LITERATURE REVIEW – Biodiversity in the Riverina: Potential impacts of irrigation change

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1.1. Introduction

Context

The Riverina is a semi-arid outwash plain of alluvial fans which issue from the eastern highlands, with sediments built up from a system of prior streams (Butler 1950). The present river systems have been cutting down through these sediments over the last 4,000 years and are now at a lower level than the prior streams. The young age of the rivers means that only a rudimentary drainage system has developed on the plain, and this together with low rainfall makes the contribution of the plain to downstream river discharge minimal (Leigh and Noble 1972). Wetlands on the plain fill from local rainfall events, or via flooding of the major allogenic rivers and streams driven by upstream rainfall. The plain supports a range of shrubland, grassland, woodland, forest and wetland vegetation, much of which has now been significantly altered.

The first major impact of European settlement in the area was the establishment of pastoralism in the mid-1800s, which resulted in clearing and serious overgrazing throughout the region. Combined with the effects of drought, pastures were damaged sufficiently to have never recovered their carrying capacity (Beadle 1948). The second major change was the establishment of extensive irrigation schemes, with the creation of the Murrumbidgee Irrigation Areas (MIA) starting in 1914, followed by the Murray Valley Irrigation Districts (Murray Valley) in the 1940s, and the Coleambally Irrigation Area (CIA) in the 1960s. Other Irrigation Districts (which are less intensive than Irrigation Areas) include Benemebah, Wah Wah, and Tabbita, which are to the west of the Murrumbidgee Irrigation Areas. These developments have resulted in the conversion of 456,000 ha of floodplains, dryland pasture and woodlands to intensively managed irrigation land with considerable expansion of human settlement and influence (Leigh and Noble 1972).

Currently, most irrigation areas are dominated by broad-acre crops and horticulture. Most of these crops require summer irrigation, significantly changing the temporal availability of water on the Riverina plain. The removal of native vegetation and the change in water use has adversely impacted some of the original ecosystems, but it has also created opportunities for some wetland species, both through the general availability of irrigation waters, and importantly, the prolonged and extensive flooding of rice crops over the summer growing season. In addition, elements of the terrestrial biota may well benefit from the extra resources associated with irrigation waters, despite 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 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.

A third major period of landscape change in the region seems imminent, driven by the projected changes in irrigation practices in rice-dominated broad-acre farming landscapes in response to climate change. These changes, as well as the direct effects of climate change itself, have implications for biodiversity both regionally and across the entire Murray-Darling Basin. Basin-wide implications arise because the predicted effect of climate change is to reduce the availability of water in the major river systems which supply the Riverina. These systems and their associated floodplains and wetlands are already under ecological stress (Walker and Thoms 1993; Kingsford 2000; Sheldon *et al.* 2000; Kingsford and Norman 2002; Arthington and Pusey 2003; Frazier *et al.* 2005) and the decrease in water availability may only exaggerate the challenge of achieving desired agricultural and environmental outcomes across the basin.

Scope and methods

This review explores some of the potential implications of projected changes for biodiversity in the major habitats of the Australian Riverina that are affected by irrigation practices. We restrict the scope to impacts on biodiversity within the Riverina, rather than basin-wide impacts. Previous sections of this report have identified the adaptations that land managers may adopt in their farming practice in response to the effects of climate change. Following on from this, we have identified (based on the literature, discussions with farmers and other land and water managers, and personal observations) the subset of changes that we believe to be most significant to local and regional biodiversity, either because they are widespread and substantial changes, or because they could have a disproportionate impact on native species. These changes are as follows:

- Reductions in the amount of surface water draining off irrigation farms due to decreased availability of water and/or more efficient practices;
- Reductions in the amount of irrigation water reaching the water table due to decreased availability of water and/or more efficient practices;
- Reductions in the amount of ponded water across the landscape due to a decrease in the use of flooding as a method of rice production;
- Increased chemical use for weed control that may be associated with a reduction in the use of flood irrigation for growing rice and/or an increase in other crops;
- Changes to the timing of irrigation;
- Changes to irrigation infrastructure such as piping of irrigation water or lining of channels;
- Increased open water storage and depth. Construction, deepening, and simplification of water storages, and/or holding water in supply and drainage channels – on farm as well as by irrigation companies;
- Habitat modification which may result from a change in the type of irrigation practice e.g. the adoption of lateral moves or centre pivots which may require removal of paddock trees.

We targeted literature relating to the Riverina bioregion of south-western NSW and north-western Victoria, Australia; however we also examined relevant international literature when local information sources proved scarce. We systematically searched for scientific publications and unpublished reports via the ISI Web of Knowledge/Web of Science, Google Scholar, CSIRO library catalogues, and relevant organisational websites. We ran searches for similar reports and publications by common authors, and screened citations in key papers, reports and websites. We also personally requested information from staff in relevant organisations such as irrigation corporations, the Ricegrowers Association, and Catchment Management Authorities.

In this review we have first outlined the major natural and constructed habitats associated with the Riverina irrigation areas and districts. We are not considering initial impacts of the development of irrigation infrastructure in the past, nor are we considering the direct effects of changes to climate on the existing habitats. Rather, we have selected the habitats that are likely to be most seriously affected by changes in irrigation practices and consider how biodiversity associated with these habitats will be impacted by changed management, and what might be done to address this issue.

Major habitats of the Australian Riverina

In this overview of habitats of the Riverina, we first describe the vegetation communities (dryland and wetland) which reflect the natural ecosystems that would have existed prior to European settlement, and thus provide a context in which to develop future conservation strategies. This account is based on Beadle (1948), Eldridge (2002), and Roberts (2005). Very few, if any, of these communities remain unaltered by human activities, and for the purposes of this review we recognize two levels of alteration:

1. *Managed* habitats include relatively unaltered vegetation communities (both terrestrial and aquatic) that may have undergone clearing, grazing, invasion by exotic species, or changes to flow regime and magnitude because of basin-scale river regulation.
2. *Modified* habitats include vegetation communities that have been significantly altered, for example via local earthworks, such as installation of dams, or irrigation influences such as drainage water. They also include rivers and streams used as canals; rivers and streams impounded with weirs or dams; former channel wetlands converted to dam storage (e.g. impounded meanders); depression wetlands converted to dam storage; deflation basins converted to dam storage; and floodplains converted to irrigated pasture. For the purposes of this review we will focus upon modifications that involve alterations to water regime.

A third important category of alteration state is that resulting from complete replacement of natural communities with structures associated with irrigation development:

3. *Constructed* habitats include irrigation canals, ring tanks or storage dams, rice bays, other irrigated crops, and dryland crops.

Within irrigation areas, all three habitat types occur.

Dryland vegetation communities

Tall woodlands

Grey box (*Eucalyptus microcarpa*) grassy woodlands occur on level to undulating topography and are associated with red brown sandy loams to clay loams. They are widespread on the NSW slopes and occur in the limited parts of the eastern Riverina. They have been extensively thinned for grazing and cleared for dryland cropping, particularly wheat.

Savannah woodlands

River red gum (*Eucalyptus camaldulensis*) forms grassy woodlands or forest in the Riverina. These communities are associated with watercourses and former channel wetlands that are regularly flooded, and occur on a range of soils from grey clays to sands. This vegetation community is relatively well retained, with >50% of pre-European extent remaining in the Murrumbidgee Irrigation Area (MIA) and districts, although the condition of the habitat, particularly the associated wetlands is often poor.

Black box (*E. largiflorens*) is also associated with areas that are subject to occasional inundation, but is less reliant on regular flooding than river red gum and consequently occurs over larger areas than the latter species. Black box woodlands are associated with rivers and streams, former channel wetlands, depression wetlands, deflation basins, and floodplains on a range of soils, but mainly occur on grey clays or clay loams. They once occurred extensively across the Riverina but are now seriously depleted. In the MIA and districts, 30-50% remains of their pre-European extent, and these remnants have been degraded by grazing, changed water regimes and rising water tables, which have in turn limited regeneration and recruitment.

Shrubby woodlands

Bimble box - White cypress pine (*Eucalyptus populnea - Callitris glaucophylla*) woodlands occur on level to undulating topography, and are associated with red-brown sandy loams and loams (calcareous earths). They support a tall shrub midstorey, including *Eremophila, Geijera* and *Acacia homalophylla*. They have been traditionally thinned to increase grass cover for grazing purposes, but irrigation development has resulted in less than 10% of this community remaining in the MIA. The remaining woodland appears to have remained generally healthy but the shrub layer has been depleted and the community is threatened by weeds (Eldridge 2002).

Boree (*Acacia pendula*) occurs on floodplains, elevated plains and levees of prior streams, on compacted grey and brown clays which are frequently self mulching, and on duplex soils on prior stream levees. It forms a low woodland and originally had a well-developed understorey of chenopod shrubs, grasses and forbs, but grazing has depleted the shrub layer. Less than 10% of this community remains in the MIA and districts due to clearing and restricted regeneration as a result of grazing (Eldridge 2002).

Mallee

The multi-stemmed nature of Mallee eucalypts denotes the community as shrubland. In the Riverina Mallee associations of *E. socialis* and *E. dumosa* are the most widespread. They occur on well-drained soils (deep red-brown sands or clay loams, usually overlying limestone) on level to undulating topography. The community has been partially cleared in the MIA and districts and 30-50% remains of the pre-European extent. In 1997 approximately 35% remained in the Riverina bioregion as a whole (ANRA 2008).

Scrubs

Dense to open scrubs dominated by rosewood - belah (*Alectryon oleifolius - Casuarina cristata*) and associated tall shrubs are scattered though the region. They are found on level to undulating topography, red-brown sands and sandy loams usually overlying limestone. This community has been impacted by grazing, is prone to erosion, and is regarded as vulnerable, with 10-30% of pre-European extent remaining (Eldridge 2002).

Chenopod shrublands

Many species of saltbush (members of the family Chenopodiaceae) occur naturally on the Riverine Plain and originally formed a considerable resource for grazing at the time of early European settlement. They form shrublands with *Atriplex vesicarium* and *Kochia* spp. being the most widespread dominants, occurring on various soils from red-brown sands and loams to grey clays. Heavy grazing has led to massive depletion of saltbushes and partial replacement by annual species. As a result, the status of these communities in terms of current extent is not well known, but is thought to be decreasing; approximately 81% of pre-European extent remained in the Riverina bioregion circa 1997 (ANRA 2008).

Grasslands

Perennial grasslands dominated by *Chloris*, *Danthonia*, *Astrebla* and *Stipa* were originally widespread in the Riverina, on level topography. *Astrebla* mainly occurs on grey self-mulching clays, *Stipa* on grey or grey-brown self-mulching clays or clay loams and the *Chloris – Danthonia* association on sandy loams to clay loams, with the latter showing puff shelf depression structure. Like shrublands, the grasslands have been considerably altered by grazing and in many areas converted to annual-dominated systems. The status of these communities in terms of current extent is unknown, as assessment is manly a question of condition rather than clearing, but they are thought to be seriously depleted; 1997 extent in the whole bioregion was 59% of pre-European area (ANRA 2008).

Overview

In summary, much of the native vegetation in the Riverina has been either replaced or altered substantially. The eucalyptus woodlands and open woodlands that once dominated the bioregion have been subject to the greatest amount of clearing; only 18.5% and 9.6% remain respectively (data circa 1997, ANRA 2008). The status of chenopod shrublands and grasslands are more difficult to asses as they are likely to be affected by gradual changes in condition and conservation status of the community rather than abrupt clearing actions. Nearly all vegetation types have been affected by grazing and this continues to threaten their status, as well as other human-related disturbances. While the impact of irrigation development has resulted on the depletion of many of these communities and the conservation management of remaining areas of native vegetation is critical, not all are directly affected by the changes to irrigation practices projected under climate change or water scarcity scenarios. For this reason, in the following sections we will focus more closely on the habitat and communities most directly affected by irrigation practices because of their common reliance on inundation and their continued close association with irrigation water management – wetlands and river red gum and black box savannah woodlands.

Wetland communities

Wetland communities are difficult to characterize, particularly in the Riverina where they intergrade with terrestrial and aquatic communities. Wetlands are frequent throughout the Riverina due to the combination of heavy soils of low permeability, and the low relief and poor drainage that are characteristic of the Riverine plain. The most significant wetlands are associated with permanent and intermittent watercourses and associated floodplains and billabongs, which is where river red gum and black box savannah woodlands are most often found. However, depression wetlands (often containing black box) of varying size that are isolated from watercourses can be found in any dryland community where relief is low and soils are poorly drained e.g. grasslands and chenopod shrublands (Beadle 1948).

There are multiple ways of classifying wetlands, and a confusing and inconsistent range of terms have been applied in studies on the Riverina, making the review and synthesis of information difficult. The classification that we have found to be most relevant and coherent is that of Roberts (2005) who identified five water regimes and five types of wetland for an audit in the eastern MIA. These are broadly applicable to wetlands in other irrigation areas of the Riverina, and are used in this review. The water regimes are defined as follows:

- *Permanent* – Water is generally retained in the wetland throughout the year and while levels may fluctuate, a substantial body of water is retained except in major droughts.
- *Seasonal* – Receives substantial flows nearly every year then dries back completely or to a small pool.
- *Intermittent* – The wetland does not flood or fill every year; water persists for months or up to three years.
- *Episodic* – Wetland is usually dry but may fill after heavy rain or high floods and retain water for several months.
- *Ephemeral* – Similar to episodic but reliant on local rainfall rather than high floods, and the wetland only remains full for a matter of weeks.

The wetland definitions are:

- *Former channel wetlands* – Remnants of old channels of the main rivers, including palaeo-channels and more recent cut-off meanders (billabongs). They are of various sizes and shapes and in their natural state would have had a range of non-permanent water regimes.
- *Depression wetlands* - Shallow depressions not associated with major rivers, these can be either isolated from, or associated with drainage lines. These have non permanent water regimes, mainly filled by local rainfall.
- *Deflation basin* – Large rounded shallow depressions that were formed by wind erosion and have a lunette of deposited material on the downwind side. They are fed by small creeks and were intermittent or episodic in their natural state.
- *Impounded meanders* – Parts of a creek or river that have been altered by retaining structures or excavations that change their previous free-draining state. The water regime is not natural and is either permanent or fluctuating.
- *Wyangan Basin wetlands (unknown hydro-geomorphic origin)*

Wetland vegetation in the Riverina varies in species composition and responses according to water regime (Beadle 1948; Williams 1955; Churchward and Flint 1956; Williams 1956; Paijmans 1978; McIntyre 1985; McIntyre *et al.* 1988; McIntyre *et al.* 1991). A range of life-forms are present that cope with varying water depths and regimes, e.g. free-floating (*Azolla*), submerged (*Glossostigma*), floating leaved (*Marsilea*), and emergent (*Eleocharis*) forms. These are mostly herbaceous species. An important exception is Lignum (*Muehlenbeckia cunninghamii*), which is a shrub of non-permanent wetlands. A feature of most wetland plants is their ability to complete their life-cycle and set seed in a drying soil, an adaptation of non-permanent wetlands. Another important adaptation to survive long periods of drying is the ability of many species a develop extremely large and long-lived seed banks in the soil (McIntyre and Barrett 1985). This has pre-adapted many native wetland plant species to survive and dominate in constructed habitats such as rice bays and ditches (McIntyre 1985).

Relatively few Riverina wetlands would have had permanent water regimes before the arrival of Europeans and irrigated agriculture, except perhaps those dominated by river red gum immediately adjacent to and fed by the main river channel. In terms of depression wetlands, large examples fed by winter rainfall may have been seasonal; deep examples with relatively large catchments possibly intermittent; shallow examples receiving little run-off usually episodic; and shallow examples with small volume and small catchments usually ephemeral (Harrison and Roberts 2005). Of the MIA wetlands examined by Roberts (2005), eleven had no evidence of structures controlling inflows or adding water. However ‘permanent’ was the most common regime overall, indicating that water regimes (and consequently habitats) are now significantly altered across the landscape. Indicators of altered hydrology identified by Roberts (2005) include: dead black box (*Eucalyptus largiflorens*) or river red gum (*Eucalyptus camaldulensis*) trees; poor canopy condition in dominant trees; stands of cumbungi (*Typha* spp.), and presence of a dam or drain.

Wetlands in the Riverina are most commonly found in woodlands dominated by either river red gum or black box. In the Eastern MIA, black box dominates woodlands associated with nearly all depression wetlands, most deflation basins and all impounded meander wetlands' (Roberts 2005). Explanations of indicators of good and poor condition, habitat value, altered condition and ecological values for Riverina wetlands are detailed by Roberts (2005), and apply to the whole site, including vegetation, fauna, substrate, water regime, anthropogenic impacts, and landscape factors such as connectivity and fragmentation. It is important to note that present habitat value in these landscapes does not necessarily equate to natural or original condition. A site may be in poor condition relative to its original state but remain important for biodiversity either because of or despite the changes that have occurred. For example, significantly altered sites such as the Barren Box deflation basin provide nesting habitat for waterbirds (predominantly via dead black box trees) despite drastic changes in water regime, vegetation type, and vegetation composition driven by grazing and irrigation water storage and earthworks.

Constructed habitats

Irrigation canals supplying water to agricultural land occur in a range of sizes, with different functions. Large open earth supply channels (7-30 m wide and up to 3 m deep; Doody *et al.* 2006) distribute water from the Murrumbidgee and Murray Rivers across the region. These channels are nearly permanently inundated and are sometimes lined with a narrow band of vegetation including shrubs and trees. A similar size range of open earth drainage channels, in some cases modified previously existing creek lines, manage used water and 'escape' or 'rain rejection' water. Rain rejection occurs when irrigators cancel their water request generally because a local rainfall event removes their need for irrigation water even though the water is already in the system. Many of these channels eventually empty into dams, rivers, depressions, or deflation basins. In the past, many of these landscape elements received significant quantities of water from drainage channels, but modifications to irrigation infrastructure, new restrictions upon drainage disposal, together with a general lack of water preventing irrigation (and encouraging water storage on-farm) have significantly reduced the amount of water reaching them in recent times. This trend is likely to continue. Smaller, shallow open earth channels (usually less than 5 m wide and less than 1 m deep) manage the distribution of water across each farm, although the use of piping is now increasing, particularly for horticulture. Most irrigation canals are bounded by levees built during excavation, and are drained periodically for dredging and vegetation management (earthworks, desiccation and poisoning).

The typical broad-acre rice farm has fields made up of a number of levelled rice bays separated by contour banks with a fall of approximately 7 cm between them. Contour banks (approximately 2 m wide and up to 0.5 m high) traditionally represented the natural contours of the land, but have tended to be straightened with the adoption of laser-levelling which has allowed improvement in the evenness of water depth in the bays and the drainage characteristics. Toe furrows are associated with the contour and paddock boundary banks, and are shallow ditches from which soil is taken to form the banks. They function to drain water away from the rice bay. Toe furrows have depths of up to 0.5 m and provide a deeper aquatic habitat than the bays, while the contour banks provide a moist but essentially terrestrial environment.

Contour banks serve to flood irrigate terrestrial crops as well as maintain floodwater on rice plants. For rice production, bays are flooded from approximately October to March at depths of 0.05-0.25 m. Terrestrial crops such as wheat and pasture are often grown in the contoured paddocks during winter generally in rotation with rice. Grazing by sheep rather than cattle prevents serious damage to the contour banks. Ring tanks or storage dams also occur on rice farms, varying widely in age, size, depth, water regime, and vegetation density and diversity. Other broad-acre irrigated crops are grown by flood irrigation (without pooling) using border-check methods and furrow irrigation. Horticulture in the Riverina occurs on the lighter soils and is dominated by grapes and citrus historically watered by flood irrigation, but the use of drip irrigation is increasing. Of the three rice-growing irrigation areas in the Riverina the Murrumbidgee Irrigation Area includes significant amounts of both broad-acre and horticulture, while the Murray Valley Irrigation District and the Coleambally Irrigation Area are dominated by broad-acre agriculture.

The biodiversity associated with constructed habitats and wetlands of river red gum and black box woodlands is discussed in the following sections.

1.2. Managed and modified habitats affected by irrigation practices

River red gum (Eucalyptus camaldulensis) communities

River red gum sites in the Riverina that have been surveyed for biodiversity are most commonly former channel wetlands (Wassens *et al.* 2004; Roberts 2005), but also include floodplains (Sass *et al.* 2004; Doody *et al.* 2006; Lewis 2006), river and stream banks (Lewis 2006), and (uncommonly) drainage line depressions (e.g. Gum Creek Lagoon; Roberts 2005; Wassens *et al.* 2004).

River red gum communities are commonly managed for grazing and forestry, and many have also experienced water regime change via river regulation, water extraction, and irrigation drainage and escape water (Roberts 2005). Other more direct modifications include:

- Reduced flooding via earthworks;
- Increased flooding via earthworks;
- Rivers and streams used as canals;
- Impounding of rivers and streams with weirs or dams; and
- Former channel wetlands converted to dam storage (e.g. impounded meanders).

These modifications have a range of effects upon the vegetation community, ranging from poor canopy health, to poor growth and plant death, ultimately changing composition, structure, and habitat suitability (Roberts 2005). Potential future changes to irrigation practices may add to these changes by further altering the timing, duration, extent and location of inundation, and hence changing water and habitat availability across the landscape for various fauna groups.

Fauna

High quality river red gum forests of the southern Riverina have the greatest diversity of native mammals compared to other vegetation types (Herring *et al.* 2006). However the only common and widespread native mammals in these habitats (and indeed, in the Riverina) are bats, the eastern grey kangaroo (*Macropus giganteus*), and the brush-tailed possum (*Trichosurus vulpecula*). The greatest abundance and diversity of bats occurs in river red gum sites along waterways and these habitats are also important for yellow-footed antechinus (*Antechinus flavipes*). Antechinus are locally common at sites with a good supply of large woody debris, especially old logs. Major rivers lined with red gums may contain water rat and platypus populations (*Hydromys chrysogaster* and *Ornithorhynchus anatinus*). These areas are also important for the black wallaby (*Wallabia bicolour*) and sugar glider (*Petaurus breviceps*), which are associated with regenerating trees and shrubs and old, hollow-bearing trees (Herring *et al.* 2006). Many mammal species known to occur in the region in the past are now rarely recorded (Freudenberger and Stol 2002; Herring *et al.* 2006; Lewis 2006).

Surveys of the southern Riverina (Herring *et al.* 2006) found that river red gum (and black box) sites along major waterways had the highest bird diversity in the region, but that other vegetation types support species not found in river red gum. River red gum sites that have experienced decreased flooding, continuous grazing or removal of fallen timber were relatively depauperate in terms of bird species. Wetlands associated with river red gum that occur in rice-growing regions provide important breeding and feeding areas for a variety of waterbird species. Many of the wetlands lie on a section of the Murrumbidgee floodplain which is listed as a nationally significant wetland (Roberts 2005). Successful breeding by waterbirds in these habitats has been linked to the water regime within them which is required to produce food resources and/or suitable habitat conditions (Briggs *et al.* 1994; Briggs *et al.* 1997; Briggs and Thornton 1999). Management recommendations have been produced that are cognisant of the changes that have occurred in these systems because of changed flow regimes associated with irrigation agriculture (Briggs and Thornton 1999). The guidelines recognise the requirements of different waterbird groups and cover issues like the timing of wet and dry cycles in various parts of the floodplain – a detailed description is beyond the scope of this review.

Reptiles are scarce and their species diversity is low in remnant woodlands of the Riverina compared to other sites in south-eastern Australia (Sass *et al.* 2004; AMBS 2005; Brown *et al.* 2008). A 2004 reptile survey of a single 10 ha inland river red gum site in the Riverina under heavy grazing found only three species (one individual of each): Carnaby's wall skink, *Cryptoblepharus carnabyi*; Boulenger's skink, *Morethia boulengeri*; and the shingleback lizard, *Tiliqua rugosa* (Sass *et al.* 2004). In contrast, a wider study of the Victorian Northern Plains (the Victorian Riverina; 1993 and 1994) immediately south of the NSW Riverina encompassing 19 river red gum sites found 8 species and 43 individuals (Brown *et al.* 2008). But again, the overall assemblage was dominated by a few common species, notably the Garden skink (*Lampropholis guichenoti*) and Boulenger's skink (together 53% of records), both habitat generalists with a wide distribution. Only four species were considered common in the southern Riverina by Herring *et al.* (2007) - Boulenger's skink, Carnaby's wall skink, the southern marbled gecko (*Christinus marmoratus*) and the eastern brown snake (*Pseudonaja textilis*).

The river red gum community was the most depauperate vegetation type surveyed by Brown *et al.* (2008) in terms of reptile species richness (compared to black box [14 spp., 213 individuals] and grey box [18 spp., 145 individuals]). Reptiles were recorded at less than half of the river red gum sites, with an average of only two species recorded per site. However river red gum habitats remain important for a range of reptile species, including skinks, geckos, and carpet pythons. The limited number of reptile species in river red gum forests is partly a function of the ability of individual species to cope with long periods of flooding – consequently resident species are usually large, mobile, generalists, or arboreal – however anthropogenic impacts are also important (Herring *et al.* 2006; Brown *et al.* 2008). Brown *et al.* (2008) suggest that regional-scale decline in the reptile fauna is a result of vegetation clearing, especially loss of native grasslands and grassy box woodlands, as well as degradation of remaining native vegetation patches by livestock grazing, timber harvesting and weed invasion. Changed water regimes may also be an underlying driver of vegetation degradation and low reptile diversity and abundance, but this issue is not addressed (by this or any other study in the region). Brown *et al.* further state that "*the relative scarcity and patchy distribution of all but a few of the 21 species recorded in this study suggest that intact assemblages of reptiles no longer exist in the Victorian Riverina*".

River red gum billabongs along the Murrumbidgee River were the only habitat type found to contain the broad-palmed frog (*Litoria latopalmata*) during a survey of MIA wetlands in the Riverina (Wassens *et al.* 2004). Largely because of the presence of this species, frog communities in river red gum habitats were significantly different to those in rain fed black box depressions, irrigation canals, and rice bays. Six species were found at river red gum sites (including the wrinkled toadlet, *Uperoleia rugosa* and Peron's tree frog, *Litoria peronii*), but like other habitats, common species dominated (Spotted marsh frog, *Limnodynastes tasmaniensis;* barking marsh frog, *Limnodynastes fletcheri;* and plains froglet, *Crinia parinsignifera*).

Potential implications of changes to irrigation strategies

Future changes to irrigation practices may alter the timing and quantity of water present in wetland systems associated with river red gum, and hence alter how the entire system should be managed to achieve outcomes for both agricultural and environmental purposes.

Since most river red gum communities are associated with river and stream channels, with either permanent or seasonal water regimes, changes to the hydrology of these habitats will change the availability of water to red gum communities and their associated fauna. Reductions in water volume, changes to timing of water delivery (possible differences ranging from weeks to seasons), and changes to flow duration will have implications for vegetation productivity, composition and regeneration, as well as for fauna species with specific requirements such as restricted breeding seasons or dense vegetation fringing water (e.g. frogs).

Improved water quality may occur due to piping of water, with potentially less need for weed poisoning, sediment disturbance and subsequent turbidity. Conversely, reduced flood irrigation frequency and duration, or even reversion to dryland ecology, may result in increased use of chemicals for weed and pest control that may negatively impact upon water quality and the food web. There are many possibilities, however beyond obvious effects (such as tree death due to drowning or water starvation), making detailed predictions is presently difficult if not impossible, given current knowledge.

Some changes may facilitate the achievement of ecological outcomes, for example decreasing irrigation runoff into wetlands that currently receive 'too much' water; or changing to irrigated winter crops may produce seasonal patterns of flow that are more closely aligned with historical patterns. Other changes may make the achievement of ecological outcomes more difficult, for example decreasing drainage water may make some parts of the system too dry to produce conditions that suit waterbirds. As articulated by Briggs and Thornton (1999), a regional or basin wide approach to management will need to be taken to achieve agricultural and environmental outcomes. This applies both now and into the future under any potential changes.

Black box (Eucalyptus largiflorens) communities

In the eastern MIA, Roberts (2005) found black box to be the dominant associated with nearly all depression wetlands, most deflation basins and all impounded meander wetlands. Most black box sites surveyed for biodiversity in the Riverina are depression wetlands. The health of black box communities is commonly adversely affected by insufficient or excess inundation (frequency, duration), salinity, poor water quality, grazing, and/or weed invasion. The priority major threat to black box condition and regeneration in the Murray Valley (MV) Irrigation Area is altered wetting regime, followed by fencing and grazing. It is thought that wetting events of between one in five years and one in ten years are ideal for these communities (Pollino *et al.* 2006). The depth to the water table in the Riverina has also been an issue of concern in the past because of its links to salinity and its implications for the health of black box remnants in depressions.

Despite changes in water regime being a primary risk factor for black box communities and biodiversity in the Riverina in general, very few data are available describing either past or present hydrogeomorphology of sites surveyed for biodiversity to-date and this is a critical area for future work. Consequently it is difficult to draw specific links between water regime and site condition or site biodiversity. Some studies have drawn comparisons between vegetation communities; but these rarely comment on site history characteristics relevant to water regime.

Black box communities in the MIA are commonly used for grazing, and disposal of drainage and escape water (Harrison and Roberts 2005). Those influenced by river flows have also experienced water regime change *via* river regulation and water extraction. Other more direct alterations include:

- Reduced flooding via earthworks;
- Increased flooding via earthworks;
- Rivers and streams used as canals;
- Impounding of rivers and streams with weirs or dams;
- Depression wetlands converted to dam storage;
- Deflation basins converted to dam storage.

Black box dominated 16 of the 38 wetland sites inventoried and audited by Harrison and Roberts (2005) and Roberts (2005) in the MIA. Three of these sites were also surveyed as part of baseline study of condition and vegetative biodiversity of vegetation remnants in the MIA (Eldridge 2002), in which black box dominated 20 of the 44 sites assessed in detail (33 of the total 70+ MIA biodiversity sites). Sites were not randomly selected – rather, they were deliberately chosen to span a range of conditions, and replication may have been insufficient for some vegetation types. Consequently the statistics derived from these surveys may not reflect the majority of black box communities in the region. In general, of the vegetation communities surveyed by Eldridge (2002), black box sites had the highest: number of hollows per tree; cover of annual grasses; cover of forbs; and soil organic carbon content. Black box sites had the lowest: proportion of native and/or perennial species in the groundstorey; canopy health score; number of shrub species; and cryptogam cover. Perennial grass cover in black box communities was generally relatively low, and logs and other woody debris were rare. Black box health and density varied widely. The most common shrubs found in the understorey were spiny saltbush (*Rhagodia spinescens*), and on regularly inundated sites, lignum (*Muehlenbeckia florulenta*). Common groundstorey species included barley grass (*Hordeum leporinum*); great brome (*Bromus diandrus*); climbing saltbush (*Einadia nutans*); ryegrass (*Lolium* spp.); white-top (*Austrodanthonia caespitosa*); rough speargrass (*Austrostipa scabra*); London rocket

(*Sisymbrium irio*); smooth mustard (*Sisymbrium erysimoides*); prairie grass (*Bromus cartharticus*); Paterson's curse (*Echium plantagineum*); horehound (*Marrubium vulgare*); common nardoo (*Marsilea drummondii*). As most of these species are exotic, this list indicates an understorey that has been highly disturbed and is in poor condition.

Fauna

The presence of black box communities on rice farms of the Riverina is associated with greater species richness and abundance of terrestrial birds, waterbirds, and reptiles, and with higher species richness of frogs and mammals, compared to farms without substantial remnants (Doody *et al.* 2006). The habitat complexity provided by trees, shrubs, grasses and fallen timber in black box communities is important for a range of native species when both dry and flooded. Fallen timber density, cover and complexity of the ground- and mid-storeys, vegetation diversity and composition are all associated with habitat quality and biodiversity, and are affected by both water regime and grazing. Surveys have found that fauna species richness and abundance within black box sites varies depending upon site isolation and connectivity, size, shape and quality (Sass *et al.* 2004; Wassens *et al.* 2004; Wassens *et al.* 2005; Doody *et al.* 2006; Herring *et al.* 2006; Brown *et al.* 2008). For example, the relationships between bird diversity and black box patch shape, size and condition in 23 black box sites were examined in 2002 in the Coleambally Irrigation Area (CIA) of the Riverina (Doody *et al.* 2006). Patch area, shape, habitat complexity and condition were positively related to species richness and abundance of woodland birds. Sites were not randomly chosen, and although the presence of water within a patch was recorded, this information was apparently not used as part of the site selection process, in calculating a habitat complexity score, or as an explanatory variable for analysis. No description of hydrogeomorphology was given. Overall, data are scarce that describe how water regime, time since wetting and either insufficient or excess water influence vegetation composition, structure, habitat suitability and the presence of fauna in black box communities of the Riverina.

Black box wetlands and deflation basins in the rice growing regions provide significant habitat for many waterbird species (Roberts 2005). Two in particular, Fivebough and Tuckerbil swamps, are listed together as an internationally important Ramsar site, while many other sites have regional or national significance (Roberts 2005). Many of these sites have been changed by irrigation practices that have either reduced or increased the amount of water available in them, as well as the timing of availability of that water. One of the most heavily altered sites is Barren Box swamp which historically was an important breeding area for waterfowl (Braithwaite and Frith 1969). Until recently the entire swamp was used for holding drainage water from the MIA. Recently it has been divided into three sections, which will have different management regimes. In 2008 cormorants and darters have bred on one section (the intermediate storage area) and other species using the swamp include pelicans, black swans, wood ducks, musk ducks, spoonbills, ibis, whistling kites and sea-eagles (K. McCann pers. comm. and pers. obs.). The current 'ecological value' of many of these sites relates to recent observations of waterbirds using them and does not necessarily reflect that they are functioning as they did historically (Roberts 2005). However, there is limited detailed understanding that has been published of how different management strategies change the suitability of these habitats for waterbirds or of how these areas contribute to regional or national population outcomes for waterbird species. In general, many waterbird species have suffered regional and national population declines in the last 25 years (Kingsford *et al.* 1999; Porter *et al.* 2006).

In a mammal survey of the MIA conducted in 2004-05 (Lewis 2006), black box dominated 6 of the 20 core sites and one of the supplementary sites. Black box communities in the floodway downstream of the Barren Box deflation basin contained significantly more native mammal species than grassland-shrubland communities. These differences were attributed to the lack of arboreal fauna and fewer bat species in grassland-shrubland communities. Bat species richness and activity were greater in black box sites than in other vegetation communities (except boree). Bats were subsequently suggested as an indicator or predictor species for biodiversity in woodland communities. Other native mammals regularly found in black box included brush tailed possums and grey kangaroos. Mammal species richness was shown to be influenced by landscape complexity, shrub and log cover, the presence of hollow-bearing trees and remnant (or patch) size (Lewis 2006).

Reptile diversity is generally low in modern black box communities. However in rice-growing areas of the Riverina, reptiles may be more abundant in black box remnants than in other rice farm habitats such as rice bays, dams, dry crops, saltbush shrubland or river red gum woodland (Doody *et al.* 2006; Brown *et al.* 2008). A reptile survey conducted in the Victorian Riverina (Brown *et al.* 2008) found on average only 1.5 species per black box site. Although species richness was lower in black box sites than in river red gum or grey box sites, reptile abundance was greatest overall in black box, and reptiles were recorded at 95% of the black box sites surveyed. The highest values for species richness, abundance and frequency of occurrence were recorded in roadside remnants, probably reflecting greater structural complexity of the ground- and mid-storeys; the lowest values were in small blocks of woodland (Brown *et al.* 2008). Similarly, a reptile survey of the MIA conducted by Sass *et al.* (2004) in 2003 found that black box communities had the lowest reptile species richness per site (2.25) compared to other vegetation communities; however no comment was made on relative abundance. This survey included 12 sites dominated by black box (of 33 sites), and focused on vegetation communities identified by Eldridge (2002), including: bimble box – cypress pine, river red gum, mallee, boree, rosewood – belah, and chenopod shrubland – grassland. The study separated out vegetation patches dominated by *Chenopodium nitrariaceum* and black box patches occurring in floodways – however no description of the hydrogeomorphology of or differences between these types was given. Assemblages were generally dominated by common species such as Boulenger's skink and wall lizards. Overall, reptile species richness was influenced by grazing pressure, fallen timber, and connectivity between patches of vegetation.

Frog surveys in 2003-2004 (Wassens *et al.* 2004) focused on the 38 wetland sites of the MIA inventoried and audited by Harrison and Roberts (2005) and Roberts (2005). Black box (wetlands and rain-fed depressions) dominated 14 of the key sites surveyed. Billabongs bordered by river red gum, canals, dams, and rice bays were also surveyed. The criteria used to define each of these habitats were not clear in terms of geomorphology, original or current water regimes/permanency/sources, or human impact (e.g. engineering, pesticides or herbicides). Frog communities in black box depressions and wetlands varied across sites (Wassens *et al.* 2004) but in general black box depressions had higher species richness (8 spp.) than river red gum wetlands (6 spp.), rice bays (6 spp.) and canals (5 spp.). Dams with abundant vegetation contained the highest number of species (9), primarily because of the density and diversity of fringing vegetation and number of microhabitats, which were the main contributors overall to good wetland condition, and consequently to frog species richness. High salinity levels were associated with poor frog species richness and abundance, even when vegetation structure was satisfactory (Wassens *et al.* 2004).

An arthropod survey of remnant vegetation in the MIA (Wassens *et al.* 2005) included black box as one of four communities investigated (also boree, bimble box - cypress pine, and mallee). Black box dominated four of the fourteen sites surveyed. Again, the hydrogeomorphology of the sites (past or present) was not described. Arthropod species richness was not statistically different between black box and other vegetation communities surveyed, however the maximum number of species found was greatest in black box sites, and there were significant differences in arthropod community composition. Species richness increased with grass cover and the amount of fallen timber and loose bark on the ground. In another study, ant and beetle species richness and composition were shown to be strongly associated with water table depth in the CIA (sites with deeper water tables yielding greater diversity and different species), and low soil salinity in particular is associated with high biodiversity in beetles (AMBS 2005).

Potential implications of changes to irrigation strategies

The greatest potential changes to black box as a result of altered irrigation practices involve the disposal of drainage and escape water and changes to the water table. As irrigation practices become more efficient and water storage in on-farm canals and dams increases, black box communities may receive fewer watering events over time, and the duration of inundation may decrease. Flooding of black box communities adjacent to canals or streams may become more controlled, with less overflow flooding. This may be a good thing for those black box communities that are currently receiving too much water, but for those that no longer receive natural inputs of water the lifeline provided by irrigation drainage will disappear if deliberate watering action is not undertaken. In addition, simply changing the timing of water use on rice or other crops may also change the timing of wetting events in black box depressions receiving overflows or drainage, with potential implications for productivity and habitat suitability for fauna. For example, in some cases reduced irrigation drainage water in black box depressions may improve the ecological values for waterbirds locally, while in others it may reduce the ecological values locally. The outcomes may also be species/group specific, because different waterbirds require different conditions in which to forage and/or breed (Kingsford and Norman 2002). Understanding how changes to irrigation practices will affect regional and national outcomes for waterbirds will require an integrated consideration of how these changes alter waterbird habitat throughout the irrigation system.

It is generally accepted that irrigation and tree clearing in the Riverina have caused water tables to rise, with associated increases in soil and water salinity. During the recent drought, lowering of the water table has temporarily reduced the urgency of this problem, and there is anecdotal evidence that some black box trees in depressions have begun to recover. Changes in irrigation practices in the future may reduce the amount of water reaching the water table and hence reduce the prevalence of its influence on biodiversity, but this will still require active management.

Water quality remains an issue for black box communities receiving drainage water, regardless of how the water regime or water tables may change. Possible water quality improvements from piping or problems because of changed timing of water application or changed crops are similar to those discussed for red gum. Again, the lack of targeted data makes prediction of changes and effects difficult. Although it is known that black box remnants are important hotspots for biodiversity in the Riverina landscape, and that their condition is controlled partly by water availability, it is not known what effect changes to water regimes have had in the past or will have in the future. This is partly because of a paucity of hydrogeomorphological data for individual sites, past or present, and partly because the question simply has not been investigated to-date. Targeted data collection with reference to past and present hydrogeomorphology would also be an important step toward facilitating prediction of the effects of changes in irrigation practice in the Riverina.

Clearing of remnants and paddock trees is a habitat issue with potential to escalate under changing irrigation techniques such as installation of lateral move and centre pivot irrigation systems which require large treeless areas to operate. Isolated paddock trees in intensively farmed landscapes are being increasingly recognized as vital and irreplaceable habitat elements for native fauna (Manning *et al.* 2006). Retained paddock trees are typically mature and bear hollows upon which the native fauna relies for breeding and shelter (Gibbons and Boak 2002; Gibbons and Lindenmayer 2002). Paddock trees may also act as ‘stepping stones’ or provide some form of connectivity across the otherwise hostile irrigated landscape. They can also provide a feeding resource for fauna such as bats, birds and mammals (Gibbons and Boak 2002; Lumsden and Bennett 2005). These trees are declining due to natural senescence, removal and the adverse effects of the surrounding land uses, and positive action is required to retain, manage and regenerate them for future habitat (Gibbons and Boak 2002).

1.3. Constructed habitats affected by irrigation practices

The most common constructed habitats in the Riverina include: irrigation canals, rice bays (and associated toe furrows and contour banks), ring tanks or storage dams, other irrigated crops, and dryland crops. This section describes the biodiversity of irrigation canals, rice bays and storage dams in separate sections, each with a discussion of the consequences for biodiversity of potential changes to irrigation practices.

Irrigation canals

The biodiversity of irrigation canals (supply channels, on-farm channels, or drainage ditches) in Australian rice landscapes is poorly studied and documented, especially when compared to international knowledge. A review of the biological communities of agricultural drainage ditches or canals in the temperate and boreal zones of the Northern Hemisphere (Herzon and Helenius 2008) found that although most drainage canals usually only support species that are common elsewhere, they can provide valuable habitats to both aquatic and terrestrial taxa, supply food resources lacking in otherwise dry or intensively managed cropland, and provide connectivity across the landscape. Irrigation channels can supplement or refresh biodiversity in rice bays and other environments in rice systems by acting as conduits, e.g. for seed, eggs, juvenile or adult organisms (Bambaradeniya and Amarasinghe 2004). It is possible that the overall biodiversity in a landscape may be affected by the type and density of irrigation channels, and their proximity to larger waterbodies (Herzon and Helenius 2008), however direct evidence for this was not apparent in the literature. Vegetation species found in and adjacent to irrigation canals are usually tolerant of flooding, disturbance, and high nutrient and herbicide inputs – characteristics of noxious, often exotic, weeds (McIntyre and Barrett 1985; McIntyre *et al.* 1988; Herzon and Helenius 2008). Aquatic invertebrate biodiversity in irrigation channels can be higher than that found in rice bays and storage dams, but is generally lower than that in more natural habitats (Doody *et al.* 2006).

Amphibians, fish and reptiles

The role of irrigation channels in the landscape may influence biodiversity at both local population and regional meta-population scales. International studies have shown that at the local scale, frogs use irrigation channels for breeding and feeding, but these habitats are not necessarily ideal for all species (Mazerolle 2005). Frogs breeding in irrigation channels may benefit from periods of disconnection or drying that temporarily exclude predators such as fish and turtles (Bambaradeniya and Amarasinghe 2004; Herzon and Helenius 2008). Conversely, dry periods may not suit some frog species or life stages, and wet channels can also facilitate the movement of predators. Channels may enable movement of frogs both locally as well as across broader, more hostile agricultural landscapes (Mazerolle 2005), however where canals contain habitat that is discontinuous or hostile to frogs they may locally expose frogs to predators, restrict frog movement, and act as population sinks (Wassens *et al.* 2008). Populations of *Bufo americanus* and *Pseudacris triseriata* in the USA have been shown to depend upon the retention of irrigation channels in farmland for regional persistence (Mazerolle 2005; Herzon and Helenius 2008).

Only five species of frog (of a possible 11-14) were found in irrigation channels of the MIA by Wassens *et al.* (2004), despite more of these habitats being surveyed than other habitats. These species are common across the Riverina, and also in the study area, with four of the five (*Limnodynastes fletcheri, Litoria peronii, Crinia parinsignifera,* and *Limnodynastes tasmaniensis*) being found in all other habitats surveyed (black box wetlands and rain-fed depressions, billabongs bordered by river red gum, dams, and rice bays). One species, the endangered southern bell frog (*Litoria raniformis*), may now rely on irrigation canals for regional persistence in the Riverina (Wassens *et al.* 2007; Wassens *et al.* 2008), where it is likely that permanently flooded irrigation channels in the Riverina act as dry-season or over-wintering refuges (Wassens *et al.* 2008). Routine drying, excavation, vegetation clearing and agrochemical treatment events in other irrigation channels reduce the suitability of these habitats as refuges for frogs.

Whether irrigation canals play a critical role in the metapopulation dynamics of species in the Riverina is not known and teasing out the relative influences of processes at different scales (e.g. farm vs. region) is difficult with limited information. Farm-scale radio-tracking of *Litoria raniformis* in the Riverina (Wassens *et al.* 2008), found that linear movements along irrigation canals were uncommon, suggesting that irrigation canals play a limited role in the dispersal of adults. However, the role canals and their associated mechanics such as gates, water wheels and pumps may play in the dispersal of tadpoles and juveniles and hence colonisation of distant areas is unknown.

Although irrigation channels in the Riverina contain fish (native and exotic), most of these populations are accidental (a product of diversions from the river; King and O'Connor 2007), and few channels can support fish reproduction and survival. A study of fish in the Murrumbidgee River and associated canal systems in the Riverina found that a wide range of fish species and size classes were entrained or extracted by channels from the river (Baumgartner *et al.* 2007). However most fish entrained in the Riverina are larvae and juveniles with poor swimming ability (Baumgartner *et al.* 2007; King and O'Connor 2007). Loss of native fish into irrigation channels may be a 'substantial problem' for regional native fish populations in rivers (King and O'Connor 2007). Drying of irrigation channels significantly affects fish populations via stranding or changes in water quality, and irrigation infrastructure such as pumps, wheels and gates can also cause injury and mortality (Baumgartner *et al.* 2007). Many native fish are migratory, moving either upstream or downstream depending on life-stage, season and river flow. Most migrations occur during the warmer months, when irrigation diversions in the Riverina are in full swing. Consequently large numbers of fish may move into irrigation systems and become trapped there, and it is generally assumed that these are 'lost' from the main river populations (Baumgartner *et al.* 2007). Management of channels also significantly affects fish populations and species richness. Simple or altered channels in the Riverina with poor habitat were dominated by Australian smelt (*Retropinna semoni*) and invasive European carp (*Cyprinus carpio*; Baumgartner *et al.* 2007). Persistence in these environments depends upon tolerance of species to restricted movement, poor water quality and habitat structure, and lack of connectivity. Habitat availability within channels (natural morphology, vegetation and physical structure) was the primary determinant of whether a species was able to form a self-sustaining population, and was also associated with greater fish species richness (Baumgartner *et al.* 2007). Comparison of the effects of channel entrainment, pumping from the river, and rapid draw down in channels on fish in irrigation areas of the Murray-Darling Basin (Baumgartner *et al.* 2007) suggested that these practices affect native fish in a range of different ways. Consequently the effects of possible changes to these practices are also likely to be complex.

A study of a single rice farm in the Riverina (Doody *et al.* 2006) showed that turtles (*Chelodina longicollis*) use large irrigation supply channels extensively (69% of daily relocations). Smaller farm-scale irrigation channels, the deep edges of rice bays (toe furrows) and storage dams were also used but to a much lesser extent. This may be related to macroinvertebrate prey diversity, which was highest in the large irrigation supply channel, followed by the farm-scale channels, toe furrows, rice bays and storage dam. Macroinvertebrate prey abundance during the survey was highest and most variable in the farm dams, higher in the rice toe furrows than in the supply channel, and rice bays had the lowest prey abundance. It is possible that this disparity between diversity and abundance of macroinvertebrate prey in irrigation channels and other habitats reflects a top-down effect of turtles in the food web. The stomach contents of these turtles were dominated by macroinvertebrates, but also included frogs, tadpoles and fish.

Birds and mammals

In general, overseas studies have shown that terrestrial bird and waterbird diversity in and use of irrigation channels is greatest when channels are large and have extensive complex vegetation, both inside and outside the channel itself (Herzon and Helenius 2008). Little is known of what effect different water regimes in irrigation channels have upon birds, but the response is likely to be complex because of the various niches and resources provided by channels when they are wet, damp, and dry. These might include '*damp soil for probing species, permanent water to provide aquatic invertebrates, bare or sparsely vegetated ground to improve access to benthic and soil invertebrates, rank emergent vegetation for nesting, and bush and tree groups to provide nesting and singing posts*' (Herzon and Helenius 2008). In the Riverina, the banks of irrigation canals are often cleared of woody vegetation and hence the food resources that could be available to sedentary terrestrial birds may not be exploited in this system, unless the canal passes close to remnant vegetation. Whether the food resources available in irrigation canals make a significant contribution to terrestrial birds in the Riverina is currently not known and deserves further exploration.

Very little information exists on the role irrigation canals and ditches play in the ecology of waterbirds (reviewed in Czech and Parsons 2002; Taft and Elphick 2007). In the rice growing regions of Italy, Mallard and Common Moorhen often nest along irrigation ditches, while in Spain, little bittern (*Ixobrychus minutus*) nest along irrigation ditches (Czech and Parsons 2002). In the rice-growing regions of California, where few natural wetlands are available for breeding, irrigation ditches and canals (along with associated rice fields) are used for nesting. However, predation rates on ducklings are high in this habitat (Taft and Elphick 2007) and hence these breeding attempts may not contribute significantly to the overall population of the species. Other species have been observed foraging in irrigation canals and ditches. For example, purple herons (*Ardea purpurea*) forage in canals in Europe when natural wetlands are dry (Czech and Parsons 2002) and diving ducks and grebes forage in deeper canals in America (Taft and Elphick 2007).

A study in Japan compared wading bird activity and the availability of prey in conventional shallow earthen ditches, deep concrete-sided ditches and in rice fields adjacent to these two types of ditches (Lane and Fujioka 1998). Prey were more abundant in the conventional ditches and the rice fields they supplied water to and the abundance of one egret species reflected this distribution of food resources; however, the abundance of four other wading bird species did not reflect this pattern (Lane and Fujioka 1998). In another study waterbirds used fields where water was supplied by either ditch type, but did not use the ditches themselves (Maeda 2001).

In the Australian Riverina, no studies have specifically addressed the role of irrigation canals and ditches in the ecology of waterbirds, although waterbirds have been observed foraging in these habitats. For example, a closely observed group of wood ducks (*Chenonetta jubata*), a grazing species, spent almost two months in spring feeding on legumes and milk thistles along an irrigation channel (Frith 1957a; b). A study on egrets showed that intermediate and great egrets spent some time foraging in channels associated with rice fields, particularly as the rice crop matured and their foraging success within the crop diminished; however, the authors concluded that the majority of foraging at this time took place in natural wetlands (Richardson and Taylor 2003). There are no published records that we could find that related successful breeding of waterbirds in Australia with irrigation channels or ditches.

Native mammal abundance and diversity in or adjacent to irrigation channels is poorly known, both in Australia and overseas. In the Riverina, the potential benefits of habitat in close proximity to a water source such as an irrigation channel are probably discounted by lack of vegetation cover and structure, competition with house mice, and the small and narrow areas involved (edge effects), with concomitant exposure to feral predators and disturbances such as channel dredging, poisons, vehicles and stock. One native mammal which may survive in these environments is the water rat; however a recent survey in the MIA failed to find water rats in or near irrigation channels (Lewis 2006). Researchers trapping house mice (*Mus domesticus*) adjacent to irrigation channels and fields on seven Riverina farms in the CIA from 1998-2002 did not capture any other species of small mammal over 45,000 trap-nights (Brown *et al.* 2004). Few other data exist assessing even presence/absence of native mammals associated with irrigation canals.

The relative value of irrigation channels compared to other habitats is not clear, and is most likely determined by landscape structure and the presence of more natural habitats. In the Riverina, the variability of irrigation channels in terms of water regime and water quality, their exposed nature, and the impacts of intensive management of their sediment, vegetation, and invertebrate populations, are likely to restrict any development of complex food webs or significant biodiversity solely associated with the channels themselves, but channels may provide significant resources to animals in the surrounding landscape.

Implications of potential changes to irrigation management (canals)

Herzon and Helenius (2008) present a review of the potential biodiversity implications of change or loss of irrigation canals in the Northern hemisphere. Many of these are relevant to Australian Riverina irrigation systems; however other issues are specific to this region. Northern Hemisphere irrigation channels frequently have greater biodiversity than those of the Australian Riverina, because of their marshland origins, climate, and long history. Consequently the removal or poor management of Northern Hemisphere irrigation channels is seen as a threat to biodiversity (Herzon and Helenius 2008) and is a serious social issue (Hietala-Koivu *et al.* 2004). In particular, agrochemical runoff and vegetation removal are seen as major threats. In Japan, concrete lining and piping of irrigation channels has resulted in loss of habitat for aquatic invertebrates, amphibians, and some waterbirds (Fujioka and Lane 1997; Lane and Fujioka 1998). Compromises in irrigation channel management that support both biodiversity and production purposes are sorely needed. In some landscapes, irrigation channels are the only wet and/or uncropped habitats remaining (Herzon and Helenius 2008).

Possible changes to Riverina irrigation channels include conversion to piping or concrete lining, and alterations in the timing, duration, water quality, and volume of inundation. These changes have implications for habitat substrate, including water, sediment, vegetation presence, structure and composition, and also for water quality and management actions, such as agrochemical applications. At the local scale, reduction in the availability of canals or simplification by lining would likely result in a reduction in abundance of species dependent on canals such as frogs and turtles and possibly sedentary terrestrial species from the surrounding landscape that obtain food resources from canals. Increasing use of drainage channels for storage of excess irrigation water may be of benefit to some species, either by making more water available during winter, or by increasing the amount of still-water habitat in the landscape; these areas may act as drought refuges for some species. Increasing use of chemicals that may be associated with changes from flood irrigated rice has the potential to have negative consequences for some species.

At a broad scale, the effect of changes to irrigation canals will depend on how/whether canals make a large contribution to the populations of some species and possibly even contribute to population persistence. Many species associated with canals appear common in the landscape and may not be significantly affected by changes, but for others canals may be critical, for example the endangered southern bell frog. A reduction in the availability of irrigation canals could have consequences if: canals provide connectivity across the landscape for species such as invertebrates, frogs or fish; canals provide alternative habitats that are relatively free from predators or the vagaries of the Australian climate and unpredictable flow regimes, and consequently acting as refugia supporting populations at broad scales (Herzon and Helenius 2008); canals provide significant food resources that support some species at broad scales. Such possibilities need to be considered as part of any investigation into trade-offs involved in local and regional change and are an important area for future research.

Rice bays

Although physically simple, rice bays are highly variable environments over time, passing through dry, flowing, stagnant, and drying phases each year a rice crop is grown, and being used for a range of other crops at different times. These phases create rapid physical, chemical, and biological changes that limit the organisms that can survive there (Bambaradeniya and Amarasinghe 2004). Variations in the timing and duration of each phase may substantially alter the suitability of rice fields as habitat or as food sources for different organisms. Some may benefit and others may not. Overall, relatively tolerant, mobile and opportunistic organisms are best able to exploit resources in rice bays.

Rice bays can be important habitats for native aquatic and semi-aquatic wetland plants that would otherwise be restricted in distribution or lost from the landscape post-development for agriculture. For example, McIntyre *et al.* (1988) found three native wetland species (*Najas tenuifolia, Gratiola pedunculata* and *Pilularia novae-hollandieae*) in rice bays of the Riverina that were not recorded in other habitats, with implications for the importance of rice bay management for biodiversity conservation in the region. In the same study, rice bays were shown to have lower plant species richness (both native and introduced) than roadside wetlands and natural wetlands, although many of the dominant species were native (see also McIntyre & Barrett 1985).

In terms of fauna, the majority of published research into the ecology and biodiversity of rice bays has occurred in Europe, the USA, and Asia (Sri Lanka, Laos, Thailand, Japan and Malaysia). Invertebrates, frogs, and waterbirds are thought to be the groups to benefit the most from flooded rice bays. In general, frogs, waterbirds, reptiles and mammals are usually regarded as temporary or ephemeral visitors that use the rice fields for feeding but rarely live or breed there in the long term (Bambaradeniya and Amarasinghe 2004).

Aquatic invertebrates are the most abundant and diverse fauna found in rice fields, and have generally received greater research attention than other groups, especially in Asia (Bambaradeniya and Amarasinghe 2004). In temperate irrigated rice systems such as the Riverina, the provision of broad-acre aquatic habitat where relatively little existed previously is advantageous to aquatic invertebrate fauna, but in such systems these are predominantly species that can tolerate frequent, rapid and drastic change (Bambaradeniya and Amarasinghe 2004; Wilson *et al.* 2008). In tropical rice systems, where most rice fields are converted from permanent wetlands, the high diversity of aquatic invertebrates has been inherited from the natural wetland or marsh system (Bambaradeniya and Amarasinghe 2004). This is not the case in the Riverina, where floodplains that were only episodically inundated and were dry for most of the time, are now artificially irrigated in summer. Invertebrate biodiversity in rice bays is also affected by application of agrochemicals – drill-sown rice bays of the Riverina that are organically managed (without agrochemicals) have macroinvertebrate communities with higher biodiversity than conventional rice fields treated with agrochemicals (aerial or drill sown; Wilson *et al.* 2008). Aquatic biodiversity in rice bays of one farm in the Riverina was found to be lower than that found in irrigation channels but higher than that found in a storage dam (Doody *et al.* 2006). The same study found that rice bays had the lowest abundance of macroinvertebrates relative to other habitats.

Amphibians and reptiles

Amphibians using rice bays prey upon pests, and are prey for other fauna groups, but are limited by the availability of water and shelter (Bambaradeniya and Amarasinghe 2004). For example, immediately after flooding and sowing, rice bays in the Riverina remain effectively bare for some time, and the frog *Litoria raniformis* will rarely move into them until the crop has grown to sufficient height and density and their invertebrate prey is readily available (Wassens *et al.* 2008). Although these frogs may disperse significant distances across rice bays, they will then abandon the bays during the drying period, returning to flooded irrigation canals. On one Riverina farm, Doody *et al.* (2006) trapped large numbers of young *Limnodynastes tasmaniensis* adjacent to a rice bay, following drainage of the bay and heavy rainfall (April 2001). It appeared that the newly metamorphosed frogs were dispersing from the rice bay (and or its toe furrows) into the adjacent riparian remnant vegetation and creek, and the large numbers were thought to indicate the importance of rice farms to frogs, and in turn, the importance of frogs in the food web and in the rice agroecosystem as a whole. Many other species consume frogs (and tadpoles) regularly, including waterbirds, terrestrial birds, mammals, and reptiles.

Frog species richness in rice bays of the Riverina is generally relatively low (3-6 species) and dominated by common species (Spotted marsh frog, *Limnodynastes tasmaniensis;* Barking marsh frog, *Limnodynastes fletcheri;* and Plains froglet, *Crinia parinsignifera*); but is similar in composition to wetlands (Wassens *et al.* 2004; Doody *et al.* 2006). Tadpoles of *Neobatrachus sudelli* were recorded in one rice bay by Wassens *et al.* (2004). This species was also recorded in irrigation canals and dams – constructed habitats – as well as in rain-fed black box depressions. *Limnodynastes tasmaniensis* was found to be significantly more abundant in rice crops than in dry crops by Doody *et al.* (2006), but mean capture rates of all frogs were higher in general in any wet habitat compared to dry habitats.

Most reptile species in the Riverina such as snakes and lizards are restricted to terrestrial habitats or the margins of wet areas and hence are not found in rice bays *per se* – even though they are known to consume frogs and insects. Surveys conducted by Doody *et al.* (2006) found no difference in capture rates (abundance) of reptiles between rice bays and dry crops – excepting turtles. Turtles are common in some rice-growing areas but not others, and the reasons for this are not clear (Doody *et al.* 2006), however it is apparent that the presence of rice *per se* does not meet all requirements for turtles to be present. Habitat use of Eastern long-necked turtles (*Chelodina longicollis*) on a rice farm surveyed by Doody *et al.* (2006) where they were abundant was similar to that observed for frogs, with occasional forays into flooded rice bays to feed, but with large irrigation channels preferred and used as refuges when the rice bays dried out. When found in rice bays they were nearly always associated with the toe furrows rather than in the rice crop itself. Toe furrows were shown to have higher macroinvertebrate prey diversity and abundance than rice fields.

Birds and mammals

Large numbers of waterbirds throughout the world exploit the food resources available in rice fields (Czech and Parsons 2002; Taft and Elphick 2007). However, the effect of rice fields on waterbird populations throughout the world appears variable either because of where the rice growing regions are located or how the fields are managed (Czech and Parsons 2002; Taft and Elphick 2007). For example, in southern Europe, increases in the number of some herons and egrets have been associated with the introduction of rice growing (Czech and Parsons 2002), presumably because rice fields provide additional resources for these species that previously did not occur there. However, in the same region, the decline in abundance of other species has been linked to the use of pesticides in rice fields (Czech and Parsons 2002). In the USA, many of the rice growing regions are where natural wetlands once provided important wintering or migratory habitat for waterbirds. These wetlands have been replaced by rice fields, and in some cases these fields are now deliberately flooded in winter to provide significant foraging opportunities for waterbirds, particularly waterfowl, with other groups including wading birds and shore birds occurring in lower densities (Taft and Elphick 2007). Far fewer species nest and breed successfully in these areas in the USA (Taft and Elphick 2007), but breeding waterbirds have been associated with rice fields in Japan (Lane and Fujioka 1998; Maeda 2001) and Europe (Tourenq *et al.* 2000; Tourenq *et al.* 2004).

Practices that make rice fields more beneficial to some waterbirds mainly result in improved food availability for them (Czech and Parsons 2002; Taft and Elphick 2007). For example, in the USA residual straw management, shallow winter flooding, reduced use of harmful pesticides (which could also have a direct effect on waterbirds) and fallow and secondary crop rotation practices that encourage the production of seed-producing plants have been identified as beneficial practices (Taft and Elphick 2007). Maintaining earthen ditches rather than using concrete channels results in higher prey abundance in associated rice fields (Lane and Fujioka 1998), and hence may improve foraging conditions for waterbirds. However, while these practices can provide some benefits to waterbirds, we currently do not know how these contribute to the overall population outcomes for waterbirds, or how they compare to the outcomes for waterbird populations that would be achieved if the water was used in natural wetlands.

In the Australian Riverina, local bird diversity and abundance in rice bays increases following flooding and decreases after draining (Doody *et al.* 2006). When rice bays are dry, bird communities are dominated by terrestrial species, however some waterbirds will continue to use rice bays for some time following draining (Doody *et al.* 2006). The increase in bird diversity and abundance during flooding is not just confined to waterbirds, but also applies to terrestrial land birds, suggesting that significant food resources become available to land birds in flooded rice fields. Whether these resources make a significant contribution to the abundance or persistence of land birds in the Riverina is currently not known and is an area that requires further research.

Although a large number of water bird species have been observed in or near rice bays in the Riverina (e.g. ducks, ibis, egrets, herons), it is not certain to what extent the bays support these mobile species in the long term. Egrets have been observed foraging in rice fields during their breeding season (Richardson *et al.* 2001; Richardson and Taylor 2003). Great (*Ardea alba*) and intermediate (*Egretta intermedia*) egrets foraged in rice fields during the early stages of crop production, but appeared to reduce their foraging as the crop progressed and the availability of vertebrate prey declined (Richardson and Taylor 2003). As the crop matured, 80 – 90 % of intermediate and great egrets shifted their foraging to natural wetlands. This period also coincided with the main chick rearing period for these two species, leading the authors to suggest that rice fields may be inadequate foraging habitats for them during the breeding season (Richardson and Taylor 2003). In contrast, invasive cattle egrets (*Bubulcus ibis*) that focus on invertebrate prey continued to forage in rice fields until after their chicks fledged (Richardson and Taylor 2003). This species also began breeding in the area earlier than the other two species, leading the authors to speculate that cattle egrets may replace the other species over time (Richardson and Taylor 2003).

Grey teal, black duck and white-eyed duck have been shown to exploit resources in rice fields, depending on where they were located (Frith 1957b). Samples of these species obtained from ducks associated with Tuckerbil Swamp had rice in their diets in November – December (i.e. early stage of crop), while black duck and white-eyed duck also had rice in their diets when the crop was maturing. All species had large quantities of barnyard millet and water couch, significant weeds of rice crops, in their diets from December – May. In contrast, grey teal and black duck associated with the nearby Murrumbidgee River where considerably more natural habitat was available had no rice in their diets despite rice being grown in nearby areas – most of their food came from the swamps and billabongs (Frith 1957b). Wood ducks rarely exploited rice and when they did it was to feed on young plants (Frith 1957b). Their food was derived from numerous sources of green herbage throughout the area. As for egrets, it is not clear if/whether rice fields play a significant role in the overall population outcomes for waterfowl. However, it should be noted that large regional declines in the populations of many waterbird species have coincided with agricultural associated modifications to natural floodplains along the Murrumbidgee (for example the Lowbidgee), large increases in the amount of water being used for irrigation purposes and the consequent reduced flows in the river system (Kingsford and Thomas 2004).

The most common mammals found in or around rice bays are house mice (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 and Amarasinghe 2004); in the Riverina they attract feral predators such as cats and foxes. They may provide significant food resources to some native raptors (Sinclair *et al.* 1990). In the Riverina house mice were found in equal abundance in rice crops and dryland crops (Doody *et al.* 2006). Water rats (*Hydromys chrysogaster*) may also occasionally use rice bays in the Riverina (Scott and Grant 1997), however most records are anecdotal, and recent surveys only found evidence of water rats at Barren Box Swamp (a black box deflation basin) and in a black box depression (Lewis 2006).

Implications of potential changes to irrigation management (rice bays)

A few studies have compared biodiversity between rice bays under different management regimes (Bambaradeniya and Amarasinghe 2004; e.g. Wilson *et al.* 2008; Lawler 2001), however these are dominated by tropical rice system studies, predominantly focusing upon invertebrates, and knowledge gaps remain. The most important controls identified to-date include water management, use of agrochemicals, irrigation and planting systems (including cropping intensity), winter management regimes, and fish population management (Lawler 2001; Bambaradeniya and Amarasinghe 2004; Donald 2004; Wilson *et al.* 2008). Similar issues are likely to apply to outcomes for invertebrate biodiversity in Riverina rice fields.

As for irrigation channels, at the local scale a reduction in the availability of flooded rice fields would likely result in a reduction in abundance of species dependent on water in the landscape and possibly sedentary terrestrial species from the surrounding landscape that obtain food resources from flooded rice fields. However, increased recycling of water on-farm may be beneficial for invertebrate biodiversity. For example, in Malaysian irrigated rice fields, fields using recycled water contained greater diversity and abundance of insects, and immature stages were retained in the system for longer, giving them time to develop (Bambaradeniya and Amarasinghe 2004). The downside to this process in the Australian Riverina is possible increased weed loads and consequent application of agrochemicals, which may disadvantage invertebrates and frogs (Wassens *et al.* 2008; Wilson *et al.* 2008).

At the broad scale a reduction in the availability of flooded rice fields will depend on how/whether they make a large contribution to the populations of some species and possibly even contribute to population persistence. Many organisms using rice bays in the Riverina are common and opportunistic, and may not rely directly upon the rice crop or its flooding for population persistence. However, reductions or removal of ponded water may have implications for some species. In terms of amphibians, Wassens *et al.* (2008) suggested that reduced flooding (natural or artificial) may limit dispersal and recolonisation opportunities across landscapes, threatening the long-term viability of regional populations. In the Riverina, this would be of particular concern for species in decline such as the southern bell frog, but also potentially for other amphibians and fauna groups that depend upon them as prey. Terrestrial land birds may also now derive significant food resources from flooded rice crops (for example insects) that have broad population level consequences. Frequently, too little is known of the life history of important or declining species or of regional food webs for reliable predictions of the effects to be made. For example, it is unknown whether the southern bell frog has any capacity for aestivation (becoming dormant through summer) during dry conditions (Wassens *et al.* 2008), or how large a role it plays in the food web of the Riverina.

The dominance of native species in the rice weed flora (McIntyre & Barrett 1985) and the extent of rice cropping (at least until recently) does indicate that this habitat is an important stronghold for significant populations of many native species (notably *Cyperus difformis*, *Elatine gratioloides*, *Damasonium minus*, *Marsilea drummondii*, *Diplachne fusca*, *Glossostigma diandrum*, *Limosella australis*, *Centipeda cunninghamii*). Species composition has been shown to be highly sensitive to agronomic methods and a reduction in ponding in rice bays will tend to favour exotics such as *Echinochloa* over native species (McIntyre and Barrett 1983; McIntyre *et al.* 1991).

Storage dams

Storage dams in agricultural landscapes are structurally variable environments, ranging from small to large, steep walled to graduated, deep to shallow, and vegetated to completely bare. Consequently their habitat and biodiversity value is also likely to be variable. The water regime within any one dam can vary widely depending on its primary purpose, water sources and management (Brock *et al.* 1999). Major influences in irrigation areas include rainfall and evaporation, irrigation drainage water and extraction, as well as stock use and groundwater. Some dams are used to retain and process agrochemical and nutrient loads on farm for pre-determined periods of time before water is released, thereby reducing their impact upon natural systems. All of the above factors influence water quality in farm dams, with further implications for biodiversity value (Brainwood *et al.* 2004).

The condition of the vegetation in and around dams is influenced by location, age, water regime, grazing history and intensity, and other management regimes such as weed control (Hazell *et al.* 2001; Jansen and Robertson 2001; Jansen and Healey 2003). Where vegetation diversity and condition is good, dams in the Riverina can be valuable habitat for frogs (Wassens *et al.* 2004) and macroinvertebrates (Doody *et al.* 2006), which in turn may be food sources for waterbirds, turtles, and other reptiles such as snakes. Dams with abundant vegetation contained the highest number of frog species (9) of the habitats surveyed by Wassens *et al.* (2004), primarily because of the density and diversity of fringing vegetation and number of microhabitats, which were the main contributors overall to good wetland condition, and consequently to frog species richness. The most common species found in dams were also found in nearly all other habitats, including *Limnodynastes fletcheri, Crinia parinsignifera,* and *Limnodynastes tasmaniensis*. One particular area (Tully's Hill near Leeton) contributed several of the additional species. The presence of permanent water is thought to be particularly important for frog species that lack adaptations for water conservation such as burrowing, such as the endangered southern bell frog (*Litoria raniformis*), however this species preferred to use irrigation channels and rice bays rather than dams during tracking and surveys conducted by Wassens *et al.* (2008).

The farm dam included as part of a turtle tracking and diet study conducted by Doody *et al.* (2006) was the least used habitat compared to irrigation channels and rice bays. This was despite this habitat containing the highest mean abundance of aquatic invertebrates compared to other habitats (although whether this abundance may be because of lack of predation by turtles is not clear). Macroinvertebrate abundance was also more variable in the dam compared to other habitats. Conversely, macroinvertebrate diversity was lower in the dam than elsewhere, and community composition shifted considerably according to season and water level. The dam comprised a single patch of cumbungi (*Typha* spp.), which contributed more to the abundance and diversity of macroinvertebrates than the open section of the dam, emphasising the importance of emergent vegetation for biodiversity.

A comparison of constructed and natural habitats for frog conservation in agricultural landscapes of the southern tablelands of NSW (Hazell *et al.* 2004) found that farm dams support different frog species to more natural habitats, although the number of species can be similar. Some species are more likely to occur in natural wetlands, and others in dams. The presence of emergent vegetation and the absence of fish are consistently associated with high frog diversity, whether in natural or constructed situations. The authors concluded that while dams may be valuable habitat, it is also important for natural wetlands to be conserved because they support species not found in dams.

Implications of potential changes to irrigation management (storage dams)

The number of dams in the Riverina may increase in response to the desire to conserve and recycle water on-farm, for irrigation, domestic, and stock use. This may change the proportion of semi-permanent still-water habitat across the landscape, and in terms of habitat, may possibly compensate to some extent for decreases in the extent of flooded rice bays. However this will depend upon the management of those dams and their vegetation and water regimes. Reductions in the total amount of water across the region may also reduce the frequency and duration with which dams are filled, and increase the variability in their water regimes. This may in turn change the type and diversity of vegetation and fauna species able to survive in these environments.

Creating physical variability within existing and new dams and improving vegetation condition and diversity in and around them has been suggested as one option for improved biodiversity management and conservation in irrigation areas (M. Pisasale pers.comm.). The extent of native canopy cover and emergent vegetation cover at the water's edge have been shown to be predictors of frog species richness and community composition in farm dams of eastern NSW (Hazell *et al.* 2001). However the potential for positive change in this respect would depend upon the exclusion or careful management of grazing (Jansen and Healey 2003; Jansen and Robertson 2005), and the extent or restoration of native vegetation surrounding dams (Hazell *et al.* 2001), issues that are particularly problematic in the context of drought and limited water availability, both locally and across the region.

1.4. Summary

The direct and indirect changes that may be associated with climate change in the Riverina are likely to present new challenges and opportunities for the persistence biodiversity in the region and more broadly in the entire basin. Below are the main issues we have identified in the review that should be considered:

a) <u>A general reduction of flows in rivers.</u>

A reduction in the availability of water in the major river systems of the basin is likely to increase the difficulty of achieving agricultural and environmental objectives across the basin. Conversely, a shift to the production of winter crops may benefit biodiversity in habitats associated with river floodplains by changing the flow patterns in these systems back to a more natural regime. Historically, peak flows in these river systems occurred in winter and spring. Whatever the scenario, achieving agricultural and environmental outcomes in the river systems will require careful basin-scale management.

b) <u>Improvement of water regimes for some natural habitats, but with some risks.</u>

Changes being considered that would lead to a reduction in the amount of surface drainage water from either farms or irrigation drainage infrastructure entering habitats such as black box depressions and red gum wetlands may help alleviate problems of excess water in some of these sites. Paradoxically, the same areas may therefore become too dry to sustain red gum or black box trees and/or associated wetland vegetation, particularly if they are isolated from natural drainage lines by irrigation infrastructure. This issue may be exacerbated by the direct effects of climate change in the region which may decrease local rainfall and increase local temperatures. In some depression/deflation basin sites ‘excess’ water associated with irrigation practice has meant that these sites, while quite modified from their historical state, now benefit some species dependent on more prolonged periods of inundation. There will be a need for the active management of water availability in some of these sites to achieve environmental objectives. However, our current understanding of how water availability affects biodiversity in these habitats is limited and this will require detailed research.

c) <u>Aquatic species in rice bays or irrigation channels and some terrestrial species may be adversely affected.</u>

Changes being considered that would lead to reductions in the amount of ponded water in rice crops or changes to irrigation infrastructure such as the lining of channels or piping of water will disadvantage some species. Local effects are likely for species that rely on water and possible for species that derive significant food resources from these components of the landscape. In general these species appear widespread or common in the region and usually occur also in the remnant native vegetation habitats which support greater *diversity* in the Riverina. However, there may be exceptions; for example, the endangered southern bell frog may use irrigation canals as critical local refuges in dry periods. At broader spatial scales, the effect of changes to the amount of ponded water or the nature of irrigation canals will depend on how/whether they make a large contribution to the populations of some species and possibly even contribute to population persistence. We currently have very limited understanding of how/if flooded rice fields and/or irrigation channels contribute to the regional persistence of species by providing things like connectivity, refuges or significant food resources. Research is required to critically address questions about regional scale effects.

d) <u>Changed methods of irrigation may threaten important habitat elements on the landscape.</u>

The adoption of lateral move or centre pivot irrigation technology would require the removal of remaining paddock trees in the local area. Current clearing regulations require that this clearing be offset by some other habitat modification – typically this involves fencing off remnant vegetation or revegetating a patch of land. *It is currently not known what value these paddock trees have relative to the areas used for offset.* Most of the biodiversity research carried out in the region has focused on how habitat structure and composition in patches of vegetation influences biodiversity. Broadly the results appear similar to those in other regions: higher diversity is associated with larger patches, more diverse and structurally complex understorey, woody debris and the presence of hollows in older trees.

e) <u>Salinity threats from raised water tables may be alleviated.</u>

Regionally, changes being considered that would lead to a reduction in the amount of irrigation water reaching the water table should help alleviate the problems for biodiversity associated with rising water tables and salinity although this will still need to be actively managed. To date, black box (*Eucalyptus largiflorens*) woodlands have been under most threat from salinity in the region.

f) <u>Increases in agro-chemical use may negatively affect biodiversity.</u>

Using methods to produce rice that decrease the use of ponded water may result in an increase in the use of herbicides. Producing other crop types may result in an increase in the use of herbicides and pesticides. The limited evidence available for Riverina systems combined with evidence from international studies suggests that increased use of agro-chemicals would probably have negative consequences for biodiversity in the Riverina.

g) <u>General changes to farming patterns could further threaten remnant native vegetation</u>

Some remnant habitats such as the shrub woodlands of bimble box and boree have been extensively cleared in the past. These could be further threatened by changing farming practices that place further pressure on them – in particular further clearing or increased grazing by livestock. There is continuing pressure from exotic plant invasion in intensively used landscapes – most human activities associated with agriculture involve disturbance and habitat enrichment and changes in management strategies will inevitably involve new engineering structures and increasing pressure to efficiently utilise the landscape for production. These pressures will continue to favour exotic species over natives and tend to degrade the condition of remaining native vegetation, even if active clearing is not undertaken.

1.5. Conclusions and recommendations

1. Overall prospects for biodiversity with changed and /or reduced irrigation activities.

   The general reduction in water availability in the Riverina due to changed irrigation practice and reduced allocations will have some local impacts on aquatic biodiversity in constructed habitats such as rice bays and channels. However, this is not necessarily a threat, as the species of such habitats tends to be generalist and disturbance tolerant. Locally occurring species that require intact vegetation communities and are sensitive to disturbance are more likely to be threatened by changed farming practices. Regionally and nationally there may be some species, most notably birds, that have been able to take advantage of the food resources associated with irrigation infrastructure and practices. There are no strong indications that this is the case. However, without exhaustive knowledge of the ecology of the biota it will not be possible to identify the degree of dependence that might have developed.

2. Knowledge gaps and research needs

   While there are some processes and changes that are intractable in terms of specific management (e.g. direct climate change effects on the Riverina ecosystems, management of nomadic fauna) there are local and regional strategies that could be implemented or investigated. However, the success of these is dependent on fundamental knowledge of the ecosystems, and significant gaps remain e.g. the responses of various components of biodiversity to past and present hydrogeomorphology of sites. These will need to be addressed in the mid- to long-term. In the meantime, action can be taken immediately to improve existing habitats, and provide alternative habitats to buffer biodiversity against change, strategies that are derived from an existing body of knowledge in conservation biology.

3. Strategies for biodiversity at the local scale – water management

   Targeted and controlled watering of a range of managed and modified woodland and wetland types and sizes across the landscape, at the same time, as well as during different seasons. This would provide options for various components of biodiversity in terms of breeding and feeding sites. This action ideally would integrate and use information on pre- and post- European water regimes to plan watering event season, duration, depth, and frequency, and would approach monitoring and evaluation before and after watering in a scientific and rigorous manner. We see this as a particularly important knowledge gap, particularly in relation to the water regime requirements of black box woodlands.

4. Strategies for biodiversity at the local scale – vegetation management

   Irrigation development had led to highly cleared landscapes and highly modified remnant native vegetation. Much of the native species diversity is dependent on good management of the remaining vegetation. Increasing site habitat complexity through controlled grazing, retaining fallen timber, and conserving standing timber (dead and alive). Recognizing the importance of protecting remnant vegetation from further soil disturbance and nutrient enrichment is vital in an environment of changing land use and practices.

5. Strategies for biodiversity at the local scale – agrochemical management

The use of fertilizers, herbicides and pesticides in irrigated crops will potentially affect any native species using the crop environment for habitat or foraging, and needs to be as minimal as possible. More importantly, residual chemicals and nutrients in drainage water that is discharged onto native vegetation can have a very serious impact on the entire ecosystem. Strategies to control residual chemicals and nutrients are vital. Beyond minimizing chemical use, a possible strategy may be to sequester agrochemicals in drainage waters upstream of the wetland by increasing water retention times in constructed habitats.

6. Strategies for biodiversity at the landscape scale – general principles

Increasing the resilience of native ecosystems though landscape planning is a key strategy of biodiversity persistence in the face of large changes. Our specific understanding of landscape scale processes operating in the Riverina and irrigation areas is very limited, but a risk-based approach can be used by applying general principles that have been drawn from a range of studies worldwide. For example, maintaining a mosaic of heterogeneous habitats at multiple spatial scales (site, farm, region), retaining bigger patches of vegetation and less isolated patches of habitat are all appropriate general strategies for the Riverina landscapes.

At the sub-regional scale, the outcomes for biodiversity probably depend on the relative mix and spatial arrangement of the different landscape elements - native vegetation remnants with varying degrees of modification interspersed with crops, pasture, and horticulture and irrigation infrastructure - as well as how water is used in these elements. However, in the Riverina we do not know whether/how this outcome is influenced by the surrounding agricultural matrix; for example, all other things being equal does biodiversity vary across landscapes where remnant vegetation is the same but the surrounding agricultural matrix is dominated by different irrigation agriculture practices or dryland agriculture? Is the outcome influenced by the resources provided by the agricultural practice (for example, availability of water or food), or by how the irrigation practice affects water availability for the remnant vegetation, or both? These are critical questions which need to be addressed, because future changes to irrigation practices in the Riverina could alter the relative mix of the components of the landscape as well as spatial and temporal availability of water.

7. The role of restoration

With unknown but substantial changes likely in the irrigation areas, we do not know the extent to which irrigated land may be converted to dryland farming or other uses. If it were to be the case, there may be opportunities to restore cropland to functional dryland vegetation that could be managed for conservation, or to have joint production / conservation values. Complete restoration of native ecosystems would be technically impossible on enriched, post-cultivated soil (McIntyre and Lavorel 2007), but some function and production could be restored by introducing key biotic elements. The establishment of semi-arid adapted native perennial grasses, shrubs (including saltbushes) and trees would go a long way to restoring a grazing and habitat resource into the future.

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