences based on surrounding irrigation intensity (LR test, χ^2_3=16.24, P=0.001; Figure 7b). Sites in the Midbidgee had approximately double the densities of sites in the Lowbidgee, with a slight trend towards lower densities in the highest irrigation intensity zone relative to the low and medium irrigation intensity zones (Figure 7b). The relative difference in density between regions was also evident if we excluded the main social species (apostlebirds, white-winged choughs and the miners, LR test, χ^2_1=15.39, P<0.001), indicating the differences were not just due to large counts of these social species. The same pattern was evident if we excluded those species that are more likely to use the agricultural land surrounding woodland patches (i.e. exclude 'matrix' species, include 'patch' species, Table 2), with evidence for both regional (LR test, χ^2_1=8.12, P=0.004; Figure 8a) and surrounding irrigation intensity differences (LR test, χ^2_3=13.22, P=0.004; Figure 8b). In the latter case there was some evidence that the high intensity irrigation zone sites had much lower densities of patch species compared with sites in the low and medium intensity irrigation zones. There was some evidence that the sites in the Midbidgee had higher species richness of our selected species compared with the Lowbidgee (9 species vs. 7 species, LR test, χ^2_1=4.08, P=0.04). There were no consistent responses to surface wetting history across regions, nor to any of the other habitat factors considered.

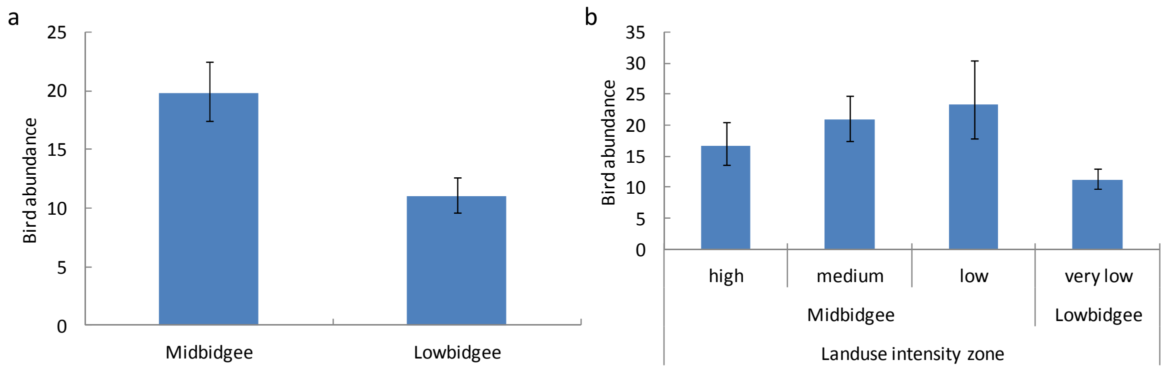

Figure 7. Abundance (number of birds per km of transect) of selected species at sites plotted against (a) Regions, and (b) surrounding irrigation intensity. Error bars show ± standard error.

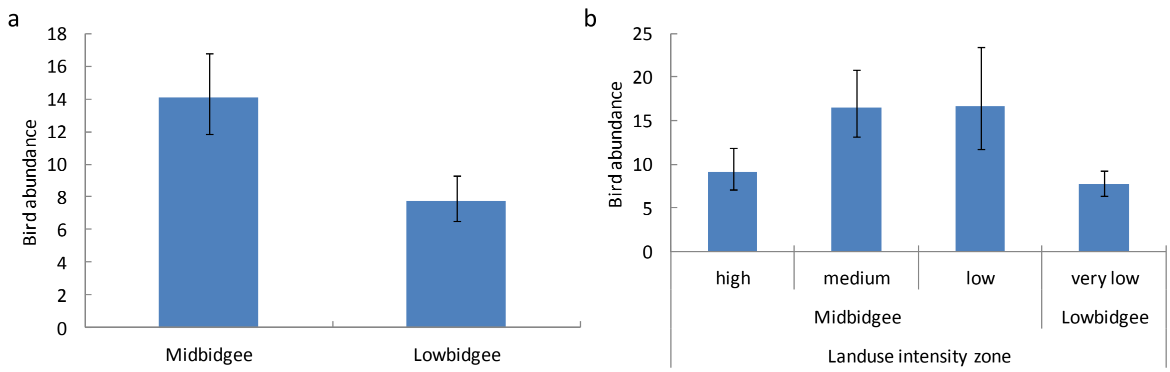

Figure 8. Relative abundance (number per km of transect) of patch specialist species at sites plotted against (a) Regions, and (b) surrounding irrigation intensity. Error bars show ± standard error.

It is important to emphasise that we did not chose a random selection of sites from the different irrigation intensity zones, with our sites specifically chosen to have certain attributes. For example, we chose sites > 10 ha in size and with hollow bearing trees. Hence, our results provide a comparison of sites that have these minimum attributes across the irrigation intensity zones. When we were looking for study sites, there were numerous sites in the Midbidgee where patch size was < 10 ha and habitat was much degraded.

Nonetheless, our results suggest differences between sites with these minimum characteristics, and they are interpretable if we consider the different amounts of food for largely insectivorous birds that are likely to have been available in these contrasting landscapes throughout the last decade. The Lowbidgee experienced limited flooding during this time, and it is likely this led to greatly reduced food resources for woodland birds and hence lower densities. In contrast, birds in black box remnants in the low and medium irrigation areas may have benefited from higher water availability in the surrounding irrigated landscape, leading to higher food availability, and hence higher survival and reproductive success, resulting in higher densities. Certainly black box tree condition seemed to reflect the higher water availability in the irrigated landscape and tree condition may be correlated with food availability.

In the high intensity irrigation area in the Midbidgee, lower bird densities compared with the medium and low irrigation intensity zones may reflect the greater isolation of these sites from other woodland patches compared with the less intensive irrigation areas, although isolation is expected to impact more on species composition rather than total abundance of a range of species. More intensive surrounding irrigation may also be correlated with some other impact on the suitability of these patches for birds. Certainly grazing intensity was particularly high in these patches and other studies have shown high grazing pressure to have a negative impact on woodland birds. Even though the overall densities of woodland birds (particularly patch species) was lower in the high intensity irrigation zone, compared with the low and medium intensity zones, most of the species we included in our study were found there, including the declining brown treecreepers and grey-crowned babblers. Only apostlebirds were not found in any of our sites in this zone. Together with our observations of higher bird densities in the low and medium irrigation intensity zones, our results suggest that these remnants are valuable for regional biodiversity and both trees and woodland birds can benefit from water in the surrounding irrigation landscape.

We found no strong relationships between bird densities and factors that in other studies have been shown to influence the diversity and abundance of woodland birds (e.g. shrub cover, woody debris), but as we indicated above we did not set out to do that in this study – a larger number of sites would be required. Nonetheless, we think it is likely that these habitat attributes would provide significant resources to woodland bird species in these landscapes and should be considered as important components of any black box remnant patch.

We did not find any strong relationships between woodland bird densities and patch scale water histories. This may reflect a dominance of the landscape-scale effect we observed, but it could also reflect the high level of uncertainly we have about the water histories at our sites. Even though a landscape level effect of water in irrigated landscapes appears to benefit woodland birds, it is possible that within the Midbidgee within-patch surface watering will provide additional benefits to resident birds. In addition, a range of other flora and fauna are likely to require within-patch watering to remain extant in these irrigated landscapes. As such, we suggest future studies should deliberately water black box remnants (Alexander *et al.* 2008), with detailed monitoring of whether and how local flora and fauna, including woodland birds, respond.

Breeding

Breeding records were rare in early spring 2009 indicating that birds had not commenced breeding in this dry season by early spring. In late spring 2009, there was some evidence that relative breeding success (proportion of bird observations with evidence of breeding) differed across irrigation intensity zones ($F_{3,29}$=4.89, P=0.003), with higher rates in the very low and high irrigation intensity zones (Figure 9). These patterns are the opposite of the relative abundance patterns and may reflect density-dependent effects on reproductive effort in the different landscapes. 2009 was a very dry year across all our sites, with limited irrigation allocations as well as low rainfall. If this led to low food availability in all sites, then per capita food availability in the breeding season may have been higher in the sites with lower densities of birds, leading to the observed result. Another possibility is that the age distribution of birds in the different zones could influence the results. Our surveys could not distinguish between reproductively mature and immature birds except for very young birds. If higher recruitment in the zones with higher densities results in a higher proportion of reproductively immature birds than in the zones with lower densities this could skew the apparent rate of breeding to what we observed. There were no differences in the relative abundance of species between zones combined with the relative breeding rate of different species that would explain the result. Regardless of what was driving the breeding rate in the month of our study, the more important observation is the greater densities of birds in the low and medium irrigation zones, which reflect the longer term patterns of survival and recruitment of birds.

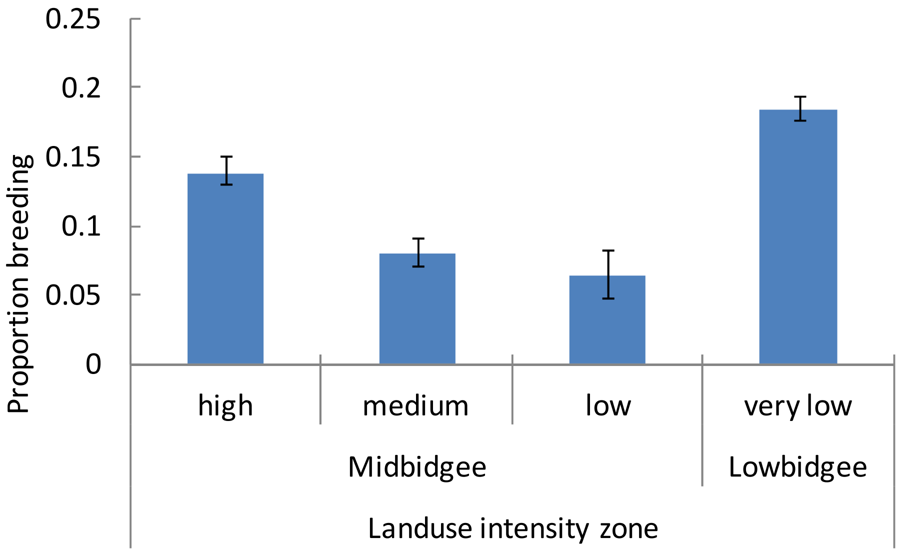

Figure 9. Proportion of bird observations with evidence of breeding in late spring 2009 in the different irrigation intensity zones. Error bars show ± standard error.

Responses of some individual species

Starlings

Starlings are an introduced species, which may benefit from modified landscapes. They nest in hollows and could have a negative impact on native species, either through competition for food or nesting sites, so we examined whether their abundance was related to any habitat or landscape attributes. Starling counts were highly variable because they were sometimes seen in large flocks. No starlings were seen in the Lowbidgee, and there was no statistical support that counts differed according to surrounding irrigation intensity in the Midbidgee (LR test, χ^2_2=1.41, P=0.49), but there was a trend towards higher counts with increasing irrigation intensity (Figure 10). It is possible that higher densities of starlings in the high intensity zone contributed to the lower densities of native woodland species in this zone (Figure 7 & Figure 8).

Noisy and yellow-throated miners

Other studies have shown that noisy and yellow throated miners can have a negative effect on other woodland bird species, so we examined whether their abundance varied with irrigation intensity. Noisy miners (which dominated our counts of miners) were common and widespread, being present in 29 of our 33 sites. There was no evidence that their abundance differed between regions (LR test, χ^2_1=1.46, P=0.23) or by surrounding irrigation intensity (LR test, χ^2_3=2.56, P=0.47; Figure 11), although there was a trend towards higher densities in the low and medium irrigation intensity zones. This trend was consistent with the overall pattern for woodland birds, suggesting that landscape level resources also benefit these species.

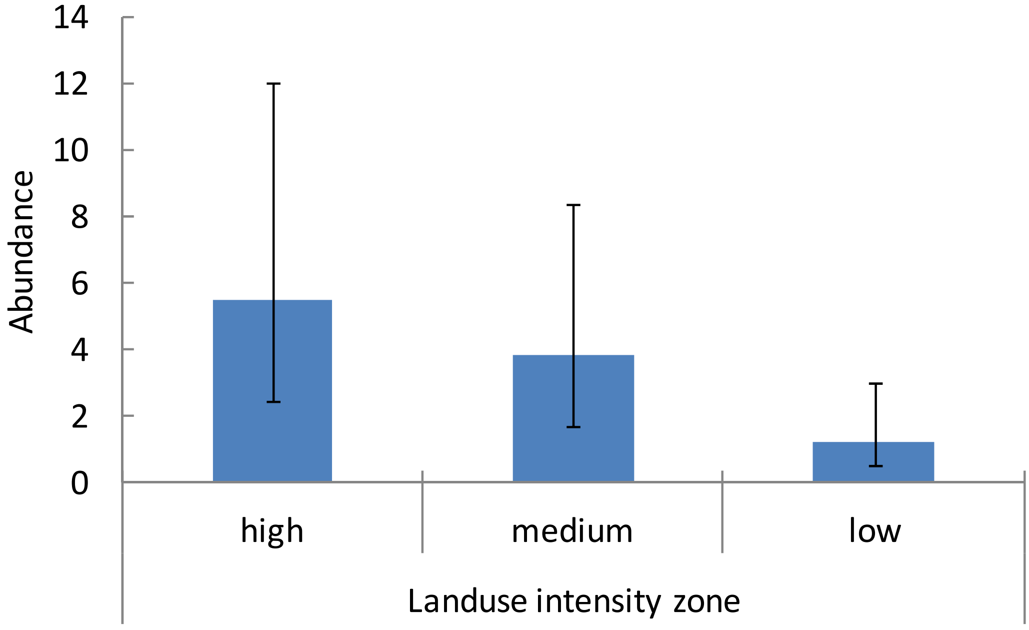

Figure 10. Abundance (number per km of transect) of starlings by irrigation intensity zone in the Midbidgee. No starlings were seen in the Lowbidgee. Differences were not statistically significant (LR test, χ^2_2=1.41, P=0.49). Error bars show ± standard error.

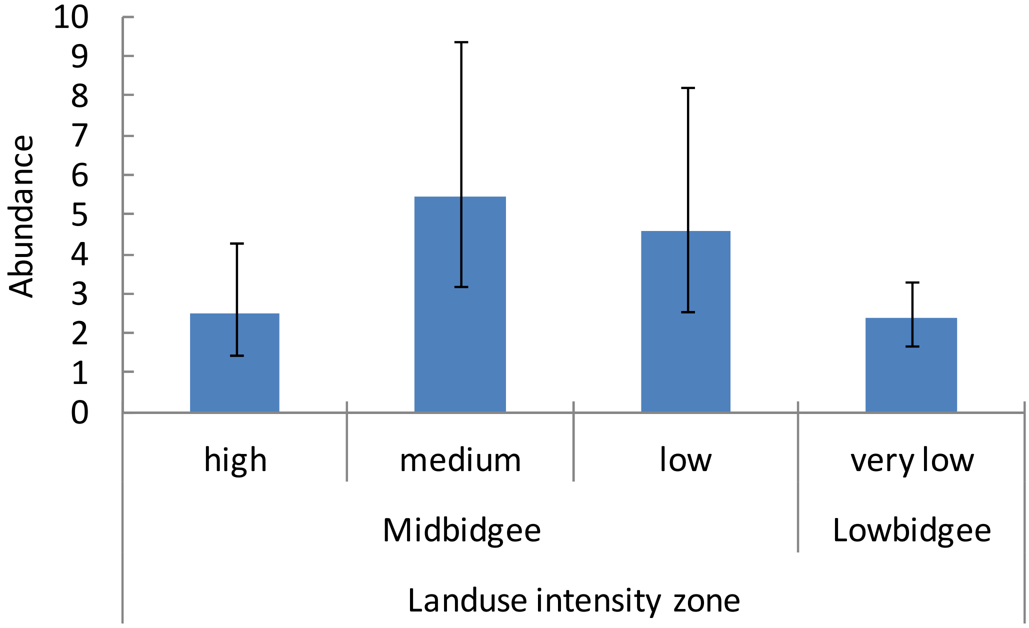

Figure 11. Abundance (number per km of transect) of noisy miners by irrigation intensity zone. Differences were not statistically significant (LR test, χ^2_3=2.56, *P*=0.47). Error bars show ± standard error.

Vulnerables – brown treecreepers and grey-crowned babblers

Brown treecreepers were only present in 8 of our 33 sites, but there was no evidence that their presence differed between regions (LR test, 1 df, *P*=0.92) or with surrounding irrigation intensity (LR test, 3 df, *P*=0.18; Figure 12). Grey-crowned babblers were present in 14 of our 33 sites, and similarly there was no statistical support that their presence differed between regions (LR test, 1 df, *P*=0.20) or with surrounding irrigation intensity (LR test, 1 df, *P*=0.38; Figure 12), although there was a trend towards higher presence in the low and medium surrounding irrigation intensity zones, consistent with the abundance patterns for woodland birds.

The abundance or presence of grey-crowned babblers was not affected by the abundance of miners, but there was evidence that either the abundance (LR test, χ^2_1=21.8, *P*<0.001) and/or presence (LR test, χ^2_1=21.9, *P*<0.001) of brown treecreepers was strongly negatively related to the abundance of miners at a site. Figure 13 shows the raw data on which this relationship was modelled. Brown treecreepers were not observed in any sites where miner abundance

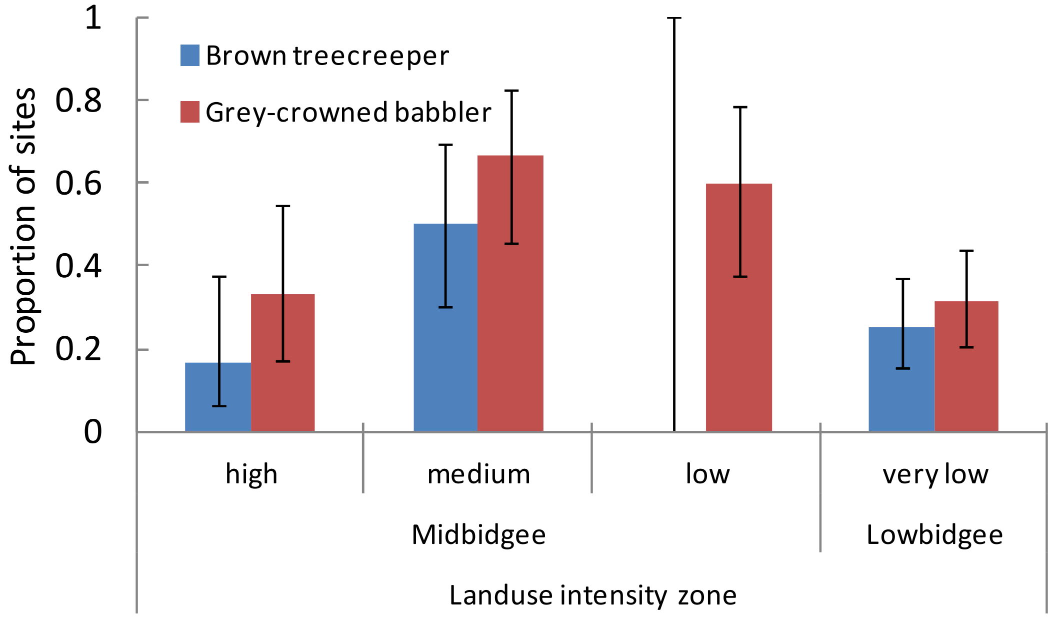

Figure 12. Proportion of sites with Brown treecreepers and Grey-crowned babblers by surrounding irrigation intensity. Differences were not statistically different. Error bars show ± standard error.

was above ~2.0 per km of transect, suggesting miners may be having a negative impact on brown treecreepers, consistent with results from other studies (Maron *et al.* 2011). This suggests that, as for those other landscapes, understanding what drives noisy miner populations would contribute to developing management actions for conserving other native bird species.

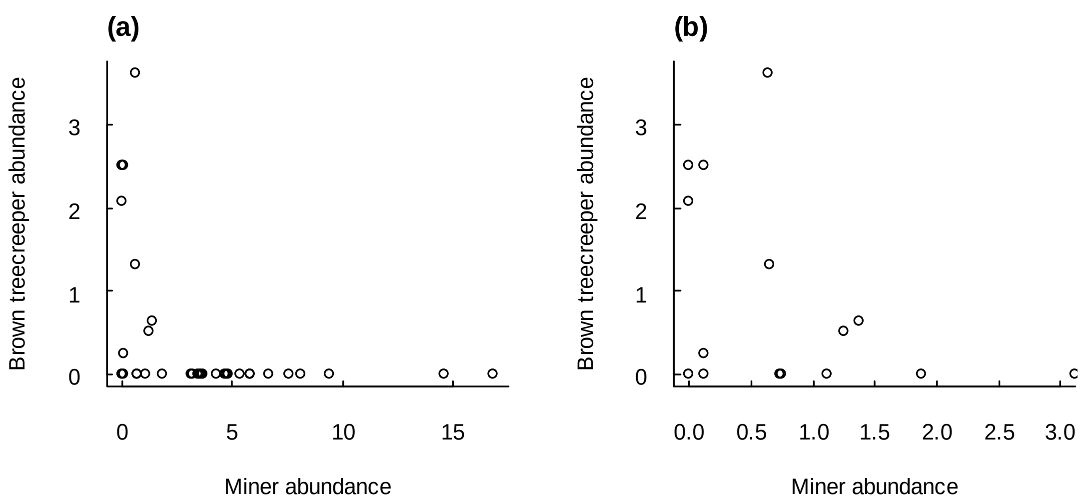

Figure 13. Abundance of brown treecreepers vs. abundance of miners (noisy and yellow throated combined) (number per km of transect). (a) Full data set. (b) Data restricted to show noisy miner abundance < 3 per km of transect.

Implications of results for on-farm and regional management

Our study suggests that irrigated regions can provide some benefits to components of the flora and woodland birds, particularly during drought periods. These benefits are likely related to water availability in the landscape, which for woodland birds probably increases the availability of food resources. The remnant vegetation in these landscapes is critical to these benefits, so regional management should focus on retaining and improving the quality of remnant vegetation patches in these landscapes. Improvements to habitat quality are likely to require similar practices to those observed for other landscapes, including restoring and maintaining a healthy ground and shrub layer, ensuring old hollow bearing trees are retained, maintaining woody debris, increasing the size of remnant patches and increasing the connectivity of vegetation patches. Retaining isolated paddock trees may also contribute to connectivity in these landscapes.

While our study did not find important links to surface wetting in the Midbidgee, there are flora and fauna species that clearly require and would benefit from surface wetting in remnant woodlands in this region. It is also likely that surface wetting would provide additional benefits to woodland birds and we recommend surface watering of remnant vegetation be undertaken with careful monitoring of the outcomes for many species including woodland birds. In appendix 6 of this report we discuss some of the opportunities for incorporating woodland watering into farm management.

Acknowledgments

This study benefitted greatly from assistance and support of the landholders on whose properties we worked, as well as staff from: the Rice Growers Association including Janelle McGufficke and Daryl Gibbs; Murrumbidgee Irrigation Ltd including Karen McCann, Cathy Semmler and Sigrid Tijs; NSW OEH including James Maquire, Paul Childs and Sharon Bowen; CSIRO including Micah Davies, Steve Henry, Jacqui Stol, Chris Davey, Damien Farine, David Gobbett and Don Gaydon. We also thank staff from the MDFRC including Darren Baldwin and Jessica Wilson and Matt Colloff from CSIRO, who introduced us to the Lowbidgee. The study was funded by the National Program for Sustainable Irrigation, the Rice Growers Association, CSIRO Sustainable Agriculture Flagship and CSIRO Water for a Healthy Country Flagship.

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Significant communication activities in the project
The project will produce at least three scientific publications which are in various stage of completion. These are:

1. McIntyre, S., McGinness, H. M., Gaydon, D. & Arthur, A. D. (2011) Introducing irrigation efficiencies: prospects for water-dependent biodiversity in a rice agro-ecosystem. *Environmental Conservation*, 38, 353-365. (Appendix 1).

2. McGinness, H. M., Arthur, A. D., Davies, M. & McIntyre, S. Floodplain woodland structure and condition: the relative influence of flood history and surrounding irrigation landuse intensity in contrasting regions of a dryland river. To be submitted to *Ecohydrology*. (Appendix 2).

3. A publication covering the main results from the bird work.

Results from the project have been presented at 2 scientific conferences and at two Rice Growers Association Environmental Champions field days:

1. McIntyre, S., Arthur, T., McGinness, H., McGufficke, J., and Gibbs, D. (2011) Woodland condition in dryland and irrigated areas. RGA Environmental Champions field day, 2 March 2011, 'Old Coree' via Jerilderee (poster presentation, Appendix 3).
2. Arthur, T., McGinness, H. and McIntyre, S. (2011) Effects of water availability on Black Box communities in irrigated regions. RGA Environmental Champions field day, Conargo 28 Jun. 2011 (spoken presentation).
3. Arthur, T., McGinness, H. and McIntyre, S. (2011) Biodiversity patterns in irrigated landscapes of the Australian Riverina. The Irrigation Australia 2011 Regional Conference & Exhibition, Launceston, Tas., 22 – 24 Aug. 2011. (spoken presentation, abstract in Appendix 4).
4. McGinness, H., Arthur, T., McIntyre, S. (2011) Flooding and surrounding irrigation intensity effects on Black Box (Eucalyptus largiflorens) woodlands. The 50th Australian Society for Limnology Annual Congress and 43rd New Zealand Freshwater Sciences Society Annual Congress, Brisbane, QLD, 26-30 September 2011. (spoken presentation, abstract in Appendix 5).

Two workshops were carried out and we produced a discussion paper on 'Management of flood-dependent vegetation on irrigation farms – opportunities for environmental watering' (Appendix 6).

Several short articles were also produced describing the project – these were featured in:

- 'Changing water regimes and biodiversity' the RiceGrowers Association Annual report, July 2009 (Appendix 7).

- '*Managed inundation of native wetlands*' in the NPSI Knowledge Harvest document ‘Irrigation Essentials – research and innovation for Australian irrigators’ August 2009 (Appendix 8).
- '*Less irrigation raises question of environmental effects*' the magazine ‘*Rice for Life*’ November 2009.
- Information sheets sent to various stakeholders.

Results will be presented in a future edition of the RGA Environmental Champions newsletter and are being incorporated into the Environmental Champions Program.

Appendix 1

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Introducing irrigation efficiencies: prospects for flood-dependent biodiversity in a rice agro-ecosystem

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SUMMARY

Worldwide, irrigation development has affected pre-existing natural habitats and created novel aquatic habitats, and future changes in management will continue to influence flood-dependent vegetation and fauna. Irrigated agriculture has had a profound influence on native biodiversity in the Riverina region of temperate Australia. Current irrigation practices provide large amounts of water to the landscape in the form of constructed wetland habitats: irrigation channels, impoundments and flooded crop-growing areas. Flooded rice bays support many species of native wetland plants, and 12 of the 14 species of frog recorded in the region. All constructed habitats provide a food resource for waterbirds, but not breeding habitat. While a species of tortoise benefits from the provision of constructed habitats, terrestrial reptiles and mammals are most abundant in remaining native vegetation. The climate is predicted to become increasingly hot and dry, with a reduced and more variable supply of irrigation water, thus placing increasing stress on farming and on natural ecosystems. The predicted reduction of constructed aquatic habitats may affect the native species using them, but may not have a major adverse impact on biodiversity regionally because the species recorded in constructed habitats tend be abundant and widespread, and such species also occur in natural wetland habitats. Sensitive species that depend on native vegetation persisting in reasonable amounts and in good condition are at greater risk. In the Riverina, the remaining native vegetation should be managed to protect and improve its condition, including appropriate managed inundation events for flood-dependent communities. The landscape should be managed to provide the best context for the function and health of existing vegetation including moderating the effects of soil disturbance, fertilizers and herbicides. The impacts of changed irrigation practices should be mitigated through managed flooding of remnant vegetation. In countries with more evolved, traditional rice-growing systems than the Riverina, there will be greater emphasis on biodiversity coexistence with cultivation. Nonetheless, in all settings there is value in jointly considering the role of both natural and constructed habitats in biodiversity research and conservation.

Keywords: amphibians, climate change, reptiles, vegetation, waterbirds, wetlands

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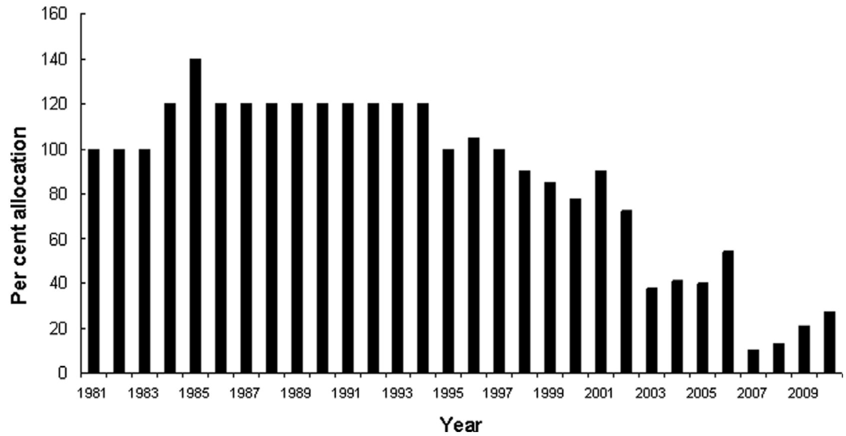
INTRODUCTION

With 155 million ha under cultivation, rice is the second most important cereal crop globally (Van Nguyen & Ferrero 2006) and accounts for over a quarter of irrigation water used (Bouman *et al.* 2007). Flooded rice cultivation (paddy rice) creates around 130 million ha of human-created wetland habitat, a significant amount compared with the 570 million ha remaining natural freshwater wetlands (Yoon 2009). A worldwide trend influencing paddy rice is that water supplies are being increasingly appropriated for human use (Postel *et al.* 1996; Molden 2007) and there are ongoing pressures to use irrigation water more efficiently and productively (Kassam *et al.* 2007). Efficient irrigation essentially involves delivery of water for crop growth with minimal losses to the wider environment (Mateos 2008), and this may have important implications for biodiversity in rice growing regions.

In a geographical sense, flooded rice culture is intimately associated with natural wetland ecosystems in most regions where it is grown (Ferrero 2006). It may have displaced natural wetland habitats though recent development, for example in California (USA), Brazil and Australia (Stenert *et al.* 2009) or have evolved intimately with the flooded environment over periods of time up to 8000 years (Ellis & Wang 1997). In either case, changed cultivation and irrigation practices, and particularly increased intensification in traditional rice-growing areas are going to have impacts on ecosystems and the biodiversity associated with them (Rijsberman 2004; Miyamoto 2007). There is little known about the relationship between flooded rice habitats and surrounding landscapes in terms of biodiversity, but this is going to become an increasingly important issue for conservation given global trends of natural wetland loss and modernization, and intensification of paddy rice cultivation (Ferrero 2006; Miyamoto 2007; Stenert *et al.* 2009).

The Riverina bioregion of south-eastern Australia provides an example of an intensive flooded rice production system that has significantly displaced natural wetland ecosystems

Figure 1 Irrigation water allocations (percentage of licensed quota) for Murrumbidgee Irrigation Area, 1980/1981–2009/2010 seasons. The trend of 100% or greater allocation extends unbroken back to 1914. Historical data source: NSW (New South Wales) Government, NSW Water Information (see http://waterinfo.nsw.gov.au/ac/alloc.xls). Recent data: Murrumbidgee Irrigation (see http://www.mirrigation.com.au/Water%20Info/season%20history-09-10.htm).



and which needs to respond to a diminishing water resource. Predictions of climate change indicate a strong warming and drying trend (Alexander & Arblaster 2009), affecting both the Riverina directly, and the broader Murray-Darling River system which provides flood and irrigation water to the Riverina. Diversion of stream flows for irrigated agriculture is placing natural flood-dependent ecosystems under additional stress (Kingsford 2000; Horner *et al.* 2009). Irrigators have already experienced a precipitous drop in irrigation water allocations over the last decade (Fig. 1), in stark contrast to over 80 years of receiving 100% or more of licensed allocations.

The purpose of this article is to review how changed management of rice cultivation may influence native biodiversity persistence in the region. To achieve this we firstly provide an account of the past impacts of pastoralism and irrigation development on the landscapes. We describe the constructed habitats and water regimes created by rice cultivation, and summarize likely changes in irrigation practices in response to water shortages. We then consider the effects on flora and fauna and discuss possible mitigation strategies. Finally, we consider the relevance of these strategies to other rice agro-ecosystems regions of the world.

PAST AND PREDICTED CHANGES

Prehistory

The Riverina bioregion straddles the Murray and Murrumbidgee Rivers, its central point being approximately 35°S and 145°E. The climate grades from temperate cool-season wet in the south, to Mediterranean and semi-arid in the north (Hutchinson *et al.* 2005). The region is dominated by a semi-arid outwash plain of alluvial fans, with sediments built up from a system of prior streams (Butler 1950). The present river systems have been cutting down through these sediments and are now at a lower level than the prior streams. Despite the relatively flat topography, a variety of plant communities occur in this bioregion, many having evolved in direct response to zones of flooding frequency (Beadle 1948). Historically, wetlands on the plain filled via flooding of the major rivers and streams, driven by upstream precipitation, or in some cases via local rainfall events. Floods would usually have occurred in late winter or spring every year, driven by snowmelt and rainfall in the headwaters. Aboriginal people lived in the region at least 40 000 years prior to the arrival of Europeans in the 19th century (Hope 1995). Their life centred on riverine and wetland sources of water, with occasional excursions into drier country.

European settlement and agricultural development

The first major impact of European settlement in the area was the establishment of pastoralism in the mid-1800s, which resulted in clearing and overgrazing throughout the region (Beadle 1948). The second major phase was the establishment of extensive irrigation schemes, with the creation of the Murrumbidgee Irrigation Area starting in 1914, followed by the Murray Valley Irrigation Districts in the 1940s, and the Coleambally Irrigation Area in the 1960s. Other less intensive developments occur to the west of the Murrumbidgee Irrigation Area. These schemes have resulted in the conversion of 456 000 ha of the Riverina to intensively managed irrigation land with considerable expansion of European settlement and influence (Leigh & Noble 1972). Floodplain agricultural development and upstream water resource development have resulted in much of the floodplain area being replaced by agriculture or isolated from natural inundation (Kingsford 2000). For example, in the western Riverina, the maximum period between Murrumbidgee River floods has more than doubled (from 4 to 10.5 years) while the average annual flooding volume has more than halved (CSIRO 2008).

Establishment of irrigation infrastructure involved the creation of supply and drainage channels, storage dams, and associated roads and settlements. Horticultural crops and broad-acre row crops (such as maize) have been generally watered by flooding furrows, while rice, wheat and pasture have been grown in levelled bays that are completely flooded. These activities involve significant and ongoing earthworks (contour banks, levees and ditches) and altered flow and drainage patterns across the landscape. Channels and flooded rice bays have provided large areas of free water continuously over the warmer months, in a landscape that would have been mainly dry in summer.

Changes to native vegetation communities

We reviewed major vegetation communities in the Riverina bioregion , and both past impacts of agricultural development on vegetation extent and ongoing threats (summarized in Table 1). Together, these communities supported the full range of the area's native fauna and flora. Virtually all community types have been seriously affected by agricultural development, either directly by clearing, or indirectly through changed flooding regimes, weed invasions and grazing by livestock. The woodlands of *Eucalyptus*, *Acacia* and *Callitris* that once dominated the bioregion have been subject to the greatest amount of clearing. Wetlands in the Riverina were most commonly found interspersed with woodlands and forests dominated by either river red gum (*Eucalyptus camaldulensis*) or black box (*E. largiflorens*). Understorey species composition and responses vary according to flooding regime (Williams 1955, 1956; Paijmans 1978; McIntyre & Barrett 1985; McIntyre *et al.* 1988). Wetlands lacking a tree layer may take the form of reed beds, rushlands and grasslands. Lignum (*Muehlenbeckia* spp.) shrubs dominate wetlands with or without a tree layer.

Most of the wetlands are impermanent, are fed by local rainfall or channel flooding, and are variable in size, depth and flood regime. Since river regulation, they have suffered from insufficient flooding, particularly those distant from the main river channels. Many are so altered that they are no longer recognized as wetlands. Others have been artificially flooded for too long or at inappropriate times, their altered hydrology being indicated by dead and unhealthy trees, and invasion of species tolerant to long-term inundation (Roberts 2005).

While the conservation management of all remaining native vegetation is critical for the region, we focus here on: (1) river red gum forests, woodlands and associated wetlands; and (2) black box woodlands and associated wetlands. These communities have been subject to the greatest impact of irrigation development and activities, and have a strong dependence on flooding. They form most of the small remnants of vegetation in the intensive irrigation areas and are therefore directly affected by changes in management.

Constructed habitats resulting from irrigation development

Two major habitats for native biota have been artificially created by irrigation development, namely irrigation channels and flooded bays in which broad acre crops are grown. Other habitats associated with farming in general are dams and impoundments that are generally permanently flooded but occupy a relatively small area.

Large open earth supply channels (7–30 m wide and up to 3 m deep) distribute water from the Murrumbidgee and Murray Rivers to the irrigation areas. These channels are nearly permanently inundated. Similar open earth drainage channels have been created to manage used and excess water. These include modified pre-existing creek lines, and many eventually empty into dams, rivers or low-lying land. Smaller shallow open earth channels (usually <5 m wide and <1 m deep) distribute water across each farm. Most irrigation canals are drained periodically for dredging and vegetation control by direct removal or use of herbicides. This dumping of sediment and mechanical disturbance results in exotic species dominating the adjoining terrestrial vegetation. Native vegetation is highly susceptible to this combination of soil disturbance and nutrient enrichment (McIntyre & Lavorel 2007).

Rice and terrestrial crops are grown in levelled bays separated by earth contour banks with a fall of approximately 7 cm between them. For rice production, bays are continuously flooded from spring to early autumn. Terrestrial crops such as wheat and pasture are often grown in the contoured paddocks during winter generally in rotation with rice. Rice bays have rapidly changing moisture conditions favourable to mobile and opportunistic organisms that are able to exploit temporary resources, such as some aquatic invertebrate species (Bambaradeniya *et al.* 2004; Wilson *et al.* 2008), some frog species (Wassens *et al.* 2004; Doody *et al.* 2006) and plants with large seed banks (McIntyre 1985).

Predicted changes to water regimes and irrigation practices

Changes in irrigation practices stem from reduced availability of water, resulting in the development of water conservation strategies and fewer areas under irrigated broad acre crops. Although Riverina irrigators have a history of increasing water-use efficiency (Humphreys *et al.* 2006), current and forecast circumstances will require even greater levels of ingenuity. Projected changes have been identified by the authors through information synthesis and consultation with the industry (see Gaydon *et al.* 2010) and include:

(1) A further general reduction of flows in rivers. Climate change is expected to result in reductions in Murray–Darling stream-flows of 16–25% by 2050 and 16–48% by 2100 (Christensen *et al.* 2007).
(2) Changes in water regimes for some natural habitats, associated with changes in management of drainage and surplus irrigation water (i.e. water rejected due to natural rainfall events). For example, surplus water may be stored for later use in crops rather than being discharged onto wetlands.
(3) Reductions in area under irrigated agriculture in a higher proportion of seasons, including reductions in the area of paddy rice.
(4) Methods of water application to reduce water use, such as increased adoption of efficient lateral move, centre pivot and drip irrigation technology on lighter soils, and

Table 1 Major vegetation formations and plant communities of the Riverina bioregion in New South Wales. Formations, community ID and status are from Benson *et al.* (2006); additional notes from Cunningham *et al.* (1981).

Formation (group acronym)	*Major communities in the Riverina (ID numbers)*	*Approximate % of pre-European extent remaining*	*Condition*
River red gum (*E. camaldulensis*) forests and woodlands of watercourses and flood plains (EIW)	Tall forests in frequently flooded areas adjacent to watercourses, woodlands on higher less flooded ground (2, 5, 7, 8, 9, 10, 11)	Taller forests logged and grazed with less clearing (> 60% remaining); on higher ground there is more clearing for agriculture (30–60%)	Moderate to poor, threats from changed flood regimes, salinity, grazing, timber removal
Black box (*E. largiflorens*) woodlands of watercourses and flood plains (EIW)	Extensive, associated with watercourses, wetlands and flood plains, less regularly flooded (13, 15, 16)	Wetter communities impacted by cropping, horticulture and grazing (30–50%) elsewhere (30–60%)	Mostly poor but recoverable condition resulting from grazing, changed water regimes and rising water tables. More impacted in the irrigation areas
Freshwater wetlands, regularly flooded (FWI)	Herblands and *Muehlenbeckia* shrublands of floodplain depressions (12,17); shallow sedgeland associated with flood plains or local drainage (53)	Cleared for crops and horticulture (40–80%). Shrublands most heavily impacted.	Moderate, though *Muehlenbeckia* shrubland poor. Threats from stock trampling, altered flood regimes and weed invasions
Freshwater wetlands, (semi-) permanently flooded (FWI)	*Typha* rushlands (182) of streams, ox-bow lakes and flood plains; forblands and sedgelands of lakes (238)	Drainage and river regulation have displaced communities (40–75%)	Moderate condition. Altered flooding, pollution and salinity
Grasslands of freshwater aquatic habitats or periodically flooded soil (GFAPF)	Tussock grasslands of drainage depressions and plains, dominated by *Eragrostis australasica* (24) and *Lachnagrostis* (47)	*Lachnagrostis* (47) most affected by clearing for agriculture (50%) *Eragrostis* (24) less cleared due to unsuitable soils (80%).	Moderate condition. Grazing, altered flood regime and weed invasion are ongoing threats
Eucalypt grassy woodlands (EBWP)	Combinations of *E. microcarpa*, *E. melliodora*, *Callitris glaucophylla* on lighter soils (75, 76, 80)	Cleared for cropping, horticulture, grazing (<30%)	Very poor, composition and structure altered, highly fragmented by clearing, natural regeneration not possible in some cases
Grey box (*E. microcarpa*) grassy woodlands (EIW)	Limited to grey clays on rises in flood plains dominated by river red gum forests along the Murray and Murrumbidgee Rivers (237)	Thinned for timber and grazing, cleared for dryland cropping and horticulture (<50%).	Poor, as structure and/or composition significantly altered. But sufficient biota remain for restoration
White cypress pine (*Callitris glaucophylla*) woodlands (CPW)	Open woodland of sand plains, prior streams and dunes (028)	Cleared for agriculture and intensive grazing (<30%)	Poor due to lack of tree and shrub recruitment, erosion, weed invasion. Highly fragmented
Weeping myall (*Acacia pendula*) open woodland (ASI)	On brown clays and loams on alluvial plains (026)	Cropping and horticulture; grazing has converted large areas to grassland (<30%)	Poor, structure and/or composition significantly altered. But sufficient biota remain for restoration
Casuarina woodlands (CCI)	Black Oak Western Rosewood (*Casuarina cristata Alectryon oleifolius*) open woodland on deep sandy loams (058)	Cleared for cropping and horticulture, used for grazing and timber production (30–60%)	Poor, structure and/or composition significantly altered. But sufficient biota remain for restoration
Chenopod shrublands (CHS)	Numerous community types on a range of soils *Maireana*, *Atriplex*, *Bassia*, *Nitraria* (153, 157, 159, 163, 164, 166, 216, 236)	Estimates of original extent and remaining areas vary greatly within and across communities	Grazing has converted shrubland to annual grasslands in many cases
Grasslands on fine-textured soils (GFTI)	(*Chloris*, *Danthonia* and *Stipa*) Widespread on clays and clay-loams (44–46)	Cleared for cropping, horticulture, used for grazing. Remaining extent varies greatly with community type from <30 to >60%	Generally poor condition. Some grasslands some converted from perennial annual. Potential for improvement with change in grazing practice

reductions and increased efficiency in the use of flood irrigation techniques.

(5) Changes in the methods of delivering water to reduce leakage and evaporative losses. This could include sealed lining of earthen irrigation channels and the piping of water which has previously been carried in open channels. Under current water prices, economics dictate that these changes are likely to be limited to locations where channels or drains cross highly permeable soils. Increasing costs of water could result in more widespread piping and lining.

(6) Increases in herbicide use may occur, because the use of ponded water has been the primary method for controlling weeds in rice crops.

(7) Adjustments to farming practices and associated changes to farm layout are likely. For example recycling of water will involve increasing on-farm water storages and associated engineering works.

If correct, these predictions will create further challenges to a biota that has already been dramatically perturbed by pastoralism and irrigation development. In the following sections, we draw on available information on species and community response to consider how the predicted changes may further affect flora and fauna conservation in the Riverina.

EFFECTS OF CHANGES IN IRRIGATION PRACTICE ON FLORA

Wetland flora

The creation of constructed habitats such as rice bays, channels and roadside ditches has provided habitat permitting native herbaceous wetland plants to persist long after their associated trees and shrubs have disappeared from these habitats (McIntyre *et al.* 1988). Unlike their terrestrial native counterparts, wetland species appear to have been pre-adapted to productive highly disturbed situations (McIntyre & Barrett 1985; McIntyre *et al.* 1988). The largest threat to this assemblage in constructed habitats will be lining and piping of channels, and reduced areas of paddy rice production. This will certainly reduce population sizes of some species. In the case of channels, where diversity is limited by deep water and the effects of dredging and herbicides, a reduction in area or impermeable lining will pose little threat. Rice bays are potentially of more concern, as a survey comparing flooded bays with natural swamps found 11 native species to be found only in rice bays compared with 29 species restricted to swamps (McIntyre *et al.* 1988). This situation would need to be reassessed to identify the current threats more precisely, as the diversity status of both habitats may have changed over the 30-odd years since this survey. The fate of wetland species is linked with that of their associated woodlands, as discussed below.

Woodlands

Notwithstanding any effects of climate change on rainfall and natural water flows, the major issues for flood-dependent woodlands are those resulting from local management of irrigation water. Irrigation infrastructure has interfered with natural drainage patterns, and where ‘waste’ water may have previously been applied to woodland remnants, there is a trend toward more careful recycling and storage of water on-farm in dams and channels. This could have positive effects on flood-dependent woodlands by avoiding prolonged waterlogging, or could have negative effects, due to induced drought compounding the effects of loss of natural flooding. More broadly, irrigation and tree clearing in the Riverina have caused water tables to rise, with associated increases in soil and water salinity. The recent drought, together with changes in infrastructure and management, has lowered the water table, and these factors have combined to reduce the urgency of this problem, at least in the short term. Changes in irrigation practices in the future may further reduce the amount of water reaching the water table; this issue requires ongoing monitoring and management.

Removal of paddock trees is a conservation issue with potential to escalate under changing irrigation techniques, as installation of lateral move and centre pivot irrigation systems requires large treeless areas to operate. Isolated paddock trees in intensively farmed landscapes are increasingly recognized as irreplaceable habitat elements for native fauna (Manning *et al.* 2006). Retained paddock trees are typically mature and bear hollows upon which native fauna rely for breeding and shelter (Gibbons & Boak 2002). Isolated trees may also act as ‘stepping stones’ or provide some form of connectivity across the agricultural landscape. They can also provide a feeding resource for fauna such as bats, birds and mammals (Gibbons & Boak 2002; Lumsden & Bennett 2005).

River red gum (Eucalyptus camaldulensis) forests and woodlands

River red gum communities are widely distributed in the Riverina and grow under a range of flood regimes (Benson *et al.* 2006) as well as accessing groundwater (Mensforth *et al.* 1994; Thorburn & Walker 1994). Communities near major rivers are generally adapted to flooding every 1–3 years, but tolerate dry or wet periods of up to two years (Bren & Gibbs 1986; Bren 1987, 1988; Robertson *et al.* 2001). Large areas are managed for grazing and forestry (Bacon *et al.* 1993; Jansen & Robertson 2005). These modifications have a range of effects upon the vegetation community, including poor tree health leading to compositional and structural change (Briggs & Thornton 1999; Robertson *et al.* 2001; George *et al.* 2005; Horner *et al.* 2009). Current responses to water shortages include substituting natural flooding in some areas with managed water allocations to restore the condition of tree and fauna populations (Nias *et al.* 2003).

Table 2 Frogs recorded in the Riverina. Summary of historic records and recent habitat records in the irrigation areas as collated and reported by: 1 = Ehmann (1996); 2 = Wassens *et al.* (2004); 3 = Doody *et al.* (2006); and 4 = Wassens *et al.* (2008).

Name	*River red gum*	*Black box*	*Dams*	*Rice bays*	*Channels*
Plains froglet (*Crinia parinsignifera*)	2, 3	2, 3	2, 3	2, 3	2, 3
Sloane's froglet (*C. sloanei*)	–	–	2	–	–
Barking marsh frog (*Limnodynastes fletcheri*)	2, 3	2, 3	2, 3	2, 3	2, 3
Spotted marsh frog (*L. tasmaniensis*)	2, 3	2, 3	2, 3	2, 3	2, 3
Giant bullfrog (*L. interioris*)	2	–	2	–	–
Eastern banjo frog (*L. dumerilii*)	–	–	–	–	–
Peron's tree frog (*Litoria peronii*)	2	2	2	2	2
Broad-palmed frog (*L. latopalmata*)	2	–	–	–	–
Southern bell frog (*L. raniformis*)	1	1	1	1, 4	1, 4
Green tree frog (*L. caerulea*)	–	–	–	–	–
Sudell's frog (*Neobatrachus sudelli*)	–	2	2	2	2
Wrinkled toadlet (*Uperoleia rugosa*)	2	2	2	2	–
Bibron's toadlet (*Pseudophryne bibronii*)	–	2	–	–	–
Crucifix toad (*Notaden bennetti*)	–	2	2	–	–

Black box (Eucalyptus largiflorens) woodlands

Despite broad-scale clearing (Table 1), black box woodlands remain widespread (Benson *et al.* 2006). These communities have been commonly used for grazing and disposal of irrigation drainage and escape water (Harrison & Roberts 2005), and their condition is often compromised as a result (Eldridge *et al.* 2003, 2007). It is thought that natural flood events occurred in 10–50% of years, for periods of 2–6 months (Jolly *et al.* 1996; Akeroyd *et al.* 1998; Slavich *et al.* 1999). Access to groundwater is important for tree survival during dry periods. Although relatively tolerant, black box trees will succumb to too little, or too much, flooding (George *et al.* 2005). Understorey composition and structure are also altered, and this affects fauna such as waterbirds breeding in reed beds, although very few data are available to identify specific links between water regime and biodiversity status of these communities.

Black box trees themselves are regionally significant in providing nesting hollows and supplying nectar for fauna (Gates 1996; Eldridge *et al.* 2003). However, in many remnants mature hollow-bearing trees have been removed, and the understorey has little fallen timber, few perennials and is dominated by exotic plants (Eldridge *et al.* 2003, 2007; Eldridge & Lunt 2010). Even under these circumstances, rice farms with black box vegetation support more fauna than farms without (Doody *et al.* 2006). As in other Australian agricultural landscapes, fauna occurrence varies with proximity of a vegetation remnant to other vegetation, as well as patch size and condition (see for example Wassens *et al.* 2004, 2005*a*, *b*; Brown *et al.* 2008).

EFFECTS OF CHANGES IN IRRIGATION PRACTICE ON FAUNA

Faunal surveys in the Riverina have included both native vegetation and constructed habitats such as irrigation channels, and constitute the main source of information in considering vulnerabilities to future changes. We consider four vertebrate groups (frogs, reptile, birds and mammals).

Amphibians (frogs)

Of the 14 species of frog that have been historically recorded in the Riverina, 12 have been recorded in irrigation areas in recent years (Table 2). The two unaccounted for, namely the green tree frog (*Litoria caerulea*) and eastern banjo frog (*Limnodynastes dumerilii*), are more likely to be detected in periods of several successive wet years. There appear to be no species restricted to rice bays or irrigation channels, though one species, the endangered southern bell frog (*Litoria raniformis*) may now rely on permanently flooded channels or dams for over-wintering and dry-season persistence (Wassens *et al.* 2007, 2008).

In general, black box depressions in the Riverina have slightly greater frog species richness (eight spp.) than river red gum wetlands (six spp.), rice bays (six spp.) and channels (five spp; Wassens *et al.* 2004). One species (the broad-palmed frog, *Litoria latopalmata*) appears to be restricted to river red gum billabongs. Dams with abundant vegetation support the highest number of species (nine spp.). We interpret this to be because of the density and diversity of fringing vegetation and number of microhabitats, which are elements of favourable frog habitat elsewhere in Australia (Hazell *et al.* 2004).

The changes in irrigation practice that are most likely to affect amphibian diversity in the Riverina are those relevant to dams, and those affecting the condition of black box depressions. While there is some chance that unpredictability in water supply may lead to construction of more dams to increase water security over time, the value of both new and old dams will depend on maintaining a variety of vegetation in and around dams (Hazell *et al.* 2001). Amphibian habitat quality of both dams and black box remnants may also be affected by agro-chemical usage. In the Riverina, organically grown rice was found to have more diverse macro-invertebrate communities than rice bays treated with agrochemicals (Wilson *et al.* 2008), which may affect the quality, if not the quantity of food supply for frogs in channel, dams and rice bays.

Reptiles

Reptile abundance and diversity are low in the Riverina compared with other sites in south-eastern Australia (Wassens *et al.* 2005*b*; Brown *et al.* 2008). Although 29 species have been recorded in vegetation remnants of the Murrumbidgee Irrigation Area (Wassens *et al.* 2005*b*), other studies in the Riverina have located far fewer species (AMBS [Australian Museum Business Services] 2005; Doody *et al.* 2006; Brown *et al.* 2008). Only four species were considered both abundant and widespread in the southern Riverina (Herring *et al.* 2006*a*, *b*, *c*, *d*): Boulenger's skink (*Morethia boulengeri*), Carnaby's wall skink (*Cryptoblepharus carnabyi*), the southern marbled gecko (*Christinus marmoratus*) and the eastern brown snake (*Pseudonaja textilis*).

In irrigation areas, reptiles are more abundant in black box remnants than in other rice farm habitats such as rice bays, dams, dry crops or river red gum woodland (Doody *et al.* 2006; Brown *et al.* 2008). Ten species have been found in black box remnants of the Murrumbidgee Irrigation Area, compared to six species in river red gum (Wassens *et al.* 2005*b*). Numbers of reptiles in river red gum communities are thought to be limited by long periods of flooding, though the habitat is important for skinks, geckos and carpet pythons. Resident species are commonly large mobile generalists, or arboreal in habit. The highest richness, abundance and frequency of reptiles have been recorded in roadside remnants of black box, possibly reflecting greater structural complexity due to protection from grazing (Brown *et al.* 2008). Overall, species richness varies with grazing pressure, fallen timber and connectivity between patches of vegetation (Sass *et al.* 2004; Wassens *et al.* 2005*b*).

Most reptile species in the Riverina are restricted to terrestrial habitats or the margins of wet areas, though they may be attracted to and benefit from the higher abundances of frogs and insects associated with irrigation waters. However, Doody *et al.* (2006) found no difference in diversity or abundance between rice bays and dry crops, except for tortoises. The eastern long-necked tortoise (*Chelodina longicollis*) uses large irrigation channels, with feeding forays into rice bays during the irrigation season (Doody *et al.* 2006). Loss of these habitats would negatively affect tortoise populations in localized areas, but being an abundant and widespread species, such changes would not greatly reduce reptile diversity in the Riverina. Improving the condition of remnant vegetation would provide significantly greater long-term benefit.

Birds

The Riverina provides internationally significant habitat for waterbirds (Kingsford & Thomas 2004) and supports a range of rare and threatened terrestrial birds (Jansen & Robertson 2005). Many Riverina bird species have suffered regional and national population declines in the last 25 years (Kingsford *et al.* 1999; Ford *et al.* 2001; Porter *et al.* 2006). Successful breeding by waterbirds in the region has been linked to the water regime required to produce suitable habitat (Briggs *et al.* 1997; Briggs & Thornton 1999) and in many sites water regimes have been changed by irrigation practices. Clearing and grazing have also affected species composition and abundance in the region (Jansen & Robertson 2001). In recent years, surveys have found that black box communities generally have had higher terrestrial bird diversity and abundance than several other major vegetation types in the region (Antos & Bennett 2005; Herring *et al.* 2006*a*, *b*, *c*, *d*).

Constructed habitats associated with irrigation have the potential to increase resources for birds (for example herons and egrets in southern Europe), but also create hazards, for example through pesticide use (Czech & Parsons 2002). A wide range of Australian birds use rice bays, irrigation channels and water storages for foraging. These habitats can partially substitute for lost or altered habitat; in the rice growing regions of Italy, Spain and California, irrigation channels (canals and ditches) and their margins provide nesting and foraging habitat for waterbirds (Czech & Parsons 2002; Taft & Elphick 2007). In general, terrestrial bird and waterbird diversity associated with irrigation channels is greatest when channels are large and have extensive complex vegetation, both inside and outside the channel itself (Herzon & Helenius 2008). Irrigation channels in the Riverina rarely have these characteristics. Lining channels with concrete further reduces habitat value (Lane & Fujioka 1998; Maeda 2001). In Australia, there is evidence of ducks and egrets foraging in channels (Frith 1957*a*, *b*; Richardson & Taylor 2003) but there are no records of associated breeding.

Waterbirds exploit rice crops for their food resources worldwide (Frith 1957*b*; Richardson *et al.* 2001; Czech & Parsons 2002; Taft & Elphick 2007). Ducks have had minor economic impacts in Australian crops through feeding on grain and young plants in the establishment phase. This was found by Frith (1957*b*) to be offset to some extent by their consumption of seed from the major grass weed *Echinochloa*, and the damage was usually confined to those areas in crops where growth was unsatisfactory for other reasons. Australian egrets (*Ardea alba* and *Egretta intermedia*) have been recorded foraging in rice during their breeding season but shifted to natural wetlands as the crops matured and chick rearing took place. In contrast the introduced cattle egret (*Bubulcus ibis*) foraged in rice fields until after their chicks had fledged, leading to speculation that this invasive species may have some advantage over the native egrets in the irrigated agricultural landscape (Richardson & Taylor 2003).

Targeted management practices can be important for improvement of food availability for birds in irrigation areas that have replaced natural wetland habitats. For example, in the USA, stubble management, shallow winter flooding, reduced use of pesticides, fallow and secondary crop rotation practices that encourage seeding plants are beneficial (Taft

& Elphick 2007). In the Riverina, reports indicate that terrestrial birds and waterbirds increase around rice bays following flooding and decrease after draining (Doody *et al.* 2006).

Although constructed habitats in irrigation areas may provide some resources for native birds, large regional declines in the populations of many waterbird species have coincided with irrigation development (Kingsford & Thomas 2004). So while we do not understand the net population effects of particular constructed habitats on birds, it would appear that irrigation development overall has not been able to do more than partially substitute for the alterations and losses of the natural habitats and resources that have ensued. Consequently the impacts of further change to water availability in the Riverina via changes in irrigation practice are difficult to estimate.

Mammals

Many mammal species present in the Riverina in the past are now rare. The only abundant and widespread native mammals are bats, the eastern grey kangaroo (*Macropus giganteus*) and the brush-tailed possum (*Trichosurus vulpecula*). Currently the greatest diversity of mammals appears to be in river red gum forests (Herring *et al.* 2006*a*, *b*, *c*, *d*), which contain several species of bats, as well as yellow-footed antechinus (*Antechinus flavipes*), water rats (*Hydromys chrysogaster*), black wallaby (*Wallabia bicolour*), sugar glider (*Petaurus breviceps*) and platypus (*Ornithorhynchus anatinus*). Black box woodland also supports bats, eastern grey kangaroos and brush-tailed possums, and the presence of these species is dependent on specific landscape and woodland characteristics, for example landscape complexity, shrub and log cover, presence of hollow-bearing trees and woodland patch size (Lewis 2006).

The use of constructed irrigation habitats by mammals is poorly known, both in Australia and overseas. There are potential benefits of habitat in close proximity to a water source such as an irrigation channel. However in the Riverina this seems to be offset by the loss of adjacent native vegetation due to channel maintenance activities. The introduced house mouse (*Mus domesticus*) was the only mammal recorded in a large survey (45 000 trap-nights) adjacent to irrigation channels and in fields in the Riverina (Brown *et al.* 2004). House mice are usually the most abundant mammals in rice bays (Brown *et al.* 2004; Doody *et al.* 2006). In tropical rice systems overseas, these may attract carnivores such as mongoose, wild cats, otter and civet cats (Bambaradeniya *et al.* 2004); in the Riverina they may attract introduced predators such as cats and foxes as well as provide food resources to some native raptors (Sinclair *et al.* 1990). One native mammal that might be expected to occur is the water rat; however a recent survey in the Murrumbidgee Irrigation Area failed to find water rats in or near irrigation channels (Lewis 2006) even though they occasionally use rice bays (Scott & Grant 1997). Overall, constructed habitats offer poor habitat for native mammals, which appear to be more dependent on native vegetation than the other fauna groups. Therefore changes in the availability of constructed habitats and water sources are unlikely to significantly change abundance or diversity of mammals in the Riverina.

MITIGATION AND ADAPTATION

We can summarize the effects of the previously listed potential changes in irrigation supply and management on biodiversity and discuss appropriate response strategies as follows.

A further general reduction of flows in rivers

A further general reduction of flows in rivers will reduce the frequency and magnitude of flooding events, which will affect natural water regimes of river red gum and, to a lesser extent, black box communities. All components of biodiversity will be affected by these changes. The Murray-Darling system is highly controlled and, except in exceptionally wet years and in circumstances of local flooding, flooding events will be explicitly controlled. There is an acute awareness of the trade-off between environmental uses of water (such as to flood wetlands) and its use for human purposes, and the issue is currently being debated at the Australian national level. It is likely that flooding regimes approximating pre-European conditions will be restored for a limited number of wetlands in the Murray-Darling system.

Changes in water regimes for some natural habitats

On-farm management of irrigation waters is important for the remnant flood-dependent woodlands that exist within the rice agro-ecosystem. For this reason, all components of biodiversity are subjected to the vagaries of individual irrigation decisions and managed flooding will become even more important in the face of more generally dry conditions due to climate change. There is great scope for refining management in ways that can benefit remnant native vegetation. The New South Wales Murray Wetlands Working Group has successfully inundated many wetlands in southern NSW, and such cooperation between irrigation companies, landholders, government departments and catchment management groups can be effective (Nias *et al.* 2003). Even partial rehabilitation of a wetland can provide multiple benefits to both irrigators and the environment. For example, Barren Box Swamp, an intermittent wetland in the Murrumbidgee Irrigation Area, was permanently inundated by irrigation drainage for about 50 years, killing most of the black box trees. Restoration consisted of splitting the area into three cells, including a deep storage cell, resulting in more efficient storage (less evaporation) and restoration of 1650 ha of the wetland to an intermittent regime (Murrumbidgee Irrigation 2009). The extent to which these habitats can be maintained, when overall water availability is likely to decline, will be driven by political and economic imperatives.

Reductions in area under irrigated agriculture

As well as reducing the average area of flooded rice bays, this may reduce the total average amount of free water in supply and irrigation channels. These are discussed under the following two headings.

Irrigation techniques for reduced water use

Future reduction in area and duration of flooding in irrigation bays is highly likely, and this will reduce a previously extensive habitat for a range of species in the warm season. As for channels, the local abundance of some frogs and waterbirds may be reduced, but these changes will not necessarily be deleterious in terms of total biodiversity in the region, providing natural habitats are maintained. The situation is less clear for wetland plants, which appear to have some dependence on flooded rice bays, but it could be argued that the improved management of natural wetlands would compensate for reduced areas of flooded rice.

Reducing leakage and evaporative losses in water delivery

In Japan, concrete lining and piping of irrigation channels has resulted in loss of habitat for aquatic invertebrates, amphibians and some waterbirds (Fujioka & Lane 1997; Lane & Fujioka 1998). If such engineering modifications are widely implemented within Australia, the likely result will be reductions in abundance of species that exploit channels (such as frogs and turtles) and possibly sedentary terrestrial species from the surrounding landscape that obtain food resources from them. However, many species associated with channels are relatively common, and while channels provide additional habitat, refuge during unfavourable seasons and connectivity of aquatic habitat across the landscape, there is no evidence that they provide habitat that cannot be maintained with appropriate management of remaining native vegetation, natural watercourses and wetlands.

Increases in herbicide use

Herbicides and fertilizer are important in rice cultivation, but there are significant contributions from flooding in suppressing some major weeds (McIntyre *et al.* 1991). Dependence on herbicides is likely to increase with reduced flooding depth or duration. While discharging drainage water on native vegetation could provide beneficial watering, residual chemicals and nutrients could be detrimental. Strategies to control these, such as retention and recycling, need to be integrated into any recommendations for changed practices to reduce water use.

Adjustments to farm layout

While most constructed aquatic habitats are likely to decline in the future, the number of dams will most likely increase to conserve and recycle water on-farm. This has the potential to benefit a range of common species, most notably frogs and turtles. There will be options to improve habitat for fauna within irrigation areas by creating physical variability within and among dams, excluding livestock and restoring vegetation (Hazell *et al.* 2001; Jansen & Healey 2003; Hazell *et al.* 2004; Jansen & Robertson 2005).

It is likely that changed farm layout will further threaten remnant vegetation with earthworks during the construction process. Modified irrigation techniques may also threaten remnant vegetation. For example, efficiency practices such as laser levelling and centre pivot irrigation may affect critical landscape elements such as isolated mature native trees, which may have otherwise persisted in paddocks. There is scope for strategies that mitigate for these effects, as well as more proactive approaches to farming that could result in better prospects for biodiversity.

CONCLUSIONS AND GLOBAL PERSPECTIVE

Summary of impacts

In the Riverina, the general reduction in water availability associated with constructed wetland habitats will have some local impacts on biodiversity. However, this is not necessarily a major problem as the plants and vertebrate fauna of such habitats tend to be common, generalist and are necessarily tolerant of some human disturbance. The population sizes of common species are likely to be reduced rather than local extinctions occurring. It should be noted that there may be more vulnerable species that are dependent on the productivity of constructed habitats that may not have been identified with the available information. The question of importance is whether there are still sufficient natural or alternative constructed habitats to support viable populations of both these 'common' and vulnerable species after the changes have taken place. This seems likely for some groups (for example frogs and invertebrates), but to understand the impacts, comparative studies of the range of possible habitats would be needed to clarify the situation for aquatic plants, mammals and birds, and for particular species (such as the southern bell frog). The scenario for waterbirds is difficult to comprehend owing to their nomadic movements and dependence on a range of alternative wetlands that may be affected by changes to water management. Scientific understanding of these dynamics is rudimentary. Locally occurring birds will be threatened by changed farming practices that result in the loss of mature trees in paddocks, further loss of native vegetation and unfavourable flooding practices.

General principles for conservation in face of water shortage

The best investment for the future will be to increase current efforts to protect and improve the condition of existing native vegetation of all community types in the irrigation areas and the region more widely. There are large areas of native vegetation that are in need of improvement in ecosystem condition (Table 1). This will require managed inundation events for flood-dependent communities, and actions to increase habitat complexity such as controlled grazing, retaining fallen timber and conserving standing timber. Recognizing the importance of preventing nutrient enrichment and inappropriate soil disturbance is also vital for function and diversity (McIntyre & Lavorel 2007).

Landscape-scale management is particularly important in times of change. By applying established principles for conservation, a risk-based approach can be used with a modest investment in new information. For example, maintaining a mosaic of heterogeneous habitats at multiple spatial scales (site, farm and region), retaining bigger patches of vegetation and less isolated patches of habitat are all appropriate general strategies for the Riverina landscape. Addressing more detailed questions of landscape design that need to take into account possible dependencies of vulnerable species to both constructed habitats and native vegetation will require considerably more knowledge.

In summary, while there are some issues that are currently intractable to address (for example direct climate change effects on ecosystems and management of nomadic fauna) there are local and regional strategies that could be implemented or investigated. Even with major knowledge gaps in the systems, action can be taken immediately to improve habitats using strategies that are derived from an existing body of knowledge in conservation biology. While details of management responses may be specific to the Riverina (for example flooding regimes for different vegetation types), we suggest that conservation strategies at the landscape and patch level should be no different to any recommended in an intensively managed agricultural landscape worldwide, namely maintain and improve natural vegetation and where possible increase its total area and connectivity (see Lindenmayer *et al.* 2008).

The global perspective

The Riverina rice growing system has considerable similarities to that of the Central Valley of California in terms of time of establishment of the industry, agronomic methods, the temperate climate and the predominantly native weed flora (McIntyre & Barrett 1985). In California, biodiversity management in the rice agro-ecosystem is focused on off-season watering of rice fields for waterbirds as a surrogate for the loss of natural wetlands in the region, these having been reduced to 5% of their original area (Sterling & Buttner 2009). In contrast, Riverina wetlands still persist in significant amounts (30–60% remain, depending on the community; Table 1). The Californian rice industry shares with Australia the problem of diminishing water supply and management of water quality (Hill *et al.* 2006), which may put pressure on environmental watering practices.

A key factor setting both Californian and Australian systems apart from many other regions is the longer cultural history of rice growing in Asia and Africa, measured in thousands of years rather than the tens of years marking rice cultivation in Australia and USA (Ellis & Wang 1997; Miyamoto 2007). In areas with a long cultural history of rice growing, it is to be expected that there has been a degree of adaptation of species to the cultivation system. In this setting, management of traditional rice growing systems will assume high importance for local biodiversity conservation compared with regions where agriculture is novel in an evolutionary sense. It should be noted that in these densely settled, long-established agro-ecosystems, species unable to adapt will have disappeared long ago from the transformed landscapes, and would no longer be considered lost. Rice fields should therefore not be considered a complete surrogate for natural wetlands in any region (Stenert *et al.* 2009). They are essentially simplified agricultural systems that provide some of the needs of some species, and which are highly vulnerable to changed economic and social settings (Czech & Parsons 2002). Rice cultivation throughout the world is subjected to the pressures of declining water supply and increased productivity, regardless of cultural history (Molden 2007; Lee 2009). Although details differ from region to region, reduced flooding and intensification of production systems are pervasive (Ellis & Wang 1997; Miyamoto 2007) and threaten biodiversity, even in traditional systems (Bambaradeniya & Amarasinghe 2003; Rijsberman 2004). Consideration of all flood-dependent biota and all habitats in the wider landscape is essential for biodiversity management in rice growing systems worldwide. This is a largely undeveloped area of research in a system where there has been an understandable focus on production. However, the links between sustainable agriculture and natural resource management, including biodiversity, are starting to be recognized (see for example Ferrero 2006; Stenert *et al.* 2009). Whether the pressures be direct climate change effects, water shortages or changes in farming practice, the essential approach to the conservation of biodiversity and ecosystem function will be to understand the ecosystem linkages between the paddy, wetlands and the wider landscape.

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Floodplain woodland structure and condition: the relative influence of flood history and surrounding irrigation intensity in contrasting regions of a dryland river

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Abstract

Forecast changes in irrigation practices and climate are likely to result in changes to surface and ground water availability for floodplain woodland remnants; however the potential regional effects of such changes are poorly understood, and have implications for management of woodland remnants for long-term biodiversity persistence. This paper examines *Eucalyptus largiflorens* floodplain woodland structure and condition in two contrasting regions within the same catchment. It assesses the effects of varying levels of irrigation and landuse intensity surrounding woodland sites and of flood history within sites. It demonstrates that where groundwater tables have fallen, rainfall is in deficit and surface flooding occurs less than once every two years, *E. largiflorens* trees will be in poor condition and are more likely to die. In the absence of sufficient rainfall and groundwater, more frequent flooding is required to maintain *E. largiflorens* in good condition (less crown death and greater crown density) than would normally be required. Landuse intensity affects variables that create habitat complexity in woodlands, such as the presence of old and young trees, and the abundance of shrubs such as lignum and sclerolaena. Flow regimes (particularly prior wetting frequency) affect both structure and condition. These results have implications for understanding and management of elements of biodiversity dependent upon the resources provided by floodplain woodlands. They emphasise the importance of maintaining healthy black box remnants in irrigation areas for biodiversity persistence, and suggest that rehabilitation of black box communities in the Lowbidgee using managed flooding could bring significant biodiversity benefits to the region.

Introduction

The floodplain woodlands of inland Australia are water-dependent ecosystems that support significant flora and fauna and extend the range of many species further inland than local rainfall would normally allow, acting as key refugia for biodiversity during droughts (Morton *et al.*, 1995). Floods in these systems supplement low and highly variable rainfall, and provide sediment and nutrients for primary production (Stafford Smith and Morton, 1990; Puckridge *et al.*, 1998). The importance of these systems has recently been reinforced by decisions to set aside large tracts of floodplain for conservation as part of State reserve systems in NSW and VIC, and by both State and Federal efforts to secure water for targeted floodplain inundation (environmental flows).

Over the last century, floodplain woodland ecosystems worldwide have undergone substantial hydrological change driven by human water use and long-term droughts (Bren, 1988; Kingsford, 2000; Thoms and Sheldon, 2000). Changes in flooding patterns have strongly influenced vegetation productivity, composition and distribution (Bren and Gibbs, 1986; Casanova and Brock, 2000; Kingsford, 2000; Alexander *et al.*, 2008; Horner *et al.*, 2009). Many of the most dramatic changes in flood regime have occurred in south-east Australia, and despite a general cessation of clearing, continuing degradation of vegetation due to inappropriate flood regimes has implications for the ecological health of these systems (Jansen and Robertson, 2001; Parkinson *et al.*, 2002; Scott *et al.*, 2003; McGinness *et al.*, 2010). Under climate change, rainfall may decrease, evaporation may increase, and river flows may decline further (CSIRO, 2008b), increasing the pressure on managers to allocate limited 'environmental flows' wisely for maintenance and improvement of ecosystem resilience.

In dryland areas of south-east Australia, black box (*Eucalyptus largiflorens*) woodland communities in good condition are generally found in areas flooded every 2-10 years for 2-6 months (Taylor *et al.*, 1996; Roberts and Marston, 2000; George *et al.*, 2005; Johns *et al.*, 2009). Several studies have established the reliance of *E. largiflorens* on groundwater for survival when rainfall and floodwater are insufficient, even where groundwater is saline, however these trees prefer to use less saline water sources whenever they are available (Jolly and Walker, 1996; Akeroyd *et al.*, 2003). Despite human impacts, *E. largiflorens* woodlands remain widespread (Benson *et al.*, 2006), and are significant in providing breeding habitat and supplying nectar and other food for fauna (Gates, 1996; Eldridge *et al.*, 2003; Lewis, 2006). However in some areas these woodlands are also influenced by irrigation practices such as deposition of surplus water, and altered groundwater depths due to irrigation seepage and groundwater extraction, the effects of which may be positive or negative (Eldridge *et al.*, 2003; Roberts, 2005). Forecast changes in irrigation practices and climate are likely to result in further alterations to surface and ground water availability for *E. largiflorens* remnants (McIntyre *et al.*, 2011), the effects of which are poorly understood, but which have implications for long-term biodiversity persistence.
In this paper, we examine *E. largiflorens* woodland structure and condition in two contrasting regions with varying levels of landuse and irrigation intensity within the same catchment. We test the following propositions:

1. Landuse and irrigation intensity significantly affects floodplain woodland condition and structure; floodplain woodlands with greater intensity of surrounding landuse and irrigation will be in worse condition and have less structural complexity than other floodplain woodlands.

2. Flood history significantly affects floodplain woodland condition and structure; floodplain woodlands with flood histories closer to suggested 'natural' regimes will be in better condition and will have greater structural complexity than other floodplain woodlands.

Methods

Study areas and design

E. largiflorens woodlands in two regions within the Murrumbidgee river catchment in south-east Australia were surveyed: mid-Murrumbidgee (Midbidgee) and lower-Murrumbidgee (Lowbidgee; Figure 1). The two regions differ in their irrigation and landuse intensities, and the westerly Lowbidgee receives lower rainfall than the more easterly Midbidgee (Table 1). Pastoralism began in these areas in the mid-1800s, resulting in clearing and overgrazing (Beadle, 1948), followed by the establishment of the Murrumbidgee Irrigation Area in the Midbidgee starting in 1914. Agricultural development and river regulation have resulted in much of the floodplain area being replaced by agriculture or isolated from natural inundation. The maximum period between river floods has more than doubled (4 to 10.5 years) while the average annual flooding volume has more than halved (CSIRO, 2008b). Since the Murrumbidgee is a losing river, responsible for recharging groundwater in most of its lower reaches, reductions in flow volume and changes in flow seasonality also directly influence floodplain watertables (CSIRO, 2008a). The Midbidgee region is now dominated by irrigation landuses (horticulture, rice and wheat) with intensive grazing, elevated watertables, and low levels of connectivity between vegetation patches. The Lowbidgee region is dominated by light grazing with irregular and limited flood irrigation, relatively low and falling watertables from the 1980s onward, and high levels of vegetation connectivity. Groundwater levels in the Midbidgee have fluctuated significantly in recent decades, with raised saline watertables due to irrigation seepage being a problem for a significant period until the long 'millennium drought' in the 2000's restricted irrigation and lowered watertables. Until recently, isolated remnant *E. largiflorens* patches in the Midbidgee were also often used as destinations or storages for irrigation drainage or surplus water.

A total of 33 sites were surveyed, all greater than 10 ha in size. Seventeen were in the Midbidgee and were chosen to span a range of irrigation intensities (high, medium, low). The 16 Lowbidgee sites were all classed as 'very low' intensity (Table 2). These classes were based on the area and frequency of irrigation surrounding the site, the density of irrigation channels and other agricultural and urban landuses, and the relative isolation of each site from other woodlands. Annual GIS map layers (shapefiles) describing rice irrigation areas for the years 1997/1998 – 2008/2009 were supplied by Murrumbidgee Irrigation. These layers were intersected with another GIS layer describing circles of 5 km radius around each site. The total area of irrigation within each circle was calculated for each site across all years, as well as the cumulative area of irrigation for the entire period (the sum of irrigation areas year upon year). These variables were chosen to represent the potential availability of water to trees at each site through soil and groundwater seepage, raised water tables, and irrigation drainage. Grazing intensity was rated as light, medium or heavy, based on management history provided by the owner and the physical evidence of grazing of the site. Heavier grazing was associated with sites having higher surrounding irrigation intensity. The inundation history of each site was obtained from landholders and GIS information and was represented by three variables: prior wetting frequency, time since the site was last wetted and time since the adjacent land area was last wetted (Table 2). Inundation history was recorded regardless of water source (irrigation, natural flooding or managed environmental flows). Most levels of irrigation intensity had a range of levels within the inundation variables, although there was a tendency for the high intensity irrigation sites to have had no wetting in the previous two years (Table 2).

Field surveys and laboratory photo assessments

Photographic vegetation assessment was used, in order to improve the efficiency of data collection and reduce field-time. At each site, three standardised digital photographs were taken at 24 evenly distributed points along four 500m transects 200m apart:

1. A full-frame photo of the nearest unobscured entire single adult or mature tree, from base to top and full width, portrait or landscape view.
2. A landscape view community photograph with the horizon line at the middle of the image
3. A groundcover photo taken at approximately 1.5 m perpendicular from the ground, using forced flash and avoiding shadows.

The cameras used had 28mm wide-angle lenses, 5x optical zoom (5mm-25mm), and produced 12.1 megapixel digital images of 2-3 megabytes. Surveys were conducted in November and December 2009, and images were assessed in detail on-screen in the laboratory. The variables recorded for each of the three photo types are summarized in Table 3. Tree and landscape image assessments were done at 37% zoom on large 380x300mm monitors unless otherwise specified. Tree flowering was recorded at 100% zoom.
Tree crown density and death scores were formulated to be compatible with Souter *et al.* (2009) survey methods and were assessed from images of individual adult or mature trees. The crown death score indicates long-term effects on tree condition (i.e. how much of the tree has died), while the crown density score represents more recent effects on tree condition (i.e. how healthy are the remaining portions of crown – influenced by recent leaf growth, epicormic or otherwise).

Tree and shrub abundance measures comprised counts of distinctly individual trees and shrubs for each image, excluding those that formed part of the blurred horizon line, were indistinct because they were too far away or too close to other trees, or that were <50% within the image. When numerous trees were present in the foreground, counts included trees where only the trunk was visible. Care was taken not to overestimate because of multistemmed individuals. When counting shrubs, size was estimated including dead or dormant portions. If shrubs formed a continuous band and individuals could not be distinguished, a count of 50 was given. It was not possible to distinguish large clumped forbs from sub-shrubs <1 m tall, so all green groundlayer clumps were counted as sub-shrubs. This was deemed acceptable because the majority observed in the field were sub-shrub species.

Six individual tree size classes were recorded as present or absent in the landscape images: Aged-mature, mature, adult, pole, sapling, and seedling. A count of the number of tree size classes present included both live and dead individuals. Aged-mature and mature trees typically contained hollows. For analysis, these classes were reduced to three: Old (aged-mature and mature), adult (adult and pole), and young (sapling and seedling). A large woody debris score was measured by counting all pieces of woody debris within the image estimated at >10cm diameter. If a complex fallen branch was present, the number of points touching the ground was counted and included in the overall score. Where high shrub and grass densities were present, the visibility of large woody debris was reduced and was therefore probably underestimated; however this occurred for a limited number of images.

Groundcover images were assessed using a point intercept sampling program 'PointSampler' as an add-in within ARCGIS to rapidly code cover classes (Gobbett and Zerger, 2011). PointSampler zooms an image to a pre-set number of random sample points in a shapefile (in this case, 50 points per image). Coding of the cover class observed at each point is done using a single keystroke and the image is automatically zoomed to the next sample point. Coded values are saved in the shapefile, and then exported for calculation of percentage cover for each variable within each image. During the image assessment process, the presence of three key indicator plants was also recorded separately: a) *Sclerolaena spp* (usually the native *Sclerolaena muricata* 'Black Roly Poly'); species from this genus are often increasers, indicative of change, overgrazing, overutilization or poor soil condition, and are intolerant of frequent inundation; b) *Hordeum spp* (Barley Grass); exotic annual weeds associated with terrestrialisation, grazing and stock camps, unusually high soil fertility, bare soil areas, and slightly saline conditions, intolerant of inundation but establishes rapidly following rain; c) *Muehlenbeckia florulenta* (Lignum); a native shrub which prefers regularly flooded low-lying clay floodplain soils, but is also drought-tolerant.

Analyses

Prior to analysis, counts of live, dead, and total numbers of trees and shrubs >1m tall were log transformed, and groundcover point intercept proportions were arcsine transformed. A set of possible explanatory models for each response variable were fitted in Program R (R Development Core Team, 2007) and Adjusted Akaike Information Criterion (AICc) was calculated from the minimised negative log-likelihood, using standard formulae to compare models (Burnham and Anderson, 2002). Normal errors were used and diagnostic tests of the best fitting models for each (transformed) variable confirmed an adequate fit to the data. Inferences were based on the relative support for the different models and the size of the effects from the models with most support. Models were run for all sites as well as separately for sites from each region (Midbidgee and Lowbidgee), because not all explanatory variables were relevant to each region. Interaction models were not included due to insufficient numbers of sites. For variables which were unlikely to be influenced by water-related factors outside of the vegetation patch, models involving surrounding rice area or time since wet adjacent to the patch were not run.

Results

All sites

Regions differed significantly in terms of both tree condition and large shrub abundance. Trees in the Lowbidgee region were in significantly worse health than trees in the Midbidgee, with more tree crown death and lower tree crown density. There were also more dead trees (and hence fewer live trees) in the Lowbidgee region (Table 4, Figure 2). In contrast, the Lowbidgee region had more shrubs >1m tall and less *Hordeum* than the Midbidgee (Table 4, Table 5, Figure 2). Only five sites within the Midbidgee recorded shrubs >1m tall, and of these, one site had significantly greater densities and was the only site at which *Muehlenbeckia* occurred.

Landuse intensity zone effects were most strongly supported for several variables affecting habitat structure. In particular, the very low intensity zone (i.e. the Lowbidgee region) had significantly fewer young trees, less *Sclerolaena*, and more *Muehlenbeckia* than other zones. The low intensity landuse zone had significantly more old and young trees. Sites from the medium intensity and low intensity zones contained significantly more *Sclerolaena* than other zones, but no *Muehlenbeckia* (Table 4, Table 5, Figure 3).

Wetting history effects were not consistent between regions or landuse intensity zones (see results for Lowbidgee sites), and hence these models received low support when regions or zones were considered together. However, across all sites, those with a prior wetting frequency of <1 event in 10 years had fewer tree size classes and significantly greater cryptogam groundcover than sites with a history of more frequent wetting (Table 4, Table 5).

Midbidgee sites

Within the Midbidgee region, there was strong support for relationships between landuse intensity zone and the presence of both *Sclerolaena* and young trees, with patterns as already described above for all sites, but there was no support for relationships between vegetation and flooding (Table 4, Table 5). The presence of flowering was related to the time since a site was last wet, with significantly more flowering trees in sites that had not been wet for >20 years, however this result was strongly influenced by a single outlier site in the >20 years category (Figure 4). In terms of the groundlayer, the presence of *Hordeum* and organic litter cover were affected by prior wetting frequency, but without any clear trends.

Lowbidgee sites

Within the Lowbidgee region, there was strong support for relationships between prior wetting frequency and multiple tree condition and habitat structure variables. Increasing prior wetting frequency was associated with decreasing tree crown death and increasing crown density, with tree condition at its best in sites with yearly or alternate year flooding (Figure 5 e & f). Sites with a prior wetting frequency of <1 in 10 years contained fewer old trees, no young trees, and consequently fewer tree size classes, indicating a loss of tree-related habitat structure (Figure 5 a & b). In contrast, large shrubs >1m tall were most abundant at the driest and wettest ends of the prior wetting frequency spectrum. Large shrubs were significantly less common in sites with a prior wetting frequency of 1 in 10 years, with an increasing trend in abundance with increasing wetting frequency (Figure 5 c). In particular, the inundation-dependent *Muehlenbeckia* was significantly more common in sites with yearly or alternate year wetting (Figure 5 d). The smaller, dry-tolerant *Sclerolaena* in the Lowbidgee was absent from sites with yearly, alternate year or 1 in 5 year wetting frequencies, and significantly more common in sites with a prior wetting frequency of <1 in 10 years (Figure 5 g). Similarly, cryptogam ground cover was greatest in sites with prior wetting frequencies of <1 in 10 years, and lowest in sites with yearly or alternate year flooding (Figure 5 h). The only variable for which the time since a site was last wet was a significant driver was the presence of flowering trees, with significantly more flowering trees present in sites wet within the previous 2 years (Figure 4).

<u>Discussion</u>

Regional differences

There were significant regional differences in the structure and condition of *Eucalyptus largiflorens* woodlands in this catchment. Overall, trees in the Lowbidgee woodlands were in worse condition than those in the Midbidgee. Although the Lowbidgee has lower mean and median annual rainfall than the Midbidgee over the long term (86 and 75 mm lower respectively), during the millennium drought (2000-2009) rainfall was more similar between the two regions; with the Midbidgee suffering approximately 100 mm p.a. rainfall deficits and the Lowbidgee relatively smaller reductions (mean 24 mm and median 53mm). During this period trees in the Midbidgee were probably buffered by continued access to elevated water tables, and in some areas relieved of significant stress by lowering of excessively high water tables. Before the introduction of irrigated rice farming, the watertable in most of the Midbidgee was about 20 m below the surface. In 2001 the watertable for around 85 percent of the mid-Murrumbidgee irrigation area was within two metres of the surface, and some areas were experiencing waterlogged soils (Singh *et al.*, 2005). These problems increased every winter and whenever rainfall was higher than usual. However the 10-year drought through the 2000's reduced watertables by 1-3 metres (CSIRO, 2008a) – keeping groundwater well within the reach of *E. largiflorens* trees through the drought, but reducing the problems associated with waterlogging and salinity. Simulations suggest that the growth response of *E. largiflorens* to a long term lowering of watertable depth by 1 m will be greater than that induced by small increases in flooding frequency (Slavich *et al.*, 1999), so it may be expected that such changes in the Midbidgee would improve tree condition more and across a broader scale than increases in flooding frequency. In addition, unseasonal high river flows in summer may have increased the buffering effect by recharging local Midbidgee aquifers during the summer months, the period of highest evapotranspiration demand.

In contrast, recovery of aquifers in the Lowbidgee has been impaired by increased groundwater extraction and river regulation over the same drought period. Most groundwater bores have not been metered or licenced, and water tables in the Lowbidgee have dropped significantly since 1980, reducing access to groundwater for trees. The last major flood to reach Lowbidgee *E. largiflorens* communities was in 1989, and only a few areas received supplementary managed water prior to 2009. This lack of surface flooding would also have reduced replenishment of shallow groundwater in the Lowbidgee, exacerbating the situation (CSIRO, 2008a). The effects of irrigation water delivery upon river seasonality and groundwater recharge are also much reduced in the Lowbidgee compared to the Midbidgee. Consequently the condition of *E. largiflorens* communities in the Lowbidgee has been adversely affected to a greater degree by the recent drought than that seen in the Midbidgee, as the Lowbidgee has had no equivalent buffers.

In the absence of groundwater buffering, flooding for vegetation condition becomes more important, hence the clear vegetation responses to wetting in the Lowbidgee, but few relationships in the Midbidgee. In particular, the significantly greater responses recorded for Lowbidgee sites receiving regular wetting (yearly or alternate years) indicate that in the absence of sufficient rainfall and groundwater, more frequent flooding is required to maintain *E. largiflorens* in good condition (less crown death and greater crown density) than would normally be required. For example, modelling of 80 sites at Chowilla on the lower Murray River floodplain showed that *E. largiflorens* tree health was significantly greater where flooding occurred more frequently than 1 in 10 years (Taylor *et al.*, 1996). Flood frequency is even more important in areas where salinity is a problem, because flooding flushes salts away from the root zone, reducing short-term salt stress in trees. Infiltration of floodwater around *E. largiflorens* can be 2-17 times faster than on adjacent bare ground (Akeroyd *et al.*, 1998; Bramley *et al.*, 2003). In the lower River Murray floodplain, low-salinity soil water overlying highly saline groundwater is the water source used by *E. largiflorens* at most sites (Jolly and Walker, 1996; Holland *et al.*, 2006). Recharge of this low-salinity deep soil water via floodwaters and vertical infiltration of rainfall is important for trees growing in depressions and on extended floodplains (Jolly and Walker, 1996; Akeroyd *et al.*, 1998; Holland *et al.*, 2006).

Another factor that may have contributed to better tree health in the Midbidgee compared to the Lowbidgee is greater flood duration and depth when using drainage or excess water. Surface watering of *E. largiflorens* woodland remnants in the Midbidgee is now almost entirely under management control, and natural flooding is rare. *E. largiflorens* remnants in this region were historically often used to collect irrigation runoff or as storages for unwanted water. In some cases inundation was brief and shallow, rapidly providing stock feed through groundcover response to flooding. In other cases, inundation was deeper and of longer duration. In contrast, flooding of Lowbidgee *E. largiflorens* woodlands has generally been shallow and of relatively short duration, except for woodlands lining distinct creeks used for water transferral and some small ‘managed’ sites. Greater inundation depth and duration in the Midbidgee will have raised the elevation and reduced the salinity of shallow groundwater, benefiting vegetation up to thresholds of tolerance, over which it will have reduced tree health or killed trees and affected species presence in the groundlayer and shrublayer (and hence woodland structure).

A third factor contributing to tree health could be incidental insect control. Fertilisers, pesticides and herbicides are used more heavily and extensively in the Midbidgee than in the Lowbidgee. Most farming areas of the Lowbidgee are managed with minimal chemical input to main their status as ‘certified organic’. It is possible that overspray and run-on of fertilisers in the Midbidgee may benefit *E. largiflorens* in the short term, while pesticides may reduce parasite loads and damage to foliage. However the influence of these factors, together with herbicide overspray and run-on, is not well understood – and they are more likely to influence groundlayer composition and condition than tree condition.

In terms of structure, the relative abundance of shrubs in the Lowbidgee sites probably reflects less intensive grazing practices,. Similarly, the abundance of *Hordeum* in the Midbidgee reflects more intensive grazing and artificial fertilisation in this region in general, as well as greater soil salinity and rainfall. The lack of shrubs in the Midbidgee may also be related to waterlogging from drainage water or raised watertables during wet periods – although most floodplain shrubs are flood-tolerant, excess flood duration or depth will kill them and their seeds. However grazing intensity is far more likely to be the main driver. Shrubs are particularly important structural components of woodlands for fauna, providing nesting and foraging habitat, protection from predators, and increasing the number of niches available within a given area. It is widely recognized that woodlands with multiple vegetation layers including shrubs support greater fauna diversity and abundance than woodlands without such layers. For example, complex vegetation structure is usually associated with greater bird species richness, diversity and abundance (Watson *et al.*, 2001; Seddon *et al.*, 2003; Briggs *et al.*, 2007). Sympathetic grazing management of *E. largiflorens* remnants known to have supported shrubs in the past, or that host shrubs in the present, could produce significant benefits for biodiversity. Such management would be enhanced by judicious use of environmental water to encourage shrub growth and reproduction – especially for lignum.

Landuse context differences (irrigation intensity zones)

Overall, there were no clear linear relationships between intensity of surrounding landuse and vegetation condition and structure when the very low intensity zone (Lowbidgee region) was included. However within the Midbidgee, vegetation structure tended to be simpler at sites from the high intensity zone, compared to the medium and low intensity zones. Specifically, landuse intensity zone was related to variables that create habitat complexity in woodlands, such as the presence of old and young trees, and the abundance of shrubs such as *Sclerolaena*. Old trees usually bear hollows that are important for many fauna species, while young trees and shrubs are important foraging substrates and cover for native fauna. It is well-known that there is a positive relationship between the number of vegetative structural levels and biodiversity – particularly for birds. The differences in structure between landuse intensity zones therefore have implications for diversity in the fauna communities that use *E. largiflorens* woodlands, because different guilds and species vary in their habitat preferences. Sites in the medium and low intensity zones also had greater vegetative groundcover than sites in other zones, indicating greater overall primary productivity with positive implications for secondary productivity and fauna abundance. Although the presence of *Sclerolaena* in these zones indicates grazing pressure and changes to soil condition, it also provides another food source for fauna, and is likely to further increase secondary productivity in these areas.

The relative lack of young trees in the very low intensity zone (Lowbidgee) and the high intensity zone is of concern for the long-term future of *E. largiflorens* woodland communities in those areas. It is unclear whether the low numbers of young trees are due to inadequate conditions for flowering, seed production and seed germination (for example, appropriate flood extent, depth and duration), or due to post-germination problems such as insufficient follow-up flooding or rainfall, or grazing impacts. Seedlings and saplings of *E. largiflorens* that germinate as a consequence of flooding tend to be spatially clumped rather than evenly distributed (George 2005). The continuing presence of *Muehlenbeckia* and relative lack of *Sclerolaena* in the very low intensity zone (Lowbidgee) reflects more intact ground and shrub layers because of lower grazing pressure.

Flood history differences

The patterns observed in the Lowbidgee confirm that flow regimes (prior wetting frequency) affect both structure and condition in the long term; but that individual flood events (time since last wet) are stronger drivers of condition and reproductive effort in the short term. The presence of significantly greater numbers of flowering trees in sites wet within the previous two years indicates the importance of flooding for maximising reproduction as well as recruitment. Flowering in *E. largiflorens* is known to occur in response to flooding or rainfall regardless of the time of year, with the quantity of buds, flowers and seed produced and retained determined by both the condition of the parent trees and water availability in the previous year (Jensen *et al.*, 2008). Seedfall coincides with the natural flood season, presumably to aid dispersal, and seedlings rely on local rainfall and flooding for survival (Jensen *et al.*, 2008). Because trees in the Lowbidgee are in generally worse condition overall, they are likely to produce less flowers, buds and seed than trees in the Midbidgee. This together with insufficient rainfall and surface flooding during the summer months is a major restriction on *E. largiflorens* recruitment and persistence in the Lowbidgee. The absence of young trees in sites with a prior wetting frequency of less than one event in 10 years reflects these issues. It is likely that these sites currently lack sufficient regeneration to compensate for adult mortality, as has been found for *E. largiflorens* sites in Murray River floodplains downstream (George *et al.*, 2005), and that they are therefore unlikely to persist in the long term without intervention.

Habitat structure in these communities is greatly affected by the presence of shrubs, which are in turn strongly affected by wetting frequency. This structure is generally provided by either *Muehlenbeckia florulenta* in wetter sites or *Chenopodium nitrariaceum* (Nitre goosefoot) in drier sites. Duration of inundation is as important for these species as frequency: *Muehlenbeckia* prefers ponding of water for several months every 1-3 years, and tolerates inundation for up to 12 months and dry periods of up to 10 years (Roberts and Marston, 2000). *Chenopodium nitrariaceum* is found in drier sites, is less tolerant of long-duration flooding, suffers under deep flooding and does not appear to require frequent wetting to survive and reproduce, though little is known of precise limits. Very dry sites with a prior wetting frequency of less than one event in 10 years appear to lose the habitat provided by young trees, old trees and their hollows, are invaded by *Sclerolaena*, and undergo soil surface changes indicated by increased cryptogam growth. Consequently flood history is just as important a driver of woodland structure as it is of woodland condition.

Overall, it is to be expected that floodplain woodlands with flood histories closer to suggested 'natural' regimes will be in better condition and will have greater structural complexity than other floodplain woodlands. This study has confirmed this, however it has also demonstrated that for *E. largiflorens* woodlands this depends on the availability of groundwater, and is more the case for tree condition than for structure. Where groundwater is abundant, of good quality, and easily accessed, flooding frequency is less important for trees. Where groundwater is less available, thresholds exist in flood frequency within *E. largiflorens* communities that affect both tree and understorey structure and condition. Specifically, flooding less than once every 10 years leads to decline, and regular flooding of approximately every one to two years may be necessary during drought in areas of higher salinity where extraction of groundwater is leading to falling watertables. These results emphasise the importance of maintaining healthy black box remnants in irrigation areas for biodiversity persistence, and suggest that rehabilitation of black box communities in the Lowbidgee using managed flooding could bring significant biodiversity benefits to the region.

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Tables

Table 1 Study region climate statistics

	Midbidgee (Griffith NSW)	Lowbidgee (Balranald NSW)
Latitude and longitude (approx.)		
Mean annual rainfall (mm)	406	320
Mean annual rainfall 2000-2009 (mm)	*305 (-101)*	*296 (-24)*
Mean maximum temperature (°C)	23	24
Mean minimum temperature (°C)	10	10

Table 2 Summary of irrigation intensity and site inundation factors of the 33 sites sampled in two regions.

Region	Surrounding irrigation intensity	Site	Prior wetting frequency	Time since wet within	Time since wet adjacent
Midbidgee	High	4	1 in 10 years	>20 years	2-10 years
		3	1 in 5 years	10-20 years	2-10 years
		11	1 in 5 years	10-20 years	2-10 years
		2	Yearly or alternate	10-20 years	2-10 years
		12	Yearly or alternate	10-20 years	2-10 years
		1	Yearly or alternate	10-20 years	2-10 years
	Medium	6	1 in 5 years	>20 years	>20 years
		7	1 in 5 years	2-10 years	2-10 years
		10	1 in 5 years	2-10 years	2-10 years
		8	Yearly or alternate	0-2 years	2-10 years
		9	Yearly or alternate	0-2 years	2-10 years
		5	Yearly or alternate	10-20 years	2-10 years
	Low	15	1 in 10 years	2-10 years	2-10 years
		13	1 in 10 years	2-10 years	0-2 years
		16	1 in 5 years	0-2 years	2-10 years
		17	1 in 5 years	0-2 years	0-2 years
		14	Yearly or alternate	0-2 years	0-2 years
Lowbidgee	Very low	33	< 1 in 10 years	>20 years	0-2 years
		32	< 1 in 10 years	0-2 years	0-2 years
		29	1 in 10 years	10-20 years	2-10 years
		22	1 in 10 years	2-10 years	0-2 years
		24	1 in 10 years	2-10 years	0-2 years
		23	1 in 10 years	2-10 years	0-2 years
		28	1 in 10 years	2-10 years	0-2 years
		26	1 in 5 years	>20 years	2-10 years
		21	1 in 5 years	10-20 years	10-20 years
		20	1 in 5 years	10-20 years	10-20 years
		19	1 in 5 years	10-20 years	0-2 years
		25	1 in 5 years	2-10 years	0-2 years
		34	Yearly or alternate	0-2 years	0-2 years
		18	Yearly or alternate	0-2 years	0-2 years
		31	Yearly or alternate	2-10 years	0-2 years
		27	Yearly or alternate	2-10 years	2-10 years

Table 3 Vegetation response variables used in analyses. Each variable was assessed from 24 images per site, and either averaged to site level, or analysed as proportions of photos on which they were present per site.

Single tree photo	**Description**
Crown death score	Percentage of the total crown completely defoliated (0 =0%; 1 = 1-10%; 2 = 11-20%; 3 = 21-40%); 4 = 41-60%; 5 = 61-80%; 6 = 81-90%; 7 = 91-100%)
Crown density score	Percentage of skylight blocked by those portions of the tree crown that were foliated (0 =0%; 1 = 1-10%; 2 = 11-20%; 3 = 21-40%); 4 = 41-60%; 5 = 61-80%; 6 = 81-90%; 7 = 91-100%).
Frequency of tree flowering	Flowers visible on tree (Yes/No).
Landscape view	
Live tree count	Number of individual live trees visible in each image, excluding those that formed part of the blurred horizon line, were indistinct because they were too far away or too close to other trees, or that were <50% within the image.
Dead tree count	Number of individual dead trees visible in each image, excluding those that formed part of the blurred horizon line, were indistinct because they were too far away or too close to other trees, or that were <50% within the image.
Total tree count	Total number of individual trees visible in each image, excluding those that formed part of the blurred horizon line, were indistinct because they were too far away or too close to other trees, or that were <50% within the image.
Frequency of old trees	Old trees visible in image (mature or aged-mature; Yes/No).
Frequency of young trees	Young trees visible in image (seedling or sapling; Yes/No).
Number of tree size classes	Of 6: Seedling, sapling, pole, adult, mature, aged-mature.
Shrubs <1m count	Total number of individual subshrubs <1m tall visible in each image, excluding those that formed part of the blurred horizon line, or that were <50% within the image.
Shrubs >1m count	Total number of individual large shrubs >1m tall visible in each image, excluding those that formed part of the blurred horizon line, or that were <50% within the image.
Large woody debris (LWD) score	Count of all pieces of woody debris >50% within the image estimated at >10cm diameter. If a complex fallen branch was present, the number of points touching the ground was counted and included in the overall score.
Groundcover photo	
Bare %	Bare soil, rocks and stones.
Live plants %	Any living plant, including trunks of living trees and upright dormant plants.
Dead plants %	Standing dead plants.
Organic litter %	Dead, detached plant material <2cm diameter.
Woody ground cover %	Dead, detached woody plant material >2cm diameter.
Cryptogams %	Any visible cryptogams, e.g. lichen.
Frequency of *Sclerolaena* spp.	*Sclerolaena* species visible in image (Yes/No).
Frequency of *Hordeum* spp.	*Hordeum* species visible in image (Yes/No).
Frequency of *Muehlenbeckia*	Lignum (*Muehlenbeckia*) species visible in image (Yes/No).

Table 4 Adjusted Akaike information criteria (AIC_c) for models describing relationships between site response variables derived from tree and landscape photographs, and water and landscape factors. Models were run for all sites as well as separately for sites from each region (Midbidgee and Lowbidgee). The most supported models are underlined and bolded while models with an AIC_c within 3 of the most supported models are bolded. Null is the model where response variables were not related to any factors, i.e. it is the mean of the sites.

	Crown death score	Crown density score	Number of live trees	Number of dead trees	Number of trees (total)	Presence of tree flowering	Presence of new buds / leaves	Presence of old trees	Presence of young trees	Tree size class count (average)	Number of shrubs <1m	Number of shrubs >1m	Large woody debris score
	AICc	**AICc**	**AICc**	**AICc**	**AICc**	**AICc**	**AICc**	**AICc**	**AICc**	**AICc**	**AICc**	**AICc**	**AICc**
All sites													
null	101.3	90.2	**42.9**	46.9	**32.2**	148.2	255.8	257.8	270.2	33.8	**251.3**	115.5	**108.5**
Irrigation intensity zone	84	**71.1**	**42.9**	34.7	35.7	**141.6**	**247.6**	**233.4**	**218.9**	35	257.4	99.1	115.1
Prior wetting frequency	102	90.4	50.3	48	39.8	152.6	255.3	243.7	256.4	**29.3**	**254.1**	118.2	114.9
Region	**79.5**	**69.6**	**40.2**	**30.8**	**33.1**	146.1	253.2	258.7	236.5	34.6	**252.7**	**95.3**	**110.8**
Time since wet adjacent	95.2	84	45.5	43.1	38.1	149.2	259	261.2	243.5				
Time since wet within	106.5	95.7	49.5	51.1	38.9	**138.8**	251.6	243.6	265.7	37.2	**251.9**	122.9	114.9
Midbidgee sites													
null	**27**	**28.8**	**18**	**-0.6**	**17.2**	87.3	133.4	165.8	157.8	**17.8**	**136.6**	**48.4**	**57.9**
Irrigation intensity zone	31.3	**27.8**	**20.8**	**1.2**	20.5	83.3	**128.3**	141	**140.8**	**18.3**	142.6	53.1	63.2
Patch size	**29.9**	**29.6**	**18.7**	**1**	**17.5**	83.3	**127**	**133.5**	157		**139.6**	**49.1**	**58.8**
Prior wetting frequency	31	32.8	23.9	**3**	23	83.5	133.5	**136.2**	163.4	23.9	**137.3**	52.9	62.4
Cumulative rice area	**29.9**	**30.1**	**20.5**	**0.2**	**19.9**	86.8	**126.2**	161.1					
Total rice area	**29.9**	**30.1**	**20.2**	**-0.2**	**19.6**	86.3	**128.2**	163.8					
Time since wet adjacent	32.3	**29.9**	24	5.4	23.2	87.2	137.7	145.1					
Time since wet within	37.5	36	26	5.9	25.7	**75.7**	139.3	151.3	**143.8**	**17.9**	140.6	57.8	67.1
Area of remnant woodland	**29.3**	**29.2**	**20.4**	**2.2**	**19.7**	86	136	165.3	155.4		**139.6**	**50.2**	**59.8**
Lowbidgee sites													
null	48	**40.9**	**24.4**	**24.9**	**18.8**	59	119.9	93.1	78.8	**19.7**	**116.7**	49.6	**55.9**
Prior wetting frequency	**43.8**	**39**	32.7	**26.8**	25.6	53.5	**92.6**	**89.8**	**59.4**	**16.9**	**118.6**	**43.4**	64.5
Time since wet adjacent	51.5	45.8	30.2	29.3	25.2	63.7	124.5	98.5					
Time since wet within	50.1	42.5	29.1	30.7	23.4	**49**	112.6	96.6	81.7	**18.5**	123.1	49.1	62.9

Table 5 Adjusted Akaike information criteria (AIC_c) for models describing relationships between site response variables derived from groundcover photographs, and water and landscape factors. Models were run for all sites as well as separately for sites from each region (Midbidgee and Lowbidgee). The most supported models are underlined and bolded while models with an AIC_c within 3 of the most supported models are bolded. Null is the model where response variables were not related to any water or landscape factors.

	Live ground cover	Organic litter cover	Bare ground cover	Woody ground cover	Cryptogam ground cover	Presence of *Sclerolaena*	Presence of *Hordeum*	Presence of *Muehlenbeckia* (lignum)
	AICc	**AICc**	**AICc**	**AICc**	**AICc**	**AICc**	**AICc**	**AICc**
All sites								
null	<u>**-5.5**</u>	<u>**-59.1**</u>	**-21.6**	**-106.7**	-39.8	143.2	284.6	122.7
Irrigation intensity zone	**-4.5**	-53.1	<u>**-22.1**</u>	<u>**-108.4**</u>	-43.2	<u>**107.8**</u>	191	<u>**100.3**</u>
Prior wetting frequency	-0.6	**-58**	-15.5	**-106.4**	<u>**-49.3**</u>	148.7	251.1	106.5
Region	**-3.8**	**-58.4**	**-19.8**	**-107.7**	**-47.2**	119.4	<u>**187.1**</u>	103.7
Time since wet within	-0.1	-52	-17.3	-100.5	-33.9	148.9	278	123
Midbidgee sites								
null	<u>**4.2**</u>	**-29.7**	<u>**-1.2**</u>	**-58.3**	<u>**-35.7**</u>	84.9	171.2	28.7
Irrigation intensity zone	**5.8**	-23.4	**0.2**	<u>**-61**</u>	-32.6	<u>**73.8**</u>	175.7	25.9
Patch size	**4.5**	-26.8	**-0.8**	-57.9	**-32.7**	82.5	171.5	<u>**7.9**</u>
Prior wetting frequency	8.1	<u>**-32.4**</u>	**0**	-54.7	-30.8	89.5	<u>**149**</u>	27.1
Time since wet within	11.4	-19.5	6.3	-52.8	-32	90.9	170.8	29.3
Area of remnant woodland	7	**-29.8**	**0.8**	-56.1	**-33.2**	85.5	173.2	29.3
Lowbidgee sites								
null	<u>**-7**</u>	<u>**-25.8**</u>	<u>**-22.9**</u>	<u>**-47.3**</u>	-14.1	34.6	<u>**16.1**</u>	75.1
Prior wetting frequency	-1.5	-15.3	-19.7	-42.2	<u>**-20.3**</u>	<u>**29.6**</u>	20.7	<u>**60.3**</u>
Time since wet within	2.9	-18.6	-12.8	-37	-15.1	37.7	22.1	67.7

Figures

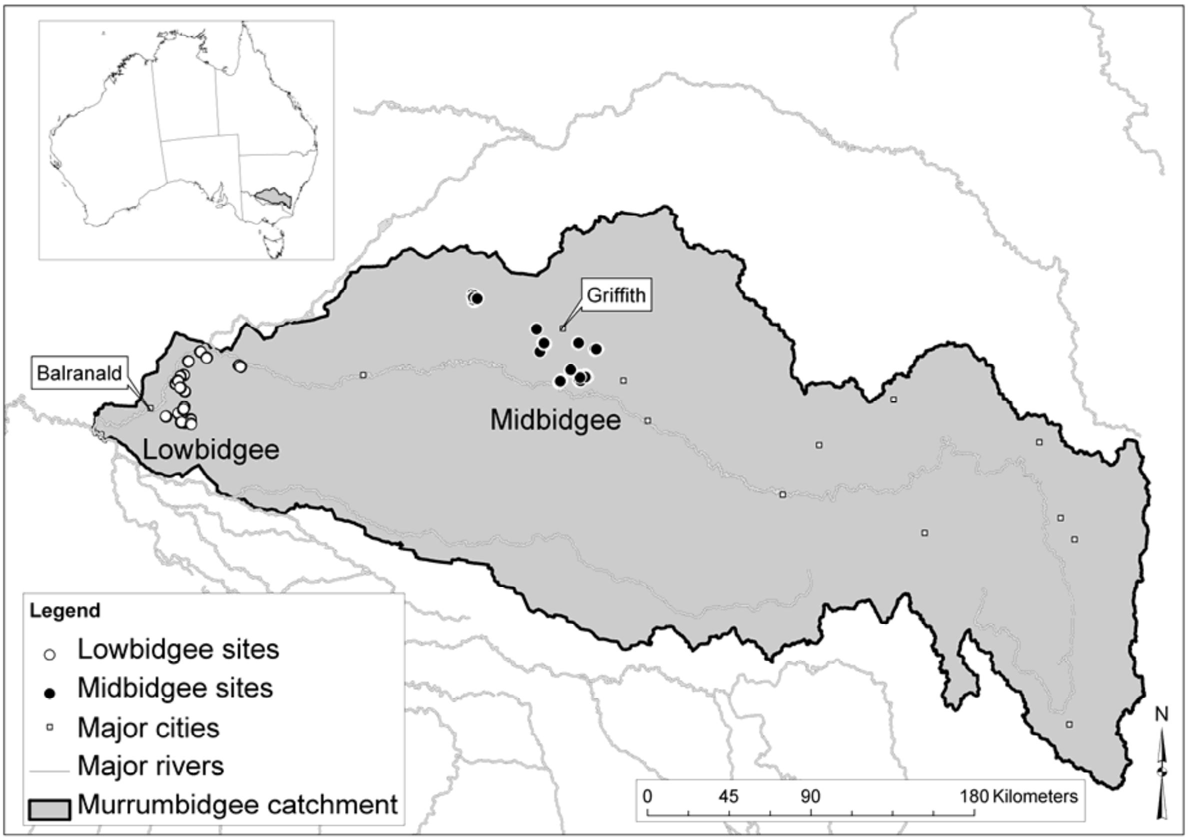

Figure 1 Region and site locations

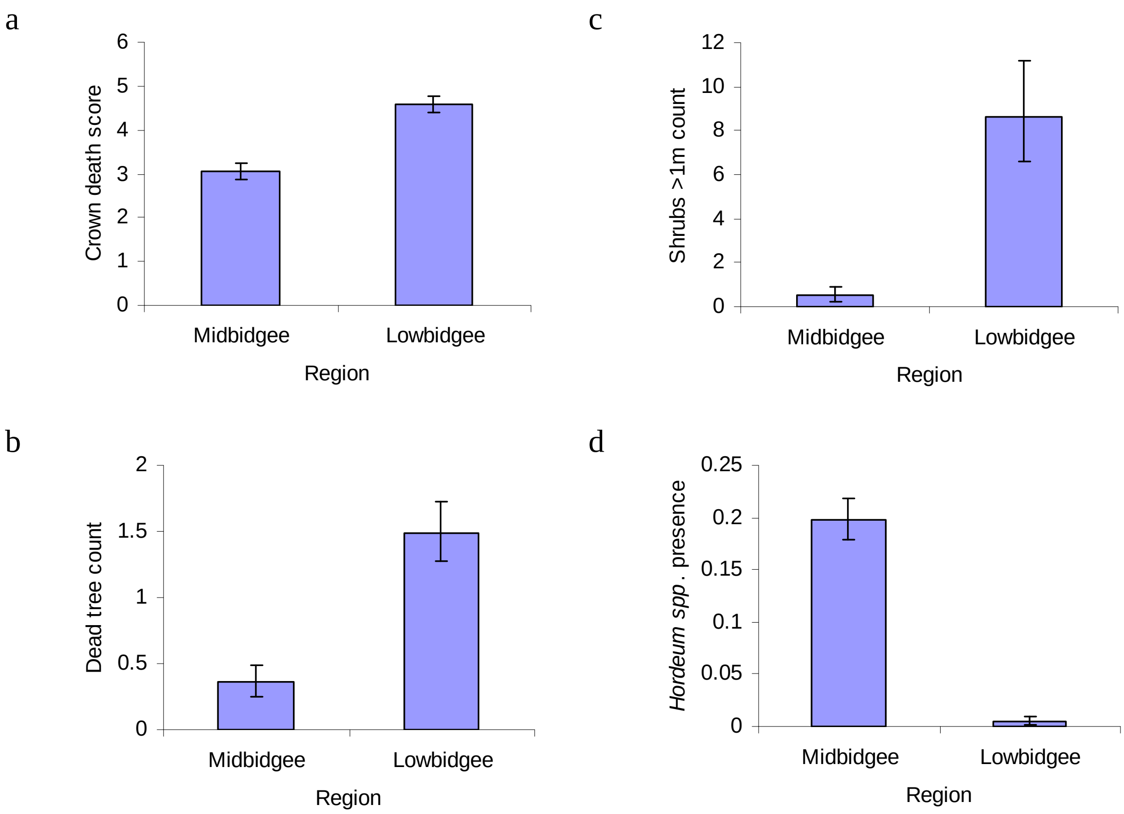

Figure 2 Regional differences in a) crown death score, b) dead tree count per photo, c) number of shrubs >1m tall per photo, and d) the proportion of photos with *Hordeum spp*. present, based on the models with most support. Fitted models with standard errors.

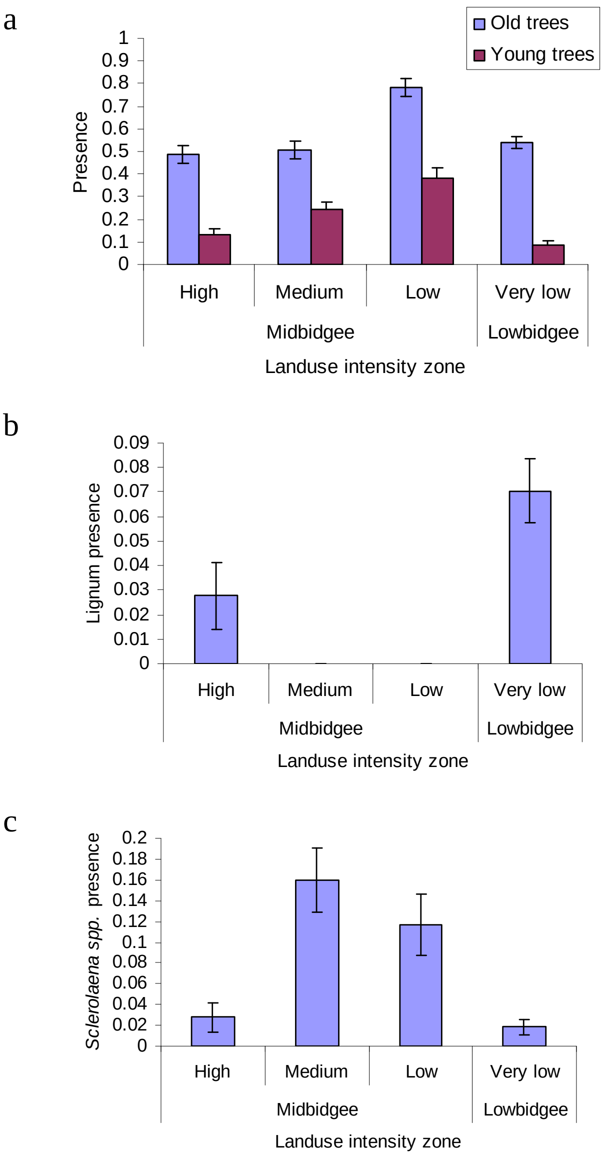

Figure 3 Landuse intensity zone differences in the proportion of photos with a) old and young trees b) lignum (*Muehlenbeckia florulenta*) and c) *Sclerolaena spp*., based on the models with most support. Fitted models with standard errors.

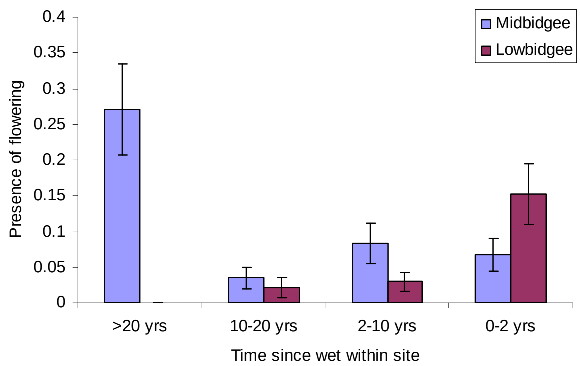

Figure 4 Time since wet within site and the proportion of photos with flowering trees present in Midbidgee and Lowbidgee regions, based on the models with most support. Fitted models with standard errors.

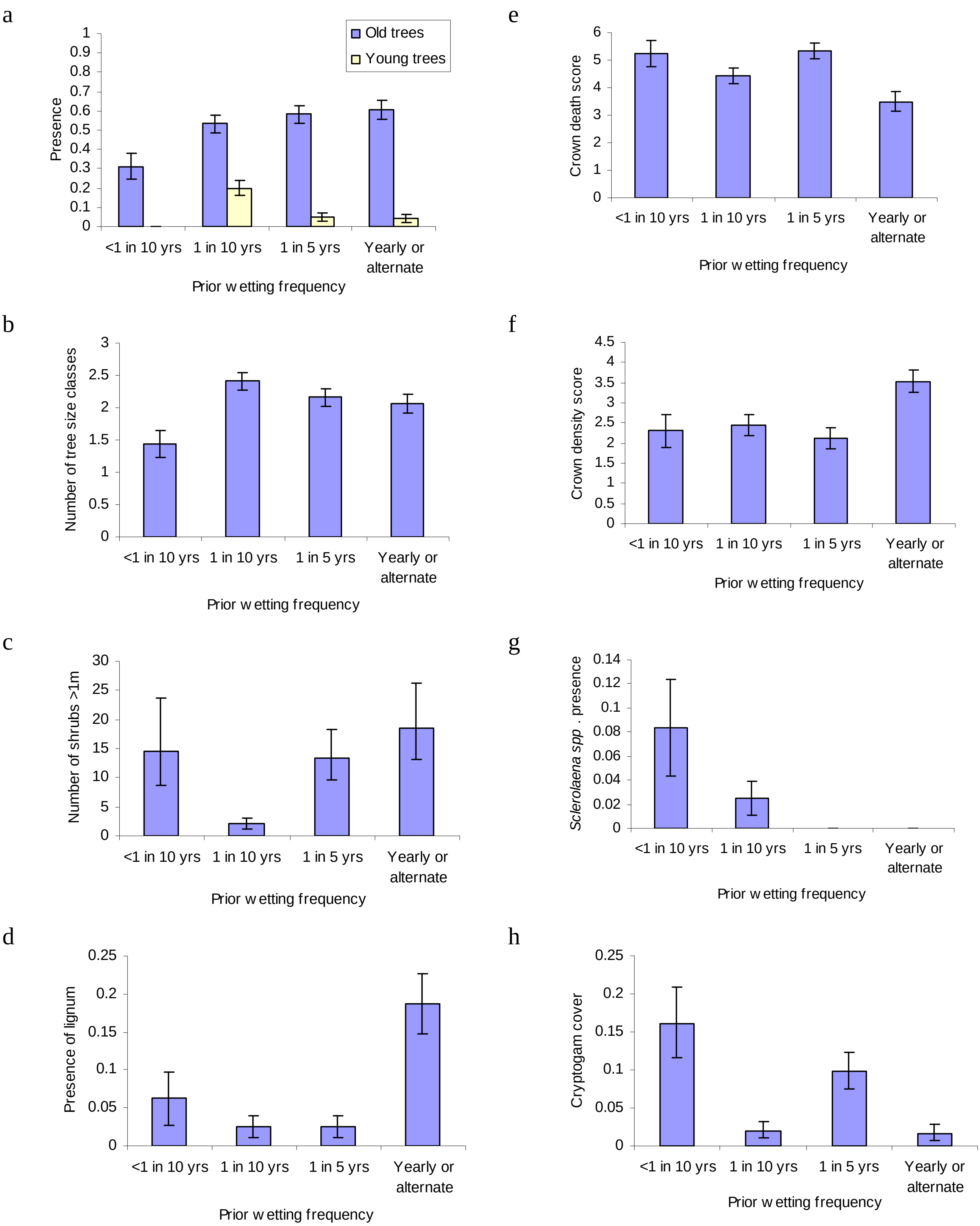

Figure 5 Vegetation responses to prior wetting frequency of a site in the Lowbidgee region, based on the models with most support. Fitted models with standard errors.

2011 RICE Field Day

Woodland condition in dryland and irrigated areas

Sue McIntyre[1], Tony Arthur[1], Heather McGinness[1], Janelle McGufficke[2] and Daryl Gibbs[2]

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Background

Irrigation practices have changed greatly over recent decades and farmers continue to adapt to changing environmental and economic conditions. Our research seeks to understand how these changes affect the biodiversity in the region, with a view to achieving co-existence of farming with native plants and animals.

The species most at risk are those that rely on areas of intact woodland or wetland vegetation, which are unable to live in constructed wetland habitats (e.g. rice fields, irrigation channels) and are sensitive to disturbances (e.g. grazing, earthworks).

Black Box (*Eucalyptus largiflorens*) woodlands and wetlands are especially important from this point of view and maintaining the health of these woodlands is an important part of managing habitat for sensitive native species.

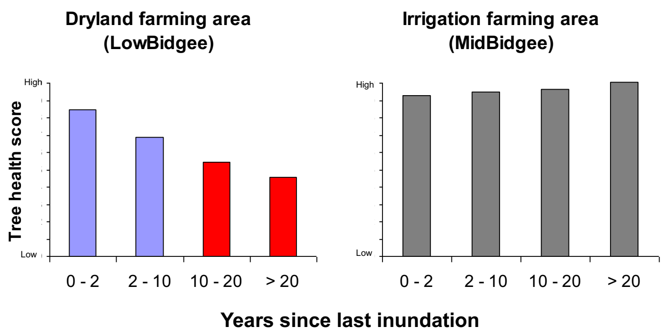
Black Box woodlands are influenced by local and regional irrigation practices. Our study is showing that tree health may have benefited from water used in the more intensive irrigation areas.

Methods

In spring 2009 we surveyed 33 Black Box woodland sites - 17 in irrigated parts of the MidBidgee (including the MIA) and 16 in the dryland LowBidgee area. Here we compare vegetation condition in the two areas and consider the effects of flooding in previous years on tree health and shrub abundance.

Tree health

The graph below shows that in the dryland LowBidgee area, woodland areas that have not had any flooding for ten years or more, are on average, in poor health (red bars) compared to the more recently flooded sites (blue bars). In the MidBidgee, tree health was generally good in the woodlands sampled, even if they had had no surface flooding for over ten years.

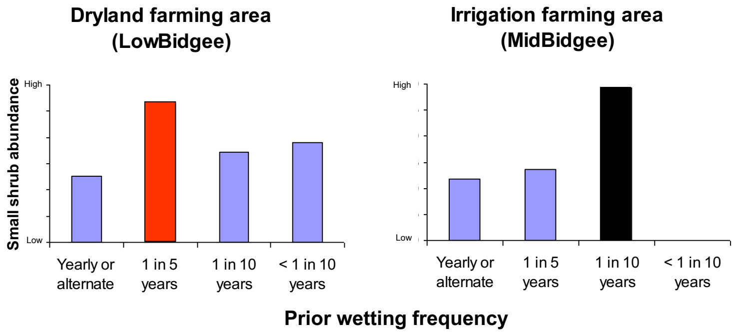


We suggest this difference might be due to the larger amount of water generally available in the MidBidgee landscape, allowing trees to access groundwater and to flourish even without surface inundation.

Shrubs

Shrubs are an important part of woodlands as they provide habitat for a diversity of plants and animals. Compared to the dryland LowBidgee area, there were very few large shrubs (e.g. lignum, nitre goosefoot) in the MidBidgee woodlands. This is possibly due to the effects of heavier grazing in the more intensively managed irrigated areas.

Small shrubs (< 1m high) showed a different pattern (below). Dry sites in the MidBidgee (black bar) had abundant Black Roly-Poly (*Bassia*), a coloniser of bare ground that is rarely grazed. There was a greater diversity of small shrubs in the LowBidgee sites, which were most abundant under moderate levels of inundation (red). This is similar to the flooding frequency thought to be normal for Black Box woodland (every 3 – 10 years).



Conclusions

Abundant water in irrigation landscapes can contribute to the health of remnant woodlands, but the effects of intensive management such as grazing need to be managed to promote biodiversity on farms.

More to come…

We are also analysing how irrigation water in the landscape affects insect abundance and bird communities in Black Box woodlands.

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NATIONAL PROGRAM FOR Sustainable Irrigation

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Appendix 3. Poster for RGA field day

Appendix 4

Abstract for the Irrigation Australia 2011 Regional Conference and exhibition

Biodiversity patterns in irrigated landscapes of the Australian Riverina.

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Introduction

Surveys indicate that much of the biodiversity in the irrigation areas of the Australian Riverina is found in Black Box (*Eucalyptus largiflorens*) vegetation remnants. These remnants are generally thought to be influenced by irrigation practices, and are likely to be affected by changes to water management – particularly the quantity and timing of water supply in the landscape as well as in the remnants themselves. However, these effects are not well understood. In this study we compared the structure and condition of black box communities, including the diversity and abundance of woodland birds, across sites in the Riverina. We asked how woodland condition and bird diversity varied with inundation history at a site, and with the intensity of irrigation in the surrounding landscape.

Methods

In spring 2009 we surveyed 33 sites at least 10ha in size. For each site the surrounding landscape was classed as 'high', 'medium', and 'low' irrigation intensity sites (located in the Midbidgee district) and 'very low' intensity sites (located in the Lowbidgee district). Intensity was determined from evidence of irrigation activity around the sites in the previous decade, including: area irrigated, irrigation frequency, proximity of irrigation channels, presence of native vegetation. Landholders provided inundation histories for each site, which were accordingly classified in to 'prior wetting frequency' classes and 'time since last wet'.

Vegetation assessments were based on 24 photo points located across each site which were used to identify structural attributes (e.g. shrubs) and to assess tree health. For the bird survey, we selected for 15 woodland species for observation: magpie, brown treecreeper, apostlebird, white-winged chough, striated pardalote, willy wagtail, noisy and yellow throated miner, rufous whistler, grey and pied butcherbird, grey-crowned babbler and magpie lark. We chose these as being insectivorous birds that are known to be resident in the region. They are therefore considered to have strong reliance on the condition of the sites, and their surrounds, and therefore be reliable indicators of habitat condition. The 15 species were counted on transects of approximately 2 km per site.

Results & Discussion

Woodland sites in 'very low' irrigation intensity area suffered poorer tree health. There were more dead trees, more extensive crown death and a lower proportion of trees flowering in the Lowbidgee compared with the Midbidgee where trees were generally in better condition. Within the Lowbidgee district, crown death decreased as prior wetting frequency increased, i.e. as prior wetting frequency increased from once every year or two, to once every 10 or more years, crown death became more extensive. The proportion of trees flowering increased if the site had been flooded more recently. This suggests that flooding is important for tree condition in the Lowbidgee floodplain, particularly given the dry conditions in that floodplain in the past decade. In the Midbidgee it appears tree condition during the millennium drought may have been supported by a higher water table due to surrounding irrigation, contrasting with the problem of water tables that were too high in the 1990's.

Large shrubs were rare in the Midbidgee, possibly reflecting clearing and grazing practices, while the Lowbidgee sites had relatively high densities of large shrubs, ranging from lignum in the wetter sites to nitre goosefoot in the drier sites. Shrubs are often associated with a higher diversity of woodland birds, but this pattern was not evident in our data. We found the highest numbers of our selected birds, and to a lesser extent higher diversity, in sites with low and medium surrounding irrigation intensity in the Midbidgee. Patch specialist species were also at higher densities in these sites, indicating that it was not just birds that would access the surrounding matrix that were at higher densities. Sites in the higher irrigation intensity area in the Midbidgee and the Lowbidgee sites had less than half the densities of those in the low and medium intensity irrigation areas. We found no clear relationships between birds and patch 'prior wetting frequency' and 'time since last wet', although these potential explanatory data were not easily collected and the categories used may need revision.

The results are interpretable if we consider the different amounts of food that is likely to have been available in these contrasting landscapes throughout the last decade. The Lowbidgee experienced limited flooding during this time, and rainfall averages 100 mm less than the Midbidgee so the region was generally drier. It is likely this led to greatly reduced food resources for woodland birds and hence lower densities. In contrast, birds in black box remnants in the low and medium irrigation areas may have benefited from higher water availability in the surrounding irrigated landscape, leading to higher densities. In the high intensity irrigation area lower bird densities may reflect the greater isolation of these sites from other woodland patches compared with the less intensive irrigation areas. More intensive surrounding irrigation may also be correlated with some other impact on the suitability of these patches for birds.

Overall our results provide further evidence that black box remnants in the Midbidgee are important for biodiversity and suggest that both trees and woodland birds can benefit from water in the surrounding irrigation landscape, particularly in low and medium intensity irrigation areas. Future studies should assess explicitly whether surface watering of these patches contributes to these biodiversity benefits.

Acknowledgements
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Appendix 5

Abstract for the 50th Australian Society for Limnology Annual Congress and 43rd New Zealand Freshwater Sciences Society Annual Congress

Black box (*Eucalyptus largiflorens*) floodplain woodlands: Flooding and surrounding irrigation intensity effects on vegetation and birds

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Introduction

The floodplain woodlands of inland Australia are water-dependent ecosystems that support globally significant species, extend the range of many species inland, and act as key drought refugia. Providing sufficient water to maintain the diversity, structure and productivity of these ecosystems is a challenge, because limited water availability forces prioritisation. Knowledge of ecological responses to flooding is essential to resolve this issue, but needs to be placed in the context of surrounding land and water use. We compared black box (*Eucalyptus largiflorens*) vegetation and woodland bird communities among a) four zones of irrigation intensity in the surrounding landscape; and b) eight inundation history classes. Preliminary results indicate that medium and low intensity irrigation zones have better overall vegetation condition and structural complexity than high intensity and very low intensity zones. Sites from these two zones also had more than double the abundance and diversity of birds than other sites, including patch specialists. In the very low intensity irrigation zone, increasing prior wetting frequency and decreasing time since last wet were associated with improved vegetation structure and condition; this was not the case in the other zones. Vegetation and birds in the medium and low intensity zones may have benefited from raised watertables and surface water associated with irrigation; in contrast, black box communities in the very low intensity zone have suffered falling watertables and greater isolation from surface water sources. Access to groundwater buffers communities where on-site flooding is insufficient, and where groundwater is less accessible, the importance of flooding is accentuated. These results show that black box remnants in irrigation areas are important and should be maintained for biodiversity persistence, and suggest that rehabilitation of black box communities via flooding could bring significant biodiversity benefits to areas with falling watertables.

Appendix 6

Discussion paper from workshops on 'Management of flood-dependent vegetation on irrigation farms – opportunities for environmental watering'

Management of flood-dependent vegetation on irrigation farms – opportunities for environmental watering

September 8-9th 2010 – Leeton and Colleambally

Background

As part of the National Program for Sustainable Irrigation, researchers from CSIRO Ecosystem Sciences are investigating the effects of current and future irrigation practices on biodiversity (native plants and animals) in the NSW Riverina. Our overview of current knowledge indicates that while rice bays can provide significant resources for native plants and animals, most species are still heavily dependent on the remaining native vegetation for all or part of their habitat. Therefore the amount and condition of this vegetation is of the utmost importance for conservation in the region.

Our particular focus for the project has been Black Box (*Eucalyptus largiflorens*) woodlands and their associated wetlands. While there are other important vegetation types on the Riverina, Black Box communities are the main vegetation type intimately associated with irrigation development. Their dependence on water beyond that of incident rainfall also means that they have been affected by irrigation development in many ways, including changes to the water regimes that they are adapted to. This has led to concerns about the health of the trees, and of the ecosystem overall. In response to this, the NSW Murray Wetlands Working Group has been pioneering the environmental watering of wetlands on private land.

In the interests of further exploring the issue of on-farm environmental watering, the CSIRO project team conducted two workshops in collaboration with the RGA Environmental Champions Program. Our premise was that with recognition of the water needs of flood-dependent vegetation such as Black Box, there would be opportunities for environmental watering on irrigation farms either through the provision of water for environmental purposes and/or through opportunistic water management within irrigation enterprises. The workshops aimed to explore with farmers the opportunities for managing and integrating environmental watering within current and future irrigation practices.

Our approach

Two workshops were held in an informal setting involving farmers from three districts: the Murrumbidgee Irrigation Area, the Murray Irrigation Area and the Colleambally Irrigation Area. Participants were from the established Environmental Champions Program run by the Ricegrowers Association of Australia. These groups had a history of open communication on environmental issues amongst themselves (Daryl – you might care to elaborate here on composition, numbers, experience etc of the groups, we did not do a head count farmers / agency people).

Our starting point was a scenario whereby water for environmental watering was provided in addition to irrigation allocations. There was no link to a specific program or policy, but as researchers, we had a general expectation that this could happen, based on the precedents in other parts of the country (e.g. stewardship schemes). Our aim was to identify practical opportunities and barriers to the management of environmental water. The questions in the following section formed the basis of a semi-structured discussion within the two groups.

The questions

The following questions were used as prompts for discussion and to ensure major issues were covered, rather than a formal structure for the reporting. We focussed on black box (and to a lesser extent red gum) woodlands during the discussion to avoid confusion owing to cross-referencing of vegetation types and in recognition of this being the water-dependent vegetation type associated with most farms and often intimately associated with farming practices. These woodlands and their associated swamps will be referred to in the document as 'wetlands'.

1) Current practice – What is the current condition of the native vegetation in the district, and how are people managing the patches of black box / red gum on their lands?

- Are the trees healthy?

- Is dryness a problem?

- Is water ponding for long periods a problem?

- Any observations about the wildlife in the native vegetation?

2) Extra water is available for environmental watering.

- What are the practical issues around it application to native vegetation (e.g. routes of delivery, timing)?

- What about running the water over a crop first or through the vegetation and then onto a crop?

3) Drainage water – can it be used for environmental watering?

- is there enough to bother with now that people have worked hard to reduce it?

- what are the water quality issues after it has run though a crop?

- What are the opportunities for native vegetation as storage?

- Can storage clean up drainage water?

4) Alteration to natural landscape overland flows – due to roads, irrigation canals, ditches, banks and bays.

- Is there any native vegetation that has been affected by changes to overland flow i.e. water starvation or accumulation.

- Are there any opportunities for changing landscape drainage to improve the water regimes of native vegetation.

5) Any other issues or opportunities?

The conclusions

While each workshop had a slightly different flavour, the emerging themes were similar and there was a general level of enthusiasm for the idea of environmental watering, particularly from the people who had actually tried it on their own properties. Our summary of the discussions will be structured around the main points that emerged from the two sessions, rather than specifically addressing each question.

Prior work of the Murray Wetlands Working Group

This group has done significant work in leading the way in implementation of on-farm environmental watering and they had worked with some of the workshop participants, to water some wetland on-farm. This had provided encouraging demonstrations for the landholders and their neighbours of the benefits of watering wetlands. Legislative requirements around these activities are complex[1] and were not addressed in the workshop. Rather we were interested in how watering might fit in with current and anticipated farming practice from a practical viewpoint. Accountability requirements mean that it is currently not permitted to use water provided specifically for environmental watering on crops. Furthermore, there are issues about water quality that are not well understood i.e. how problematic is the agri-chemical and nutrient load in drainage waters for the health of remnant vegetation? (*Clarification needed: can farmers use their own drainage water to water wetlands within the boundaries of their own properties?)*

Drainage waters – an opportunity to explore?

Most farms currently have a system of water recirculation with recycling being of increasing importance. Generally speaking, participants saw opportunities to integrate wetland watering into these systems. Importantly farm infrastructure provides opportunities for moving water in ways that are not possible in undeveloped landscapes.

Many of the suggestions for watering wetlands involved the use of drainage water from crops onto wetlands, this was seen as an activity that could contribute positively to farm water management in the future. The practicality of this is partially explained by the fact that the wetlands are often in the lowest part of the landscape on a property and there is an existing gravity-driven system whereby the water moves from the supply to the irrigation bays to the wetlands. Wetlands could 'assist' though a role in temporary water storage and potentially clean up the water for re-use. The latter is potentially a major problem for the health of the vegetation but the full range of issues is unknown in the context of water quality, amounts of water involved and the comparable effects of other management on the wetlands e.g. the impacts of grazing and stock camping. Irrigation efficiencies are such that increasingly small amount of drainage water may become available leading to this approach being unviable. One suggested timing was to use water to flush winter crops and then store this water in wetlands for later use on (for example) rice crops. Negative consequences for biodiversity of rapid draw-down associated with the re-use of this water may need to be considered.

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[1] Bowen, P. M. and Nias, D. J. (2008) Adaptive Environmental Water Use in the NSW Murray Valley 2004-2008. NSW Murray Wetland Working Group Inc., Albury, NSW.

Temporary storage of supply

There is certainly potential to use wetlands as temporary storage of irrigation water before its use on crops, but opportunities will depend on the layout of individual farms, and the position of the wetlands in relation to storage dams and irrigation bays. There will be periods when there is water in excess of dam capacity which can be diverted to wetlands. In terms of timing, the diversion of water to wetlands in August – September before its use on summer crops would be a practical option. Also, temporary storage of water in April – May, before use on winter crops would be an option. Storage of water in summer may create significant problems for wetlands – see later comment.

Restoring natural landscape drainage patterns

With the use of laser levelling, there has been major changes to natural overland flows that result from rainfall runoff. The natural concentration of these flows would have determined the development of wetlands in particular parts of the landscape. Disruption of flow patterns has in some cases assisted wetlands, but in others has resulted in too little or too much water for the health of the vegetation. In some cases engineering works could have inadvertently resulted in a poor water regime for wetlands. It was recognized that there were opportunities to improve the situation through engineering adjustments or adapting management to drain or apply water as appropriate.

The multiple uses of wetlands

While providing environmental water is motivated by the need to regain tree health and provide resources for other native plants and animals, the wetlands are also used for farming activities: (firewood?), grazing, stock shelter and the provision of dry areas on farm. These activities are not always compatible with native plant and animal conservation so providing environmental water needs to go hand in hand with a broader management strategy that maintains the condition of the wetlands. An example of adapting management given was to limit grazing of wetlands to summer, when the shade of trees was critical. Weed management is a major aspect of remnant health, and the use of flooding to control terrestrial weeds was suggested. It would be useful to determine the relative value derived for biodiversity and production (grazing) from watering of remnant vegetation patches under different grazing management regimes.

Microspore protection and opportunities for wetland watering

There was broad endorsement of the idea that the practice of deep flooding to protect rice from cold during microspore stage could be turned to advantage for wetlands. Immediately after the critical protection period, the excess water that was providing the depth needed, could be temporarily diverted to a wetland and returned in later summer to finish the crop. This water would be of high quality and unlikely to create the water quality problems that might be associated with water drained at other times of crop development. A consideration would be that the application of water to wetlands in summer was seen by some as problematic – water temperatures causing algal growth and killing plants. The counter argument is that the temporary wetlands have evolved in an environment where summer storms can fill wetlands and there are species that may require this timing, or at least be adapted to it. The complication may mean that if the wetlands are nutrient-enriched, summer flooding may be problematic in a way that is not the case for wetlands in a more 'natural' state.

Timing to reduce transmission losses

Transmission losses on farm can be significant so timing environmental water with agricultural water could produce significant savings of water. This could act as an incentive for farmers to use environmental water on their properties if it was available.

The wider landscape

Participants in the Environmental Champions Program saw themselves as being able to provide the lead in good management of on-farm wetlands, and they claimed a level of motivation to do so. Non-participants were seen by some participants to need a higher level of incentive to take on similar levels of management. Previous work by some Environmental Champions to consider landscape level conservation issues were discussed and there is some implementation to restore elements of landscape connectivity though tree plantings. It was apparent to us that the same landscape level thinking could be applied by farmers to consider ways to improve the natural and managed flows of water across the landscape to improve water regimes for the health of wetlands.

Research

CSIRO research partnership

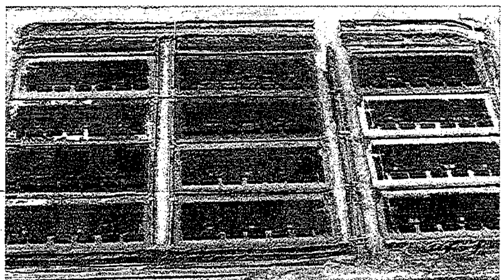
In 08/09 RGA and CSIRO undertook a 12 month project looking at climate change scenarios for the Riverina, likely adaptations to farming systems and possible issues for biodiversity.

Building on this research two research projects have commenced, one focussing on farming systems and one on biodiversity.

Farming systems research

With rice being a key aspect of many farm businesses in the irrigation areas there is an ongoing movement to increase water use efficiency in rice production to enable adaptation to lower and more variable water availability.

The CSIRO and NSW DPI are undertaking experiments on “delayed permanent water” technique of growing rice, to evaluate the comparable water use efficiency and productivity from the water used. The project links into a much broader irrigation research project led by QLD DPI.



Experimental rice plots at Yanco Agricultural Research Centre. Photo courtesy Brian Dunn NSW DPI

The first years results indicated a reduction in water use and some overall increase in productivity for the water used. Flush irrigating in the early stages of growth however does lead to increased loss of nitrogen.

A second year of experiments will be carried out in 2009/10.

Changing water regimes and biodiversity

The movement and availability of water in the Riverina landscape is influenced by both climate and management practices. With an ongoing movement toward more efficient irrigation practices, including water delivery systems, water which previously provided opportunistic habitat and other benefits to biodiversity is less often available in the landscape. With predictions of less reliable rainfall and reduction in irrigation water availability due to climatic changes, this trend is likely to continue.

CSIRO Sustainable Ecosystems are looking into these implications as part of a 3 year research project funded by the former Land and Water Australia.

The research is particularly focussing on Black Box depressions and aims to increase knowledge about potential impacts on these vegetation communities as a result of changing water regimes and to provide management recommendations.

University of Canberra biodiversity research

The University of Canberra's research project looked at 3 key areas, vertebrate abundance and diversity in revegetated areas in the rice farming landscape, the role frogs play in controlling pests in rice crops and how carpet pythons utilize agricultural landscapes.

Severe drought conditions in the sampling years greatly impacted on the results of the vertebrates in revegetation studies.

Appendix 8. Irrigation Essentials article, Aug 2009

Managed inundation of native wetlands

Drainage water from irrigation areas is often thought to create difficulties for the environment, but that is not always the case.

The landscapes in irrigation areas are usually considerably modified from natural conditions and, in some cases, native plants and animals now rely on irrigation water for survival.

Irrigation creates new habitat areas (e.g. in channels and irrigated fields) that may help support native aquatic animals and birds. These 'constructed wetlands' tend to support species that are adaptable and not generally under threat. More at risk are the sensitive species that rely on areas of intact woodland or wetland vegetation (e.g. patches of vegetation or wetlands that have become isolated from rivers or overland flow).

In irrigation areas, some of these remnant woodlands and wetlands (and their associated species) rely on surplus irrigation water for survival.

Research in the Riverina has identified areas of Black Box (Eucalyptus largiflorens) woodland in this situation. Black Box woodland communities were one of the most widespread floodplain vegetation types in the Riverina before agricultural development and, despite broadscale clearing, remain one of the most common remnant types. It is thought that these woodlands flooded naturally about once every two to 10 years, for 2-6 months, depending on location. Black Box trees suffer and eventually die without sufficient flooding, or where water is ponded for too long. Such changes also alter the understorey and affect native animal and bird populations. Managed flooding of these areas is recommended to ensure the survival of the native plants and animals that live in them, to enhance and maintain the biodiversity value of irrigation landscapes.

More information: Heather McGinness, CSIRO Sustainable Ecosystems.

Source: Heather McGinness, CSIRO

INSERT PICS – B Box & Goanna – email 30/7/09

Source: Heather McGinness, CSIRO