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The effect of changing irrigation strategies on biodiversity

Final report to the National Program for Sustainable Irrigation

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RICEGROWERS' ASSOCIATION OF AUSTRALIA INC

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Executive summary

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.

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. Overall these changes will result in a reduction in the amount of water in irrigated landscapes available in constructed wetland habitats. These reductions may have some negative consequences for some common, generalist species that are tolerant of human disturbance and that also occur in natural wetland habitats. However it is likely that changes to irrigation practices will not have large regional-scale negative effects on these widespread species. A more significant issue in 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. We 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.

Irrigated agriculture in Australia has increased water availability to native flora and fauna in some areas by creating artificial open-water habitats and raising water tables. However at the same time it has resulted in loss of native woodlands and serious reductions in the frequency, extent and duration with which floodplains are inundated. The effects of such changes on terrestrial floodplain vegetation and fauna communities are poorly understood. This study examines 1) vegetation condition and structure; and 2) abundance of selected bird species in remnant *Eucalyptus largiflorens* floodplain woodlands of two contrasting regions within the same drought-affected catchment. It assesses the effects of varying levels of irrigation landuse intensity surrounding woodland sites and of flood history within sites, testing the following propositions: a) floodplain woodlands with greater intensity of surrounding irrigation landuse will be in worse condition and have less structural complexity than other floodplain woodlands; b) floodplain woodlands with flood histories closer to 'natural' regimes will be in better condition and will have greater structural complexity than other floodplain woodlands; c) greater surrounding irrigation intensity will be associated with higher bird abundance in remnant floodplain woodlands; and d) lower flood frequency will be associated with lower bird abundance in remnant floodplain woodlands.

This study 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. Irrigation 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. Two contrasting levels of the effect of irrigation landuse intensity on woodland bird abundance were found. Firstly, a broad scale positive relationship between irrigation water availability and bird abundance at a regional scale; and secondly, a within-region negative effect of very high intensity irrigation landuse upon

bird abundance. Site flood history was not related to bird abundance, primarily because of the dominance of the regional and irrigation landuse intensity effects observed.

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 using managed flooding could bring significant biodiversity benefits. We suggest that future studies will be needed focusing on links between site flood history, vegetation condition and woodland bird abundance in the absence of intensive irrigation land use to quantify the direct importance of flooding to woodland birds.

1 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.

2 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 floodplain woodlands, because many of the 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.

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

Together, the original vegetation communities of the Riverina bioregion supported the full range of fauna and flora that are native to the area. 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 and Barrett 1985; McIntyre *et al.* 1988). There are also wetlands lacking a tree layer that take the form of reedbeds, rushlands and grasslands. Also notable is lignum (*Muehlenbeckia* spp.), a shrub dominating wetlands with or without a tree layer.

Most of the wetlands are not permanent, 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 recognised 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, further discussion will focus 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 therefore directly affected by changes in management.

3.1 Constructed habitats resulting from irrigation development

Two major habitats for native biota have been artificially created by irrigation development – 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 e g. 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 seedbanks (McIntyre 1985).

3.2 Effects of changes to irrigation practice on flora

3.2.1 WETLAND FLORA

The creation of constructed habitats such as rice bays, channels and roadside ditches have provided habitat for native herbaceous wetland plants that have persisted long after their associated trees and shrubs have disappeared from these habitats (McIntyre *et al.* 1988). Unlike their terrestrial native counterparts, wetlands 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 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. In other respect, the fate of wetland species is tied up with that of their associated woodlands discussed below.

3.2.2 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 be negative, 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 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 and this is an issue requiring 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 and 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 and Boak 2002; Lumsden and 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 water (Mensforth *et al.* 1994; Thorburn and Walker 1994; Jolly *et al.* 1996). Communities near major rivers are generally adapted to flooding every 1-3 years, but tolerate dry or wet periods of up to 2 years (Bren and Gibbs 1986; Bren 1987; 1988; Bacon *et al.* 1993; Robertson *et al.* 2001; Page *et al.* 2005; Frazier and Page 2006). Large areas are managed for grazing and forestry (Bacon *et al.* 1993; Jansen and Robertson 2005). These modifications have a range of effects upon the vegetation community, including poor tree health leading to compositional and structural change (Jolly *et al.* 1996; Briggs and Thornton 1999; Robertson *et al.* 2001; George *et al.* 2005; Horner *et al.* 2009). Current responses to water shortages includes substituting natural flooding in some areas with managed water allocations to restore the condition of tree and fauna populations (Nias *et al.* 2003).

Black box (*Eucalyptus largiflorens*) woodlands

Despite broadscale 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 and Roberts 2005), and their condition is often compromised as a result (Eldridge *et al.* 2003; Roberts 2005; Eldridge *et al.* 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; Roberts and Marston 2000). 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 e.g. waterbirds breeding in reedbeds, 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; Lewis 2006). 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; Benson *et al.* 2006; Eldridge *et al.* 2007). 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 (Wassens *et al.* 2004; Wassens *et al.* 2005a; Wassens *et al.* 2005b; Herring *et al.* 2006b; c; d; a; Brown *et al.* 2008).

3.3 Effects of changes to irrigation practice on fauna

Faunal surveys in the Riverina have included both native vegetation, as well as constructed habitats such as irrigation channels. These are the main source of information in considering vulnerabilities to future changes. Four vertebrate groups (frogs, reptile, birds and mammals) are reviewed below.

3.3.1 AMPHIBIANS

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; Wassens *et al.* 2008).

In general, black box depressions in the Riverina have slightly greater frog species richness (8 spp.) than river red gum wetlands (6 spp.), rice bays (6 spp.) and channels (5 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 contained the highest number of species (9 spp.). We interpret this to be because of the density and diversity of fringing vegetation and number of microhabitats, which were elements of favourable frog habitat elsewhere in Australia (Hazell *et al.* 2004).

The changes in irrigation practice which 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.

3.3.2 REPTILES

Reptile abundance and diversity are low in the Riverina compared with other sites in south-eastern Australia (Sass *et al.* 2004; AMBS 2005; Wassens *et al.* 2005b; Brown *et al.* 2008). Although 29 species have been recorded in vegetation remnants of the Murrumbidgee Irrigation Area (Wassens *et al.* 2005b), other studies in the Riverina have located far fewer species (AMBS 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.* 2006a-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 (Wassens *et al.* 2005b; 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.* 2005b). 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.* 2005b).

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 localised 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.

3.3.3 BIRDS

The Riverina provides internationally significant habitat for waterbirds (Kingsford & Thomas 2004) and supports a range of rare and threatened terrestrial birds (Briggs and Thornton 1999; Kingsford and Thomas 2004; Jansen and Robertson 2005). Many Riverina bird species have suffered regional and national population declines in the last 25 years (Kingsford *et al.* 1999; Reid 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 and 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 and 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 and Bennett 2005).

Constructed habitats associated with irrigation have the potential to increase resources for birds (e.g. herons and egrets in southern Europe), but also create hazards, e.g. through pesticide use (Czech and 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 e.g. 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 and Parsons 2002; Taft and 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 and Helenius 2008). Irrigation channels in the Riverina rarely have these characteristics. Lining channels with concrete further reduces habitat value (Lane and Fujioka 1998; Maeda 2001). In Australia, there is evidence of ducks and egrets foraging in channels (Frith 1957a; b; Richardson and Taylor 2003) but there are no records of associated breeding.

Waterbirds exploit rice crops for their food resources worldwide (Frith 1957b; Richardson *et al.* 2001; Czech and Parsons 2002; Richardson and Taylor 2003; Taft and 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 (1957b) 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 and 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 and 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 and 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.

3.3.4 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.* 2006b; c; d; a) 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 which 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 and 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.

4 New information on biodiversity responses to irrigation practices

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

- Black box communities comprise a large percentage of the remaining remnant vegetation in Riverina irrigated landscapes.
- Black box woodlands are generally the major remnant vegetation type on irrigated farms in the Riverina.
- These woodlands have a natural surface flooding regime of once every three – ten years and hence would be impacted by changes to surface flooding.
- 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; Figure 1). Data from the latter were collected under another project, but results are presented here because they aid interpretation of the Midbidgee results.

The two regions differ in their irrigation and landuse intensities. The Midbidgee is now dominated by intensive irrigation landuses, including rice and wheat cropping and horticulture. Native vegetation remnants in this region are highly fragmented and frequently completely isolated and grazed. 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 millenium 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. Until recently, isolated remnant *E. largiflorens* patches in the Midbidgee were often used as destinations or storages for irrigation drainage or surplus water. In some cases this practice ensured the survival of isolated patches that were not adversely affected by high water tables, while in others it resulted in the death of trees via drowning and/or salinity.

In contrast, the Lowbidgee region is dominated by light grazing with irregular and limited flood irrigation, and very high levels of vegetation connectivity across the landscape (Kingsford and Thomas 2001; CSIRO 2008b). Large areas of connected remnant floodplain vegetation are now managed by the New South Wales (NSW) state government as part of the recently opened Yanga National Park, while others are managed by private landholders. While the NSW state government has been actively rehabilitating areas of *E. camaldulensis* (river red gum) forest and woodland within Yanga National Park since 2005, most deliberate watering of *E. largiflorens* remnants has been conducted on private land by landholders who use remnants for grazing. Many areas of *E. largiflorens* woodland in the Lowbidgee region have not received water for more than 20 years, while some have been flooded relatively frequently – the latter tend to be privately owned. The last major flood to reach Lowbidgee *E. largiflorens* communities was in 1989, and only a few areas received supplementary managed water during the millennium drought. In addition, 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 (CSIRO 2008a).

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.

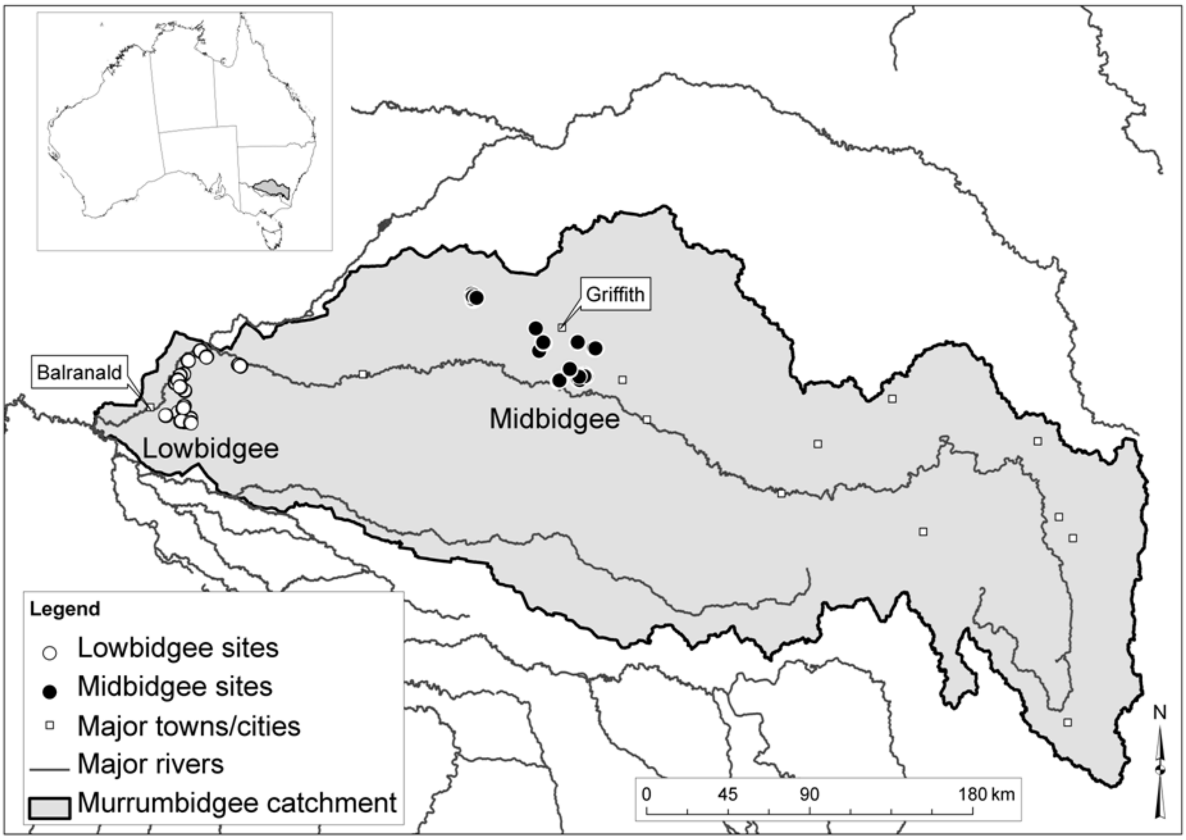

Figure 1 Locations of the survey sites in the two study regions of the Murrumbidgee catchment.

4.1 Vegetation patterns and responses

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

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:

- 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.
- A landscape view community photograph with the horizon line at the middle of the image
- A groundcover photo taken at approximately 1.5 m perpendicular from the ground, using forced flash, no zoom, and moving away from shaded areas.

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 (480 mm) 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.* 2010) 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 distinct 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.

Tree size classes were assessed because the presence and absence of individual size classes is influenced by site conditions including water availability, and because they affect the habitat complexity of each site. Six 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 (ESRI 2010; Gobbett and Zerger 2011). PointSampler zooms an image to pre-set 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.

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

REGION	SURROUNDING IRRIGATION 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

4.1.1 SHRUB AND GROUNDLAYER

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 2a). 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 2b). *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 3a). In the Lowbidgee it was absent from the sites with a more frequent wetting frequency and most common in the driest sites (Figure 3b). 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.

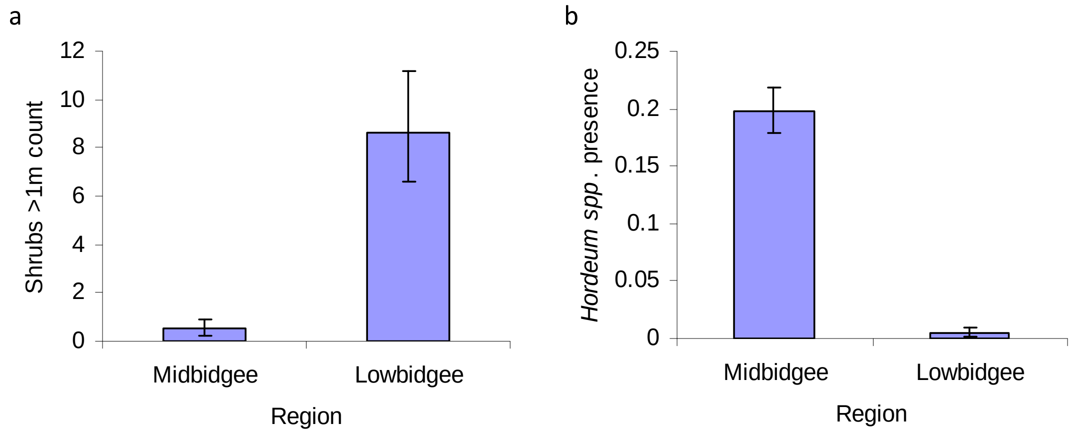

Figure 2 a) Number of shrubs 1 m tall per photo. (b) Proportion of ground photos with *Hordeum spp.* present (see Appendix 2 for methods, McGinness et al.). Error bars show ± standard error.

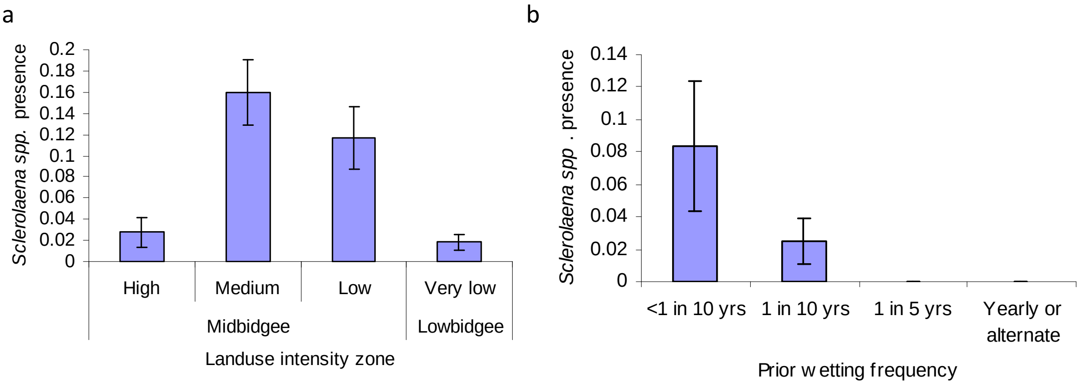

Figure 3 a) Proportion of ground photos with *Sclerolaena spp*. present (see Appendix 2) in (a) Landuse intensity zones, and (b) Prior wetting frequency categories in the Lowbidgee. Error bars show ± standard error.

4.1.2 BLACK BOX (*EUCALYPTUS LARGIFLORENS*) 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 4). 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 5).

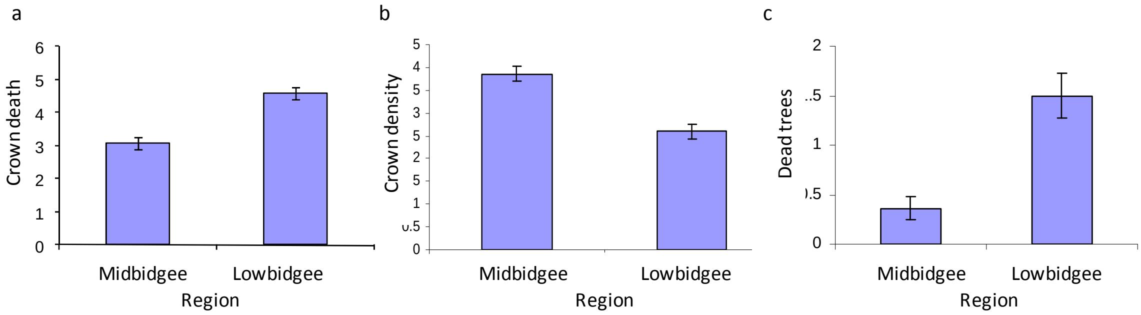

Figure 4 Regional differences in sites for a) Crown death score (higher = more crown death); b) Crown density score where leaves were present; and c) the number of dead trees per photo. Error bars show ± standard error.

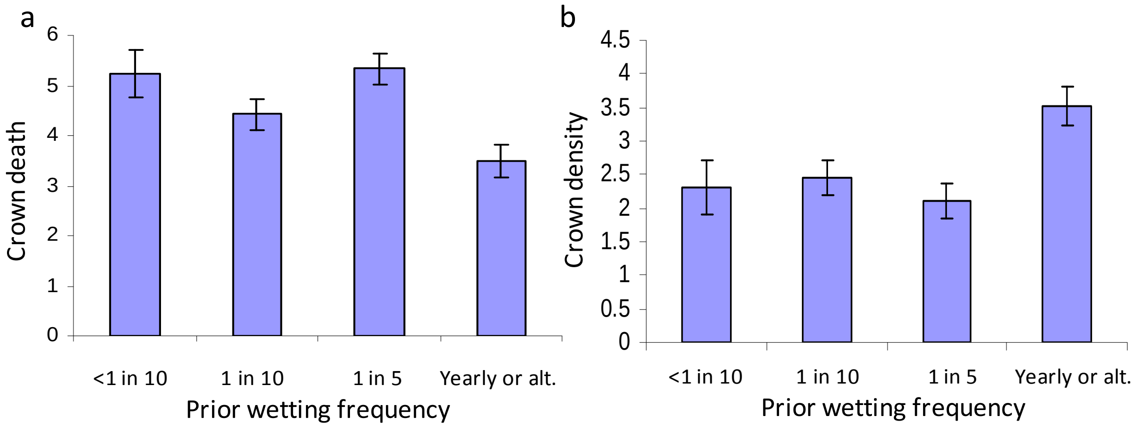

Figure 5 Differences in the amount of (a) crown death (higher is more crown death), and (b) crown density where leaves were present, in Lowbidgee sites based on the prior wetting frequency category. Error bars show ± standard error.

During the millennium drought 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. 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 by 1-3 metres (CSIRO 2008a). 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. In contrast, recovery of aquifers in the Lowbidgee has been impaired by increased groundwater extraction and river regulation over the same drought period. The 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 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 6). 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 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).

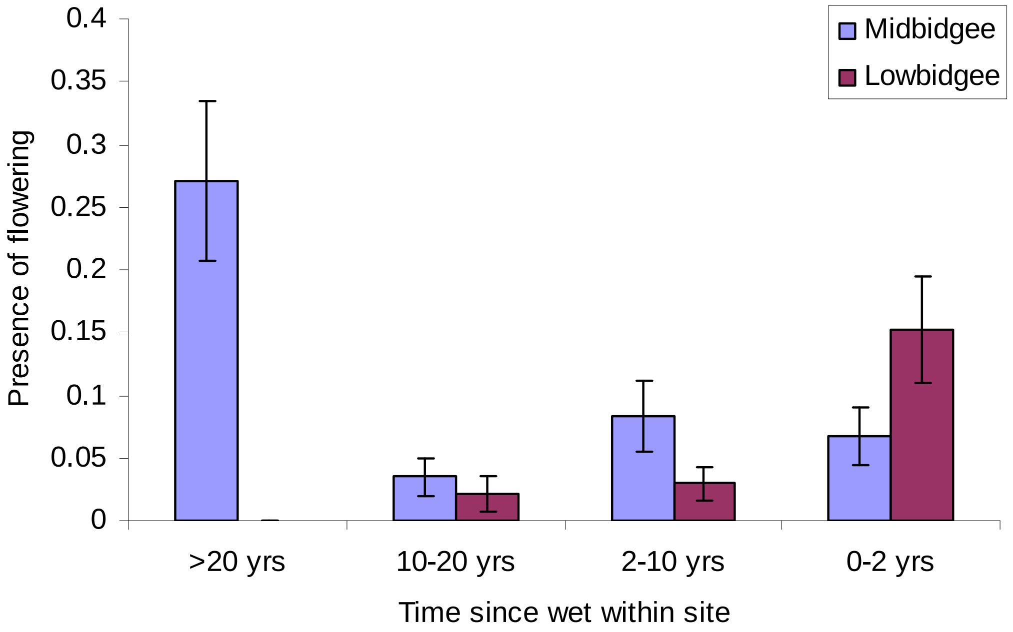

Figure 6 The proportion of photos with flowering trees based on the time site a site was last wet. Error bars show ± standard error.

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 7), 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.

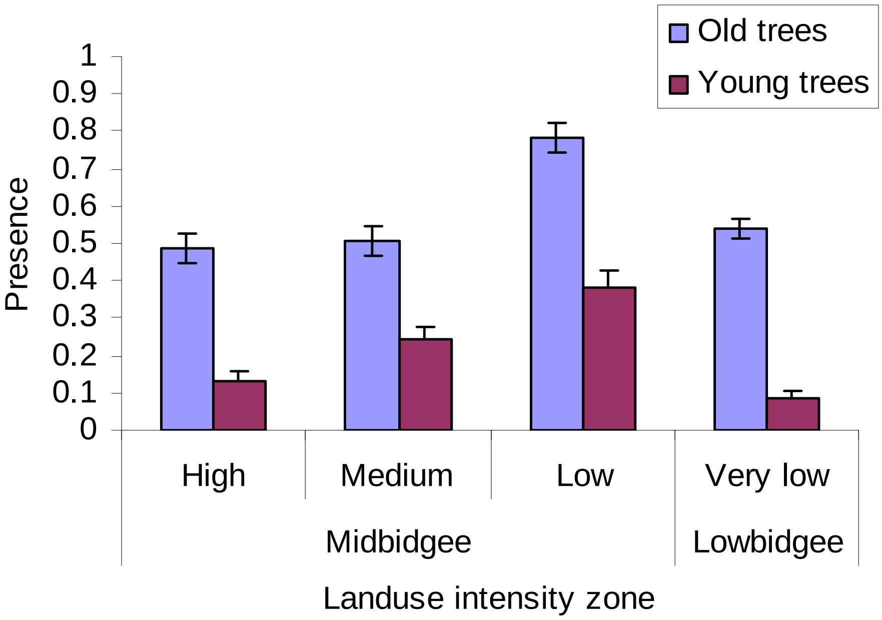

Figure 7 The proportion of photos with old or young trees based on the surrounding irrigation intensity. Error bars show ± standard error.

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.

4.2 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.

4.2.1 ABUNDANCE

The total abundance of our selected species was best explained by regional differences between sites (LR test, χ21=13.97, P<0.001; Figure 8a). We also show differences based on surrounding irrigation intensity (LR test, χ23=16.24, P=0.001; Figure 8b). 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 8b). 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, χ21=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, χ21=8.12, *P*=0.004; Figure 9a) and surrounding irrigation intensity differences (LR test, χ23=13.22, *P*=0.004; Figure 9b). 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, χ21=, *P*=0.04.). There were no consistent responses to surface wetting history across regions, nor to any of the other habitat factors considered.

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 HABIT[4]
Grey-crowned babbler *Pomatostomus temporalis*	Patch	Vulnerable, declining	Sedentary, resident	Insectivorous; also seeds	Ground – leaf litter, 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; b; Reid 1999; 2000; Seddon *et al.* 2003; Antos and Bennett 2005; 2006; Briggs *et al.* 2007).

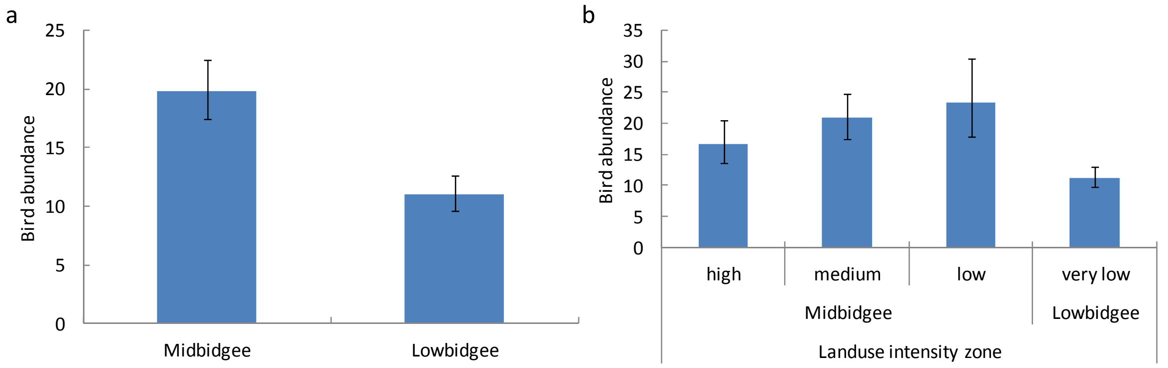

Figure 8 Abundance (number of birds per km of transect) of selected species at sites plotted against (a) Regions, and (b) surrounding irrigation intensity. Error bars show ± standard error.

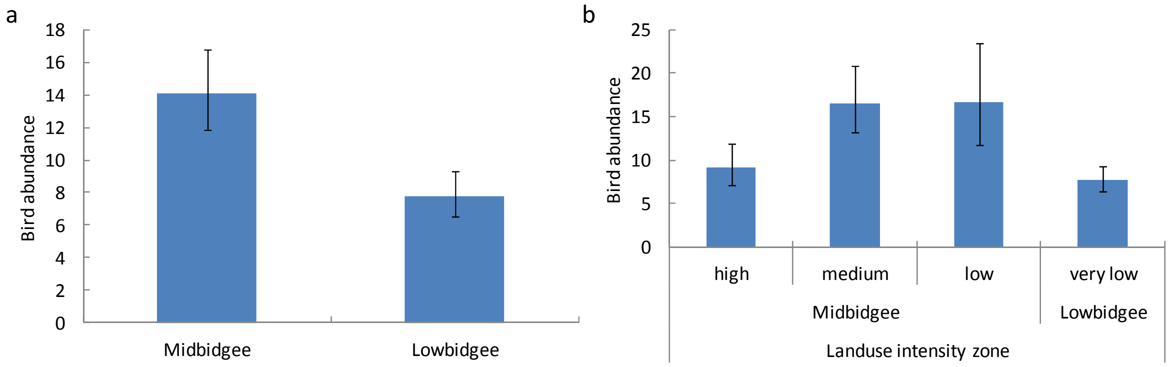

Figure 9 Relative abundance (number per km of transect) of patch specialist species at sites plotted against (a) Regions, and (b) surrounding irrigation intensity. Error bars show ± standard error.

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.

4.2.2 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 10). 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.

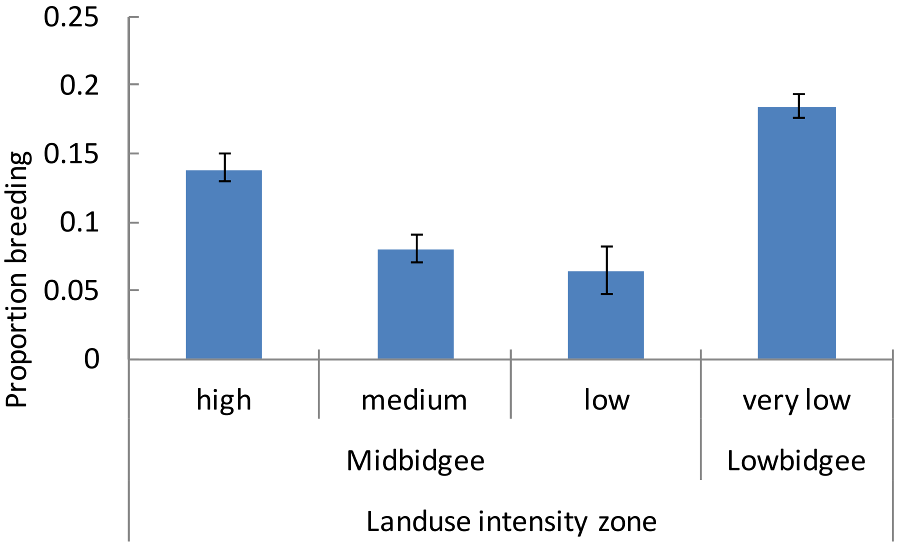

Figure 10 Proportion of bird observations with evidence of breeding in late spring 2009 in the different irrigation intensity zones. Error bars show ± standard error.

4.2.3 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, χ22=1.41, *P*=0.49), but there was a trend towards higher counts with increasing irrigation intensity (Figure 11). 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.

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, χ21=1.46, *P*=0.23) or by surrounding irrigation intensity (LR test, χ23=2.56, *P*=0.47; Figure 12), 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.

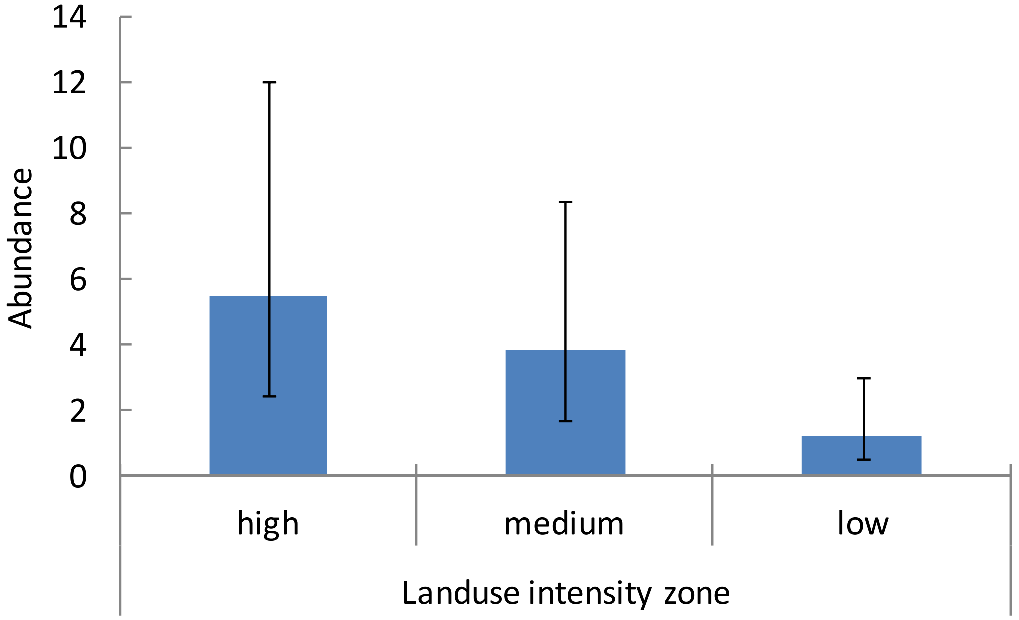

Figure 11 Abundance (number per km of transect) of starlings by irrigation intensity zone in the Midbidgee. No starlings were seen in the Lowbidgee. Differences were not statistically significant (LR test, χ^2_2=1.41, *P*=0.49).

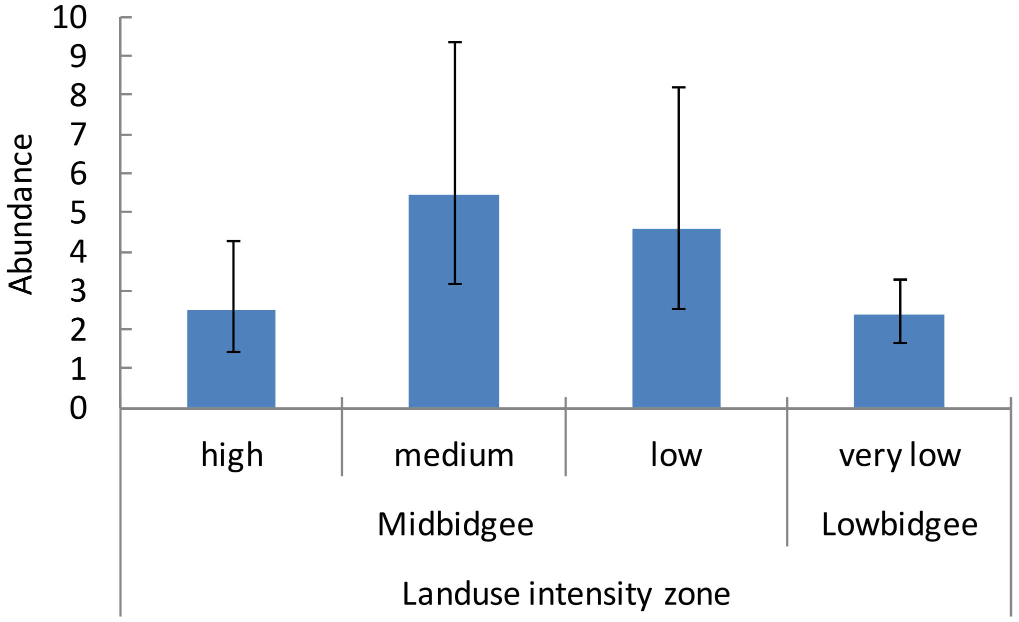

Figure 12 Abundance (number per km of transect) of noisy miners by irrigation intensity zone. Differences were not statistically significant (LR test, χ^2_3=2.56, *P*=0.47).

Vulnerable species – 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 13). 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 13), 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, χ21=21.9, *P*<0.001) of brown treecreepers was strongly negatively related to the abundance of miners at a site. Figure 14 shows the raw data on which this relationship was modelled. Brown treecreepers were not observed in any sites where miner abundance 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.

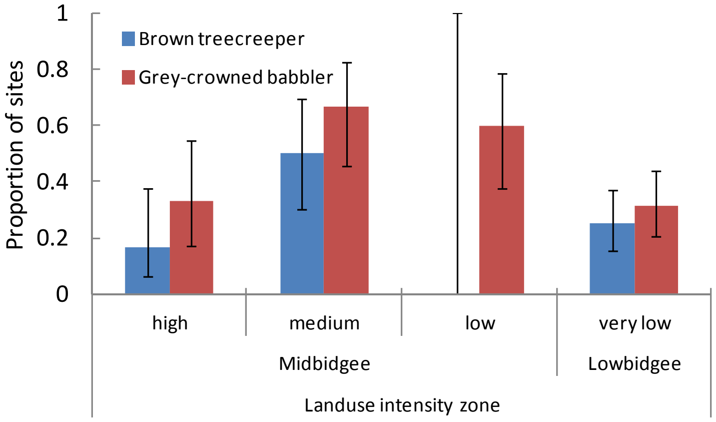

Figure 13 Proportion of sites with brown treecreepers and grey-crowned babblers by surrounding irrigation intensity. Differences were not statistically significant.

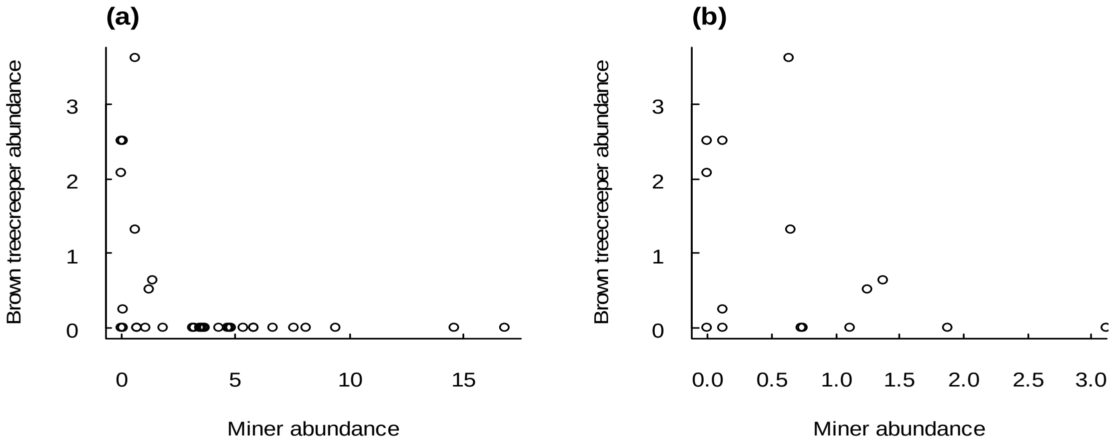

Figure 14 Abundance of brown treecreepers vs. abundance of miners (noisy and yellow throated combined) (number per km of transect). (a) Full data set. (b) Data restricted to show noisy miner abundance < 3 per km of transect.

By comparing two regions with differing irrigation landuse intensities, this study demonstrates a positive relationship between woodland bird abundance (density) in remnant woodlands and water availability at a regional scale. This suggests that irrigated regions may provide significant benefits to woodland birds, particularly during drought periods. These benefits are most likely mediated by positive vegetation condition responses to greater water availability from higher water tables. However the intensity of irrigation landuse must be taken into consideration, since it is apparent that high intensity irrigation landuse may have relatively negative effects on woodland birds, compared to medium and low intensity use. These negative effects are exacerbated by the abundance of invasive feral species such as starlings and competitive species such as noisy miners in high intensity irrigation landuse areas. Other aspects of water availability such as site flood history are also likely to be important for woodland birds, but in this study their effects are overwhelmed by the overarching regional and landuse intensity differences. Consequently, future studies focusing on potential links between site flood history, vegetation condition and woodland bird abundance in the absence of intensive irrigation land use will be needed to confirm or reject this hypothesis.

4.3 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 existence of remnant woodland vegetation in these regions is critical to the conservation of woodland birds and other components of regional biodiversity. These remnants require regional and local management that is focused on retaining and improving their habitat quality and productivity. This is 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, and increasing the size and connectivity of remnant patches. Retaining isolated paddock trees may also contribute to connectivity and woodland bird persistence in these landscapes. However other essential components of floodplain woodland ecology are the frequency, extent, and duration of flooding. Appropriate flood regimes will need to be reinstated for optimum ecosystem health, particularly in areas such as the Lowbidgee where groundwater tables have fallen, irrigation water is not available, and flood regimes have been drastically altered. While this study did not find strong links between bird abundance and site flood history, there are flora and fauna species that clearly require and would benefit from managed flooding of remnant floodplain woodlands. There are opportunities for incorporation of woodland watering into public and private land management, and in appendix 6 of this report we discuss some of these; however managed flooding should always be undertaken with careful monitoring of the responses of and outcomes for both fauna and flora.

5 Project communications

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

- 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).
- McGinness, H. M., Arthur, A. D., Davies, M. & McIntyre, S. (2012 In Press) Floodplain woodland structure and condition: the relative influence of flood history and surrounding irrigation landuse intensity in contrasting regions of a dryland river. *Ecohydrology*. (Appendix 2).
- A publication covering the main results from the bird work: McGinness, H. M., Arthur, A. D., Davies, M. (In preparation) Floodplain woodland bird abundance and landscape water availability.

Background information from this project also contributed to an additional scientific journal paper that was produced for a special issue of *The Rangelands Journal*, for which NPSI was acknowledged:

- McGinness, H. M., Arthur, A. D. and Reid, J. R. W. (2010). Woodland bird declines in the Murray-Darling Basin: are there links with floodplain change? *The Rangeland Journal* **32**: 315-327.

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

- 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).
- 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).
- 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).
- 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 and factsheets were also produced describing the project – these were used by the NPSI communication team in research bulletins and other material, and were also 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*' in 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.

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