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Environmental Watering for Waterbirds in The Living Murray Icon Sites

A literature review and identification of research priorities relevant to the environmental watering actions of flow enhancement and retaining floodwater on floodplains

Report to the Murray–Darling Basin Authority Project number MD1248

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Brandis, K., Roshier, D. and Kingsford, R.T.

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Acknowledgments

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Sedge (*Eleocharis spatheolata*) in Barmah–Millewa Forest icon site (photo by Keith Ward, Goulburn Broken CMA)

Small mouthed hardyhead (photo by Gunther Schmida ©MDBA)

Royal spoonbill adult and chick (photo by Keith Ward, Goulburn Broken CMA)

River red gum in Gunbower–Koondrook–Perricoota Forest icon site (photo by David Kleinert ©MDBA)

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Contents

1. Introduction

Habitats used by waterbirds in Australia are increasingly well known (Kingsford and Halse 1998; Halse *et al.* 1998). While there may be many wetlands across the continent, relatively few are used by most of the waterbirds (Kingsford and Porter 2009). These are usually the large wetlands on the floodplains of rivers. There is also increasing evidence that these major waterbird habitats in the Murray–Darling Basin are affected by loss of habitat as a result of diminishing flows, affecting abundance, densities and species richness (Kingsford and Thomas 1995; Kingsford *et al.* 2004; Kingsford and Thomas 2004; Nebel *et al.* 2008). As many medium to large flows are reduced by river regulation, there are generally fewer breeding attempts and these have become less extensive (Kingsford and Johnson 1998; Leslie 2001; Kingsford and Auld 2005). Long term (1983 – 2008) waterbird abundance data (Kingsford *et al.* 2006) shows a decline in total waterbird populations in eastern Australia. Continued reductions in waterbird abundance highlight the need to actively manage wetlands for waterbirds.

Conservation of many of the large wetland systems in the Murray–Darling Basin is established through the available mechanisms of identifying conservation reserves and Ramsar sites (Kingsford *et al.* 2004). Although, there is increasing recognition that such forms of protection have not effectively protected major wetlands in the Murray–Darling Basin with severe degradation occurring on most of the major reserves and wetlands. To attempt to reverse some of the degradation, Governments in the Murray–Darling Basin are now buying back water for the environment, specifically major wetlands.

In Northern America, and Europe there has been a history of managing wetlands for waterbirds (Schekkerman *et al.* 2008; Bancroft *et al.* 2002; Eglington et al, 2009; refs in Bennett *et al.* 2006). In Australia management of wetlands for waterbirds has been predominantly through flow management and is reactionary rather than pre-emptive. For example ibis chick abandonment in both the Narran (2008) and Gwydir wetlands (1995) was managed through the provision of additional flows, but not until significant numbers of chicks had been abandoned (Kingsford et al 2008, Brandis and Kingsford in prep, McCosker 1996). There are no examples in Australia of the managed provision of waterbird habitat to initiate foraging or breeding responses. The lack of wetland management for waterbirds may be attributed to our limited understanding of the explicit relationships between waterbird species and triggers for breeding.

Australia has numerous Ramsar wetlands that are recognised as internationally significant waterbird habitat (for example Narran Lakes, Macquarie Marshes, Gwydir Wetlands). Management of these wetlands for waterbirds does not extend beyond the attempt to maintain current ecological values. It is now being acknowledged that we need to actively manage for waterbirds through the provision of foraging/breeding habitat and the initiation of breeding cues. The purchasing of water for the environment provides managers with a tool that can be used to target specific wetland ecosystem components and used as a trigger for ecological responses. This project examines the use of environmental water for waterbird management.

2. Overview

This literature review addresses the topic "Creation of suitable habitat for waterbirds through retaining floodwater on floodplains or flow enhancement management interventions" with particular reference to six hypotheses identified by the Murray–Darling Basin Authority as key areas for greater understanding. Where appropriate some hypotheses have been addressed together.

The relationships between river flows and aquatic biodiversity are widely acknowledged (Bunn and Arthington 2002; Bunn *et al.* 2006) as is the influence of flow on specific components of aquatic ecosystems, birds (Nebel *et al.* 2008, Kingsford *et al.* 2008, Schneider and Gresser 2009) seed banks (James *et al.* 2007) vegetation (Bren 1987, Briggs *et al.* 1998) invertebrates (Quinn *et al.* 2000), amphibians (Wassens *et al.* 2008) and reptiles (Kingsford *et al.* 2006). Changes to natural flow regimes and extraction of water has affected the structure and function of river ecosystems worldwide (Richter *et al.* 2003) and in Australia (Boulton *et al.* 2000, Kingsford 2000; Bunn and Arthington 2002, Gippel *et al.* 2002, Page *et al.* 2005). Dams, diversions and river regulation have reduced flooding to wetlands (Kingsford 2000), altering their ecology and causing the reduction in distribution and abundance of wetland dependent species. Recognition of the ecological impacts of river regulation has led to the provision in many Australian regulated rivers of environmental flow allocations aimed at recovering critical aspects of the natural flow regime while still enabling water extraction for human use (Arthington 1998; Arthington *et al.* 2003). However, there are considerable knowledge gaps as to how to best use the environmental water to achieve the maximum environmental benefit, particularly for mobile waterbird populations. Waterbirds are different to most other aquatic organisms with patterns of resource use that transcend catchment boundaries (Roshier *et al.* 2002; Roshier et al 2008a).

All landscapes are dynamic and characterized by compositional (structural) attributes and process (functional) attributes (Bennett *et al.* 2006; Lindenmayer *et al.* 2008). These attributes ultimately determine patterns of habitat occupancy and movement, depending on how sought-after resources for feeding and breeding are distributed and the mobility of the organism (see Roshier and Reid 2003; Oppel *et al.* 2009). Habitat is generally defined in two ways: (i) a species-specific entity—the environment and other conditions suitable for occupancy by a particular taxon or (ii) a particular land cover type (Lindenmayer *et al.* 2008). The species specific concept of habitat is multi-scaled, and the requirements of a given taxon may vary between habitat types, regions or life stages (Haig *et al.* 1998; Lindenmayer *et al.* 2008). These issues are particularly relevant to waterbirds whose interaction with the habitat is influenced by both the compositional and process attributes of the landscape and vary in space and time (Haig *et al.* 1998; Roshier *et al.* 2008b).

Australia's waterbirds are usually characterised as nomadic, capitalising on aquatic resources that are highly variable and often temporary (Roshier *et al.* 2001a and b; Kingsford and Norman 2002; Kingsford *et al.* in review; see Marchant and Higgins 1990). In Australia, patterns of resource availability for waterbirds are mostly pulsed (Puckridge 1998; Bunn *et al.* 2006) with peaks of productivity that may differ for different waterbird groups, even within the same flood (Kingsford *et al.* 1999). The mechanism by which they exploit these changing habitats is rapid movement at spatial and temporal scales commensurate with the resource.

River regulation has reduced wetland habitat availability decreasing the opportunities for waterbirds to use patches in the landscape. One method of creating habitat patches that are available and suitable for waterbirds is through the management of environmental flows.

3. Hypotheses 1 & 2:

An appropriate landscape mosaic for waterbirds will be created through flow enhancement.

An appropriate landscape mosaic for waterbirds will be created through retaining floodwater on floodplains.

Waterbirds use an array of habitats, ranging from sewage treatment ponds, swamps, lagoons, freshwater lakes, estuaries, rivers, dams and floodplains (Belanger and Couture 1988, Kingsford and Norman 2002). Many of these habitats are affected by flooding regimes. Australia has some of the most variable flooding and river flow regimes in the world (Puckeridge *et al.* 1998; Roshier *et al.* 2001b; Kingsford and Norman 2002). Large rainfall events produce considerable flooding and create widespread habitat on the floodplains. These contribute to a large population increases when wetland habitat becomes available for waterbirds to utilise (Kingsford and Norman 2002; Roshier *et al.* 2002).

Habitat mosaics and waterbirds

Diverse mosaics of wetland habitats are important determinants of waterbird distribution and abundance at all scales from the local to the continental as many waterbird species use different habitats for feeding and breeding and must move between them to survive, reproduce and recruit (Maher and Braithwaite 1992; Haig *et al.* 1998; Halse *et al.* 1998; Roshier *et al.* 2002, 2006, 2008a & b). This is particularly so in Australian landscapes dominated by temporary wetland resources.

To date most research on waterbirds in Australia has been limited to studies of the feeding and breeding ecology of particular species at specific sites (e.g. Frith 1957; Braithwaite & Frith 1969; Briggs *et al.* 1985; Lawler & Briggs 1991; Briggs 1990; Kingsford 1990a & b; Minton *et al.* 1995 and others). The effects of changes in water regime on the distribution and abundance of waterbirds are infered from these site specific studies and patterns of association with wetlands of various types (Briggs *et al.* 1997; Halse *et al.* 1998; Leslie 2001; Dorfman & Kingsford 2001; Roshier *et al.* 2001a & b, 2002).

Due to their particular feeding behaviours water depth is a habitat variable significant to influencing waterbird diversity (Bancroft *et al.* 2002, Kingsford *et al.* 2004). Particular waterbird species occupy specific habitat types defined by water depth. Waterbirds can be categorised based on feeding behaviour; dabbling and diving ducks, herbivores, large waders, shorebirds, and piscivores (Table 1).

Table 1: Functional (ecologically related) groups of the waterbird community based on broad resource use (habitat and feeding) Source: Kingsford *et al.*, in review

Waterbird group	Food resources	Habitat use	Breeding strategy
Dabbling and diving ducks	generalist; plankton, small invertebrates, plant material	shallow water, littoral zone	solitary
Grazing waterfowl (swan, shellduck, wood duck)	plant material	shallow water, littoral zone	colonial or solitary
Piscivores (pelican, cormorants)	fish	open and deeper (>1m) water	colonial
Large waders (spoonbill, ibis, egret, heron)	macroinvertebrates, fish, amphibians	littoral zone	colonial or solitary
Small waders (shorebirds)	small invertebrates, seeds	littoral zone and mudflats	solitary

The availability and quality of resources in mosaic patches influences waterbird diversity. Breeding waterbirds have high nutritional and energetic demands and can be expected to select foraging habitats that have a high abundance of accessible foods (Laubhan and Gammonley 2000). Gawlik, 2002, found that the feeding strategies employed by wading birds i.e. searching for high quality food rather than staying and exploiting food in declining patches influenced bird abundance and diversity. Bancroft *et al.* 2002 found that while vegetation and water depth influence wading bird abundance, water depth has the greatest influence. These are key ecological variables that can be managed for when manipulating flow regimes or creating wetland mosaic habitats.

Mosaic creation

Landscapes around the world are being modified to actively manage for specific species with the creation of artificial landscape elements (Quinn *et al*. 1996, Taft *et al.* 2002, Parsons *et al.* 2002, Bennett *et al.* 2006), such as flooded grasslands for small wading birds (Eglington *et al.*, 2009; Schekkerman *et al.*, 2008) and variable water drawdown for shorebirds, diving birds and waterfowl (Taft *et al.* 2002). Wetland habitat mosaics are created and used as a tool for waterbird management (Quinn *et al*. 1996, Taft *et al.* 2002, Schekkerman *et al.* 2008; Bancroft *et al*. 2002; Eglington *et al*, 2009; Bennett *et al.* 2006).

North American experiences have illustrated that wetland management that provides the greatest diversity of habitat types including variable water depths, mud flats, inundated vegetation and deeper water areas results in the greatest abundance and diversity of waterbirds (Taft *et al.* 2002; Parsons 2002).

Many European wetland mosaics are in the agricultural landscape context (Bechet *et al.* 2009; Poulin *et al*. 2009, Schekkerman *et al.* 2008) and involve the development of management strategies complimentary to the surrounding agricultural practices. European examples of wetland mosaic management include reed bed management for species of conservation concern, for example the cryptic Eurasian bittern (*Botaurus stellaris)*. This management experiment involved changes to reed harvesting practices to provide a mosaic of different aged vegetation and variable water depths. This resulted in a greater understanding of how Eurasian bitterns use the habitat and the development of reed bed management recommendations (Poulin *et al*. 2009).

The Tour du Valat wetland program in France has recognised the loss of wetlands in the Mediterranean Basin and aims for the sustainable management of wetlands in a developing agricultural region. (http://en.tourduvalat.org/) The Tour de Valat estate manages 2,600 ha of different wetland habitats, its management strategies focus on research and sustainable management of the wetland areas including some agricultural practices. The Tour du Valat has contributed to the conservation of species and ecosystems, both in the Camargue and around the Mediterranean. This wetland management program is a key example of how wetlands can be managed for more than one management outcome. By using a mosaic of wetland patches the Tour du Valat provides areas for research, sites for experiments, agricultural management and high quality wetland habitat for birds and other biota.

Watering regimes

Naturally occurring wetland habitat mosaics may be enhanced through the manipulation of flows. Water depths and duration of inundation may be artificially determined through flow management techniques. Management of flow and manipulation of water levels has been studied in North American wetland systems (Collazo *et al.* 2002, Parsons 2002, Taft *et al.* 2002, Bancroft *et al*. 2002). Results have shown that wading bird abundance is related to both water level and vegetation community, but water level generally has the greatest effect (Bancroft *et al.* 2002). Studies also showed that for wading birds there was a water level threshold above which wading bird abundance was predicted to decline (Bancroft *et al.* 2002).

Artificial wetland mosaics can be created through the retention of water on floodplains via the use of earthworks to create areas of variable water depth and duration of retention. Artificial wetlands may include agricultural land that is managed for waterbirds in the non-growing season, such as rice field in California (Elphick and Oring 1998) un grazed marsh areas in England (Eglington *et al.* 2009) and staggered mowing of fields in the Netherlands (Schekkerman *et al.* 2008).

Variable flow water management has been used in wetlands in California for multispecies management (Taft et al. *et al.* 2002) and at tidal impoundments in Delaware Bay USA. (Parsons *et al.* 2002). Both these studies have shown that variable flows and water depths result in greater habitat heterogeneity and greater waterbird diversity. Drawdown patterns were important as they changed composition of habitat types and presence of waterbird species. Changes in waterbird community structure during flood pulses have also been observed on Australian wetlands (Figure 1).

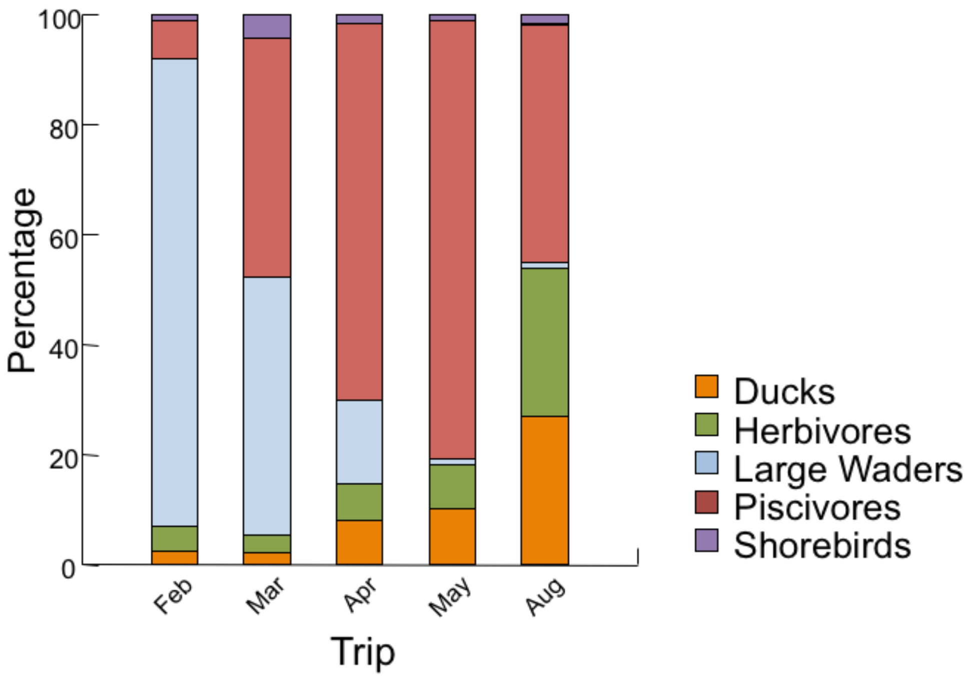

Figure 1: Changes in waterbird community structure during February—August 2008 on wetlands in the northern Murray–Darling Basin (Kingsford *et al.* 2008)

Scale and other influences

Changes in waterbird abundance on a wetland may be a response to changes at the wetland, catchment or landscape scale (Roshier *et al.* 2001). On individual wetlands, abundance of waterbirds may vary in response to food availability, availability of nest sites, predation risk or some other factor (e.g. Halse *et al* 1993; Kingsford and Porter 1994; Savard *et al.* 1994; Murkin *et al.* 1997; Timms 1997). Alternatively, waterbirds may feed on one wetland and roost or breed at another, depending on the local distribution of resources (Maher and Braithwaite 1992; Kingsford and Porter 1994).

At the catchment or landscape scale changes in abundance may reflect general behavioural responses at that scale or the hydrology of individual wetlands or groups of wetlands. For example, canvasback ducks (*Aythya valisineria*) in North America adjust their distribution by hundreds of kilometres in response to weather and ice conditions and changes in food abundance (Lovvorn 1989). Similarly, pintail ducks (*Anas acuta*) in North America may breed north of the Arctic Circle when breeding habitat is scarce on the Canadian prairies during drought (Smith 1970). Thus, changes in waterbird abundance may occur in response to changes in habitat availability at different spatial scales and these may vary with geographic location. Such responses may vary among species or functional groups of waterbirds (eg dabbling ducks, piscivores, etc). Different groups of waterbirds respond to habitat at different scales, for example colonial species (e.g. ibis, spoonbills) respond to habitat availability at the landscape scale and can provide information of wetland functioning at a broad scale. Other species such as cryptic waterbird species (e.g. bitterns, rails, night herons) provide information on the local wetland habitat. Due to the habitat requirements of these species their presence provides an indicator to local wetland health and functioning.

4. Hypotheses 3 & 4:

Nesting/breeding habitat for waterbirds will be created through retaining floodwater on floodplains.

Nesting/breeding habitat for waterbirds will be created through flow enhancement.

Current understanding of waterbird breeding requirements and cues for breeding are based on Australian (Kingsford *et al.* 2009, Kingsford *et al.* 2008; Kingsford and Auld 2005, Ley 1998a & b, Roshier *et al.* 2002, Roshier *et al.* 2008a & b, Leslie 2001, Lowe 1983) and international studies (Gawlik 2002, Bancroft *et al.* 2002, Crozier and Gawlik 2003, Burger and Miller 1977, Ivey and Severson 1984).

Waterbirds require suitable flooding, habitat availability, food resources and seasonal conditions for breeding to occur (Leslie 2001). Carrick (1962) reports 'the situation in the Macquarie Marshes in 1954 and 1955 clearly illustrates that suitable flood condition, and not day length, temperature, local rainfall, or even abundant food supply, is the essential proximate stimulus for breeding'. While many studies have reported on waterbird breeding (Kingsford and Auld 2005, Ley 1998a & b, Carrick 1962, Lowe 1983, McKilligan 1975, Waterman *et al.* 1971, Marchant and Higgins 1990) few document the specific nesting habitat requirements for waterbird species. Much of our knowledge is based on observational data (Kingsford and Auld 2005; McCosker 1996, 1999a & b, 2001; Ley 1998a & b) rather than quantitative studies. For example while it is known that some species of waterbirds, particularly ibis, have water depth requirements it is not known what the actual water depth requirement is, and while the depth threshold may vary between wetlands the exact nature of the relationship between water depth and reproductive success is poorly understood.

Waterbird breeding strategies include colonial nesting (ibis, spoonbill, pelicans) solitary nesting (ducks, small waders including cryptic species) or the ability to utilise either strategy (large waders, grazing waterfowl i.e. swans). The availability and quality of breeding habitat may influence the breeding strategy utilised by waterbirds. This adaptive ability may allow birds to take advantage of a wider range of habitats than otherwise available. The impact this may have of reproductive success is also unknown.

Increased opportunities for breeding and reproductive success may be achieved through the manipulation of flows or the retention of water on the floodplain provided key habitat requirements are met. Key nesting/breeding habitat variables include:

Duration of inundation

For colonially nesting birds to reproduce successfully, flooding is required for three and a half months after egg laying (Leslie 2001). The interval consists of one month incubation and two and half months for fledging (Marchant and Higgins 1990). Prior to laying birds need time to prepare behaviourally, nutritionally and hormonally for breeding. In total breeding habitat needs to be flooded for at least five months (Leslie 2001; Briggs and Thornton 1998).

For Cormorants, Marchant and Higgins (1990) report that birds require about 3 months from egg laying to fledging and then adults will continue to feed young birds for another 80 days, taking about 6 months in total to successfully raise chicks to independence. Pelicans require 5 weeks for egg incubation and then will continue to feed young birds up to a least 3 months old (Marchant and Higgins 1990). Wading birds such as Egrets require approximately 2.5 months from egg laying to fledging and then for a further 3 weeks the young bird continues to return to the nest for feeding by the adult (Marchant and Higgins 1990). Ducks require between 3–4 months incubating eggs and raising young to fledging (Marchant and Higgins 1990). For most waterbird species several months of suitable nesting and foraging habitat is required to successfully raise young.

Cryptic species such as the Australasian Bittern (*Botaurus poiciloptilus)* for which there is very little quantitative breeding information available (Marchant and Higgins 1990) have been observed building nests in inundated reeds, *Phragmites australis* and *Typha spp.* The nests are usually about 30 cm above the water, which may vary with fluctuations in water levels (Marchant and Higgins 1990).

Water levels

Water level changes are known to illicit behavioural responses such as nest construction or abandonment (Leslie 2001). For ibis, which nest colonially and build their nests on inundated vegetation, drops in water level can trigger abandonment of nests and chicks (McCosker 1996; Scott 1997, Kingsford 1998, Kingsford *et al.* 2008).

Nest abandonment has also been observed by pelicans, swans, silver gulls (J. Porter pers comm.) terns (K. Brandis) in response to changes in water levels.

In Europe variable water management practices on manmade wetlands such as commercial salt ponds have been shown to impact on waterbird abundance and breeding success (Bechet *et al*. 2009, Poulin *et al.* 2002).

Hydrology

Several studies have been conducted showing the relationship between river flows and breeding success (Leslie 2001, Chowdhury and Driver 2007, Brandis and Kingsford in prep). The study undertaken by Leslie examines the timing of flows, total flow volume and the rate of fall with relation to behavioural responses in waterbirds in the Barmah–Millewa Forest.

Altered flow regimes result in fewer breeding opportunities for waterbirds (Kingsford and Johnson 1998, Kingsford and Auld 2005, Leslie 2001, Brandis and Kingsford in prep.) Altered flow regimes often result in the reduction of overall flows, both in volume and frequency (Ren *et al.* 2009) limiting periods of inundation or the provision of suitable habitat for both foraging and breeding.

Similar results are also reported in Northern America where wetland loss and declines in ecosystem integrity due to altered hydrology have resulted in reduced breeding effort by a range of wading birds (Crozier and Gawlik 2003).

The greatest positive responses in waterbird abundance and diversity in managed wetland systems is where hydrological management mimics natural flow conditions (Galat *et al.* 1998).

Seasonality

Unlike the Northern Hemisphere where waterbird breeding tends to be seasonal, Australian waterbird breeding is a combination of seasonality, particularly on the coast and more persistent wetlands, and opportunistic breeding following flooding (Briggs and Lawler 1989). Braithwaite and Frith (1969) found that some species of waterfowl, the black duck (*Anas superciliosa)* and the hardhead (*Aythya australis)* have breeding seasons that tended to be regular but were capable of breeding out of season whenever there was extensive flooding.

There is very little data available on the impact of temperature or season on nesting success in Australian waterbirds, although there are reports of nesting attempts failing during the colder months (Magrath 1991).

Vegetation

Vegetation plays an important role in providing nest sites and nesting materials for many species of waterbirds (Bancroft *et al,* 2002). Colonially breeding waterbirds generally build nests/platforms on inundated vegetation such as Lignum, *Phragmites*, *Melaleuca* (Marchant and Higgins 1990). Other species such as ducks use tree hollows, herons use dead trees standing in water or living tall trees such as *Eucalyptus, Angophora, Melaleuca* (Marchant and Higggins 1990). While cryptic species such as bitterns, crakes, rails and night herons use dense reed beds or fringing vegetation (Marchant and Higgins 1990) (See Figure 7).

5. Hypothesis 5:

Foraging habitat for waterbirds will be created through retaining floodwater on floodplains.

Studies on waterbird foraging habitat have largely been on North American wader species (Gawlik 2002; Colwell and Taft 2000; Laubhan and Gammonley 2000). For example; Colwell and Taft (2000) published accounts of interspecific differences in habitat use by waterbirds predicting that shallow wetlands should accommodate more species and greater numbers of waterbirds than deep wetlands. This hypothesis was evaluated by examining relationships between winter (January/February) waterbird use (presence/absence, density and number of species) and average depth, variation in depth and size of 25 wetlands in the northern San Joaquin Valley, California. Bird densities correlated consistently with depth. Likelihood of use increased in shallow wetlands for all nine wading birds (shorebirds and ibis); densities of three dabbling duck species and Black-necked Stilt (*Himantopus mexicanus*) also increased in shallow wetlands, whereas use and densities of two diving birds increased in deep wetlands. The number of species of waterbird, dabbling duck, and wading birds increased in shallow wetlands, whereas the number of species of diving bird increased in deep wetlands. Wetland size and topographic variation inconsistently predicted waterbird densities, but both characteristics correlated positively with number of species. These results provide general support for shallow flooding of wetlands to provide habitat for more species.

For long-legged waders, such as spoonbill and herons, key resources are wetlands of a particular water depth and ultimately prey availability. Prey availability differs from prey abundance in that not all prey items present may be accessible or detectable and therefore not be vulnerable to predation. As a result some long-legged waders are more sensitive to changes in prey density, water depth or period of inundation than others. In turn, prey availability has been hypothesised to limit population size and constrain the distribution of wading birds (see Gawlik 2002 and references therein). In a study of the effects of water depth and prey density on prey availability, Gawlik (2002) showed that tactile feeders such as ibis and storks respond strongly to changes in both. These species seek the highest quality feeding sites and do not attempt to exploit sites where water depth and prey density increase energetic and fitness costs. This contrasted with visual feeders such as the larger egrets and herons that feed across a greater range of water depths and continue to exploit prey to much lower densities. Gawlick (2002) hypothesised that species using only high quality feeding sites would require a greater area to meet their nutritional requirements as there would be fewer of these sites (Figure 2). Moreover these differences between tactile and visual feeders were hypothesised to account for the differential declines in wading birds in the Florida everglades (Bancroft *et al.* 2002).

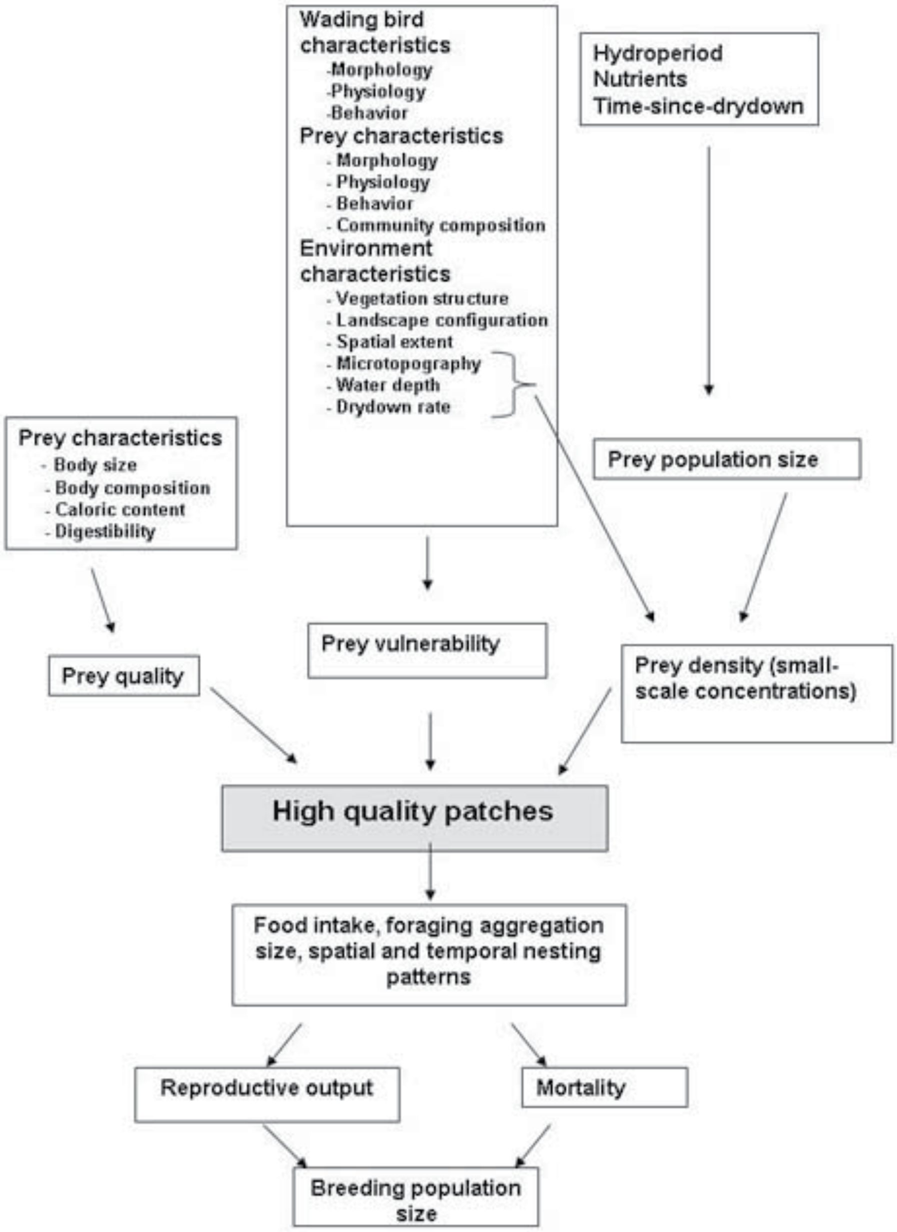

Figure 2: Interactions between patch quality, hydrology and waterbirds (source Gawlik 2002)

Specific foraging studies in Australia are limited, (Baxter and Fairweather 1998) but the requirements of functional feeding groups are comparable with overseas studies. Table 1 identifies the food resources and foraging habitats of functional waterbird feeding groups.

Retaining water on floodplains will provide foraging habitat for waterbirds (Taft et al 2002, Gawlik, 2002, Collazo *et al*, 2002). The quality of the habitat will vary with water depth and topography (Taft *et al.* 2002) vegetation (Bancroft *et al.* 2002) prey availability and quality (Gawlik, 2002) seasonality (Taft *et al.* 2002) and the heterogeneity of foraging habitats created and the spatial and temporal context in which they are created (Tori *et al.* 2002).

6. Hypothesis 6:

Breeding cues for waterbirds will be created through flow enhancement.

The literature on breeding cues for waterbirds is largely correlative and relies upon observations of waterbird responses at particular wetlands e.g. Narran Lakes—Magrath 1991; Gwydir wetlands—McCosker 1996; Macquarie Marshes—Kingsford and Auld 2005; Lachlan wetlands—Driver *et al.* 2004; Booligal Wetlands—Magrath 1991. It is intuitively understood that breeding cues for waterbirds exist but there is limited data on the relationships between cues and responses.

Breeding cues are intrinsically linked with the availability of suitable breeding habitat. For colonially breeding waterbirds there are thresholds in the provision of habitat that may trigger breeding. It is understood that a range of variables influence the initiation of and the success of breeding (See Hypotheses 3 & 4). These variables include water depth, duration of inundation, the availability of nesting habitat, food resources, season, and population health and age structure. Not all of these variables are applicable to all species and the relative importance of cues will differ amongst species.

Crozier and Gawlik, 2003 reported on wading bird nesting effort as an index to wetland ecosystem integrity in managed wetlands. They found that as flow regimes became increasingly altered from the natural and wetland habitat was lost that there were fewer breeding attempts by wading birds.

As previously identified colonially breeding waterbirds have specific water depth and duration requirements for successful breeding. Flow management practices that may potentially provide enough water to achieve these thresholds may provide more opportunities for breeding than were otherwise available under a non-management scenario. Water management for colonially breeding species will also provide suitable breeding habitat and conditions for other species such as ducks and cormorants.

7. Conceptual Models

Conceptual models provide a way to understand the relationships between model components. They can be non-quantitative and can identify drivers and stressor on natural systems, the ecological effects of these stressors, and the best biological attributes or indicators of these ecological responses (Ogden *et al.* 2005). Conceptual models can be used as a communication tool between scientists and policy makers for planning and decision making.

A series of conceptual models have been developed as part of this project. The first conceptual model (Figure 3) is an overarching model that shows the major waterbird related ecological responses triggered by a flow event or levels of flow. A conceptual model has been developed for each of these ecological responses with regards to waterbirds. Using flow as the primary driver the following conceptual models have been developed:

- waterbird response (Figure 4)
- food resource response (Figure 5)
- foraging habitat response (Figure 6)
- breeding habitat response (Figure 7).

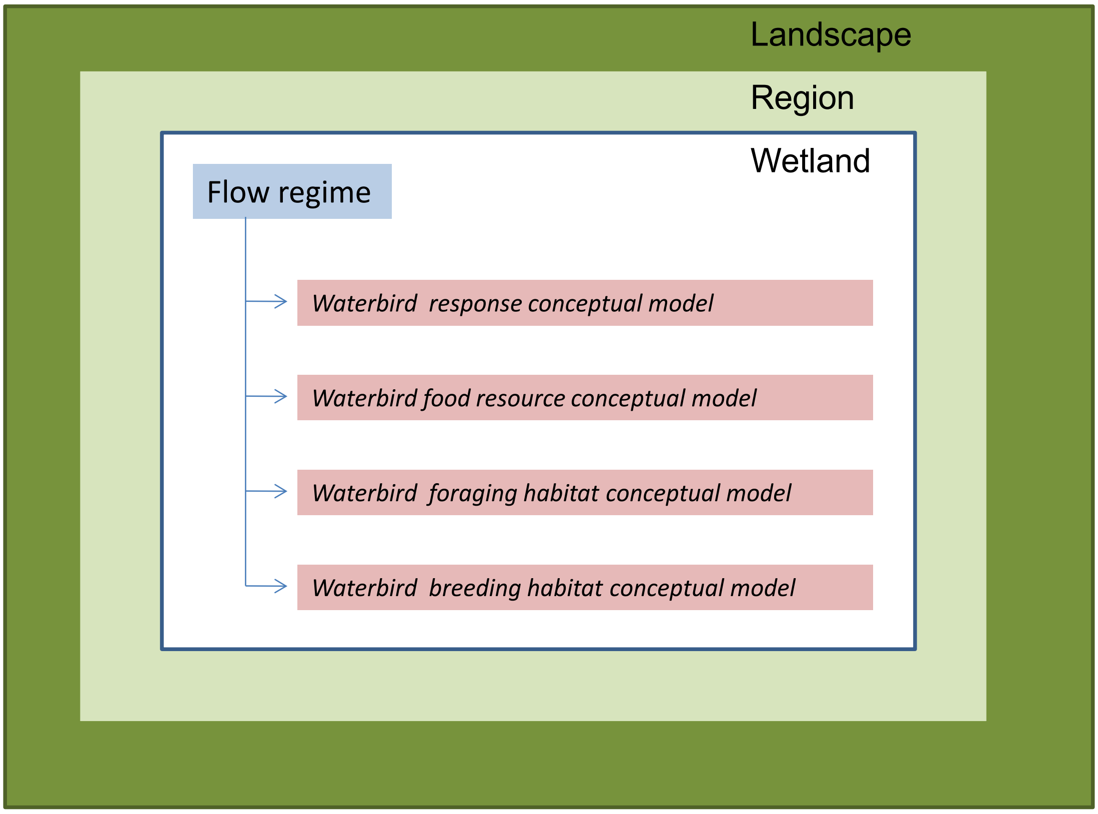

Figure 3: Flow and waterbird ecological triggers conceptual model

This conceptual model (Figure 3) identifies that a flow triggers a range of ecological responses that influence the distribution and abundance of waterbirds and waterbird habitat. It should be noted that the response of waterbirds to flow is not necessarily cause and effect. Responses of waterbirds at a wetland will be influenced by other factors occurring at the region and landscape scale. Influences such as availability of habitat in the region or past opportunities for breeding will influence the response of birds. For example if suitable breeding habitat is available elsewhere in the region prior to the 'flow managed wetland' becoming suitable/available then birds may not respond as anticipated in the ways identified in these conceptual models.

The waterbird response conceptual model (Figure 4) recognises that waterbird response will vary with flow volumes. It identifies the key components of flow that influence breeding initiation and success as outlined in the literature review (Hypotheses 3,4, & 6). This model also shows the relationship between habitat types (Figure 4 & 5) and food resources to flow variables (Figure 5).

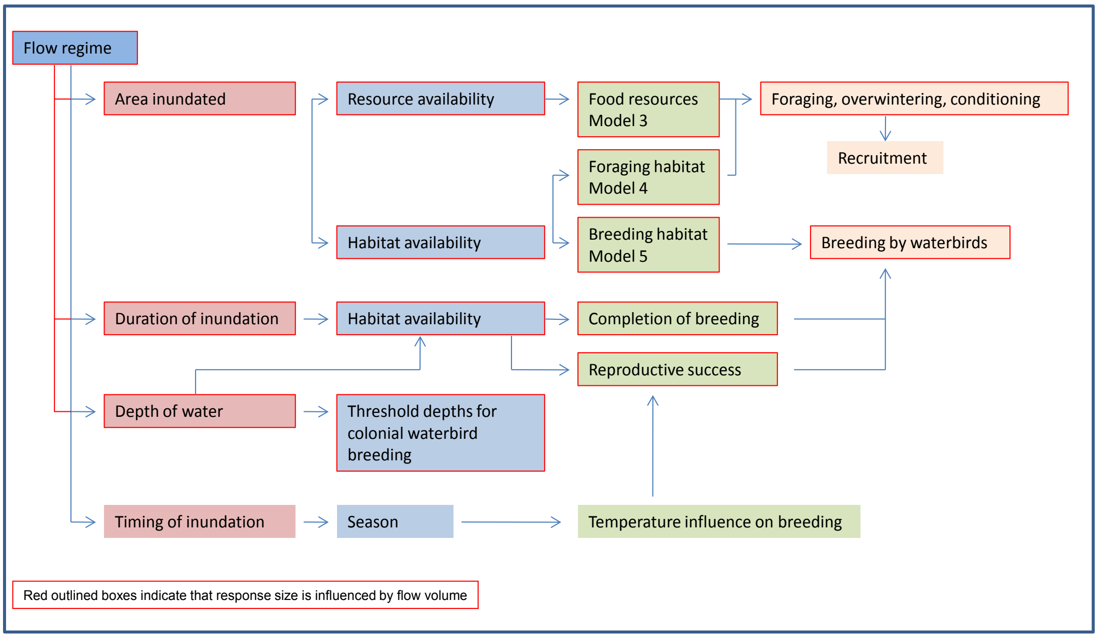

Figure 4: Waterbird response conceptual model

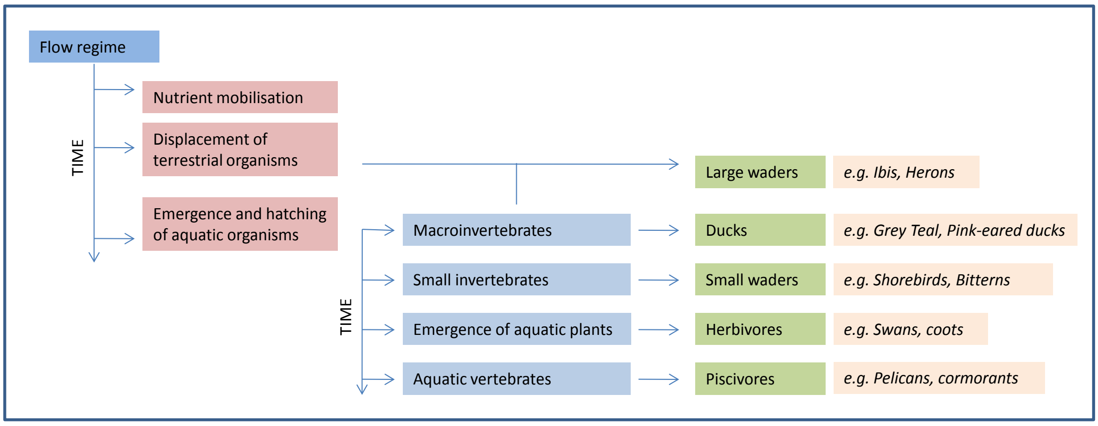

Figure 5: Waterbird food resources conceptual model

Figure 5, waterbird food resources conceptual model, identifies waterbird food response and the changes in food availability over time with flow regime. This model illustrates the triggers for changes in bird community composition as discussed in Hypotheses 1 & 2. This model should be viewed in conjunction with Figure 6, Waterbird foraging habitat conceptual model, as different food resources are available in different foraging habitats (see Hypothesis 5). Figure 7 the waterbird breeding habitat conceptual model shows the habitat requirements of different waterbird species and the role the flow regime has in providing these habitats.

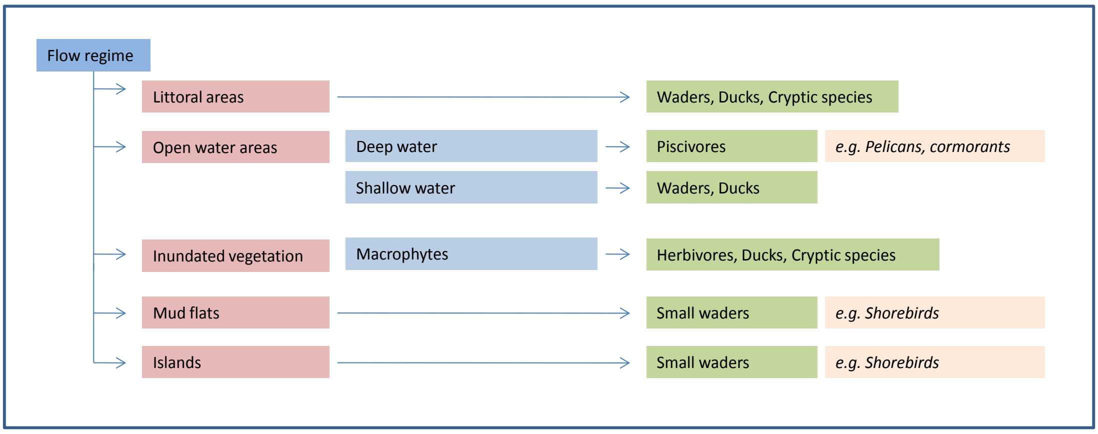

Figure 6: Waterbird foraging habitat conceptual model

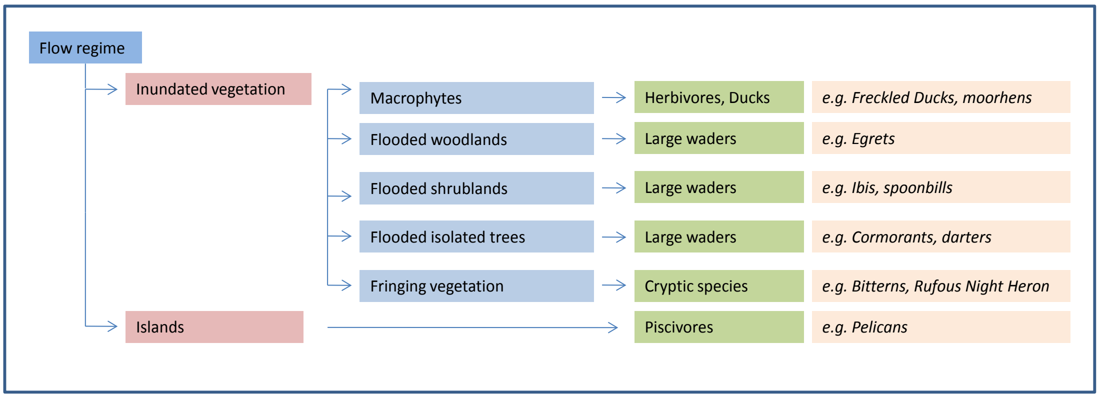

Figure 7: Waterbird breeding habitat conceptual model

8. Knowledge gaps

The literature review identified key areas of waterbird ecology and management where the current understanding is lacking.

Waterbird responses

While much of our understanding of waterbird responses has come from observational data there are very few studies that quantify the response of waterbirds to different habitat or hydrological regimes. Unlike North America, Australia does not have a history of manipulative wetland habitat experiments to collect these data.

Hydrology

To understand how birds might respond to changes in water regime there is a need for an explicit understanding of how birds perceive and use different landscape elements, the scales at which they interact with those elements and any threshold effects. While it is known in broad terms what local conditions are conducive to the formation and success of breeding colonies of colonial-nesting species (Leslie 2001), little is known of the structure of landscapes that maintain breeding populations or the responses of individuals to changes in floodplain water regimes at broad scales. Key to understanding these processes is an explicit understanding of where birds feed, breed and roost; how far and how often they travel; the diversity of habitats used; and the similarity of these responses between individuals and populations. The only means to understand these processes is by individually marking birds and tracking their movements.

Mosaics

Much of the research into the interaction of wetland mosaic patches and waterbird responses has been done in the northern hemisphere. Other than recognition that Australian waterbirds use a mosaic of wetland habitats there is limited quantitative data available for Australia. Roshier *et al.* 2008 demonstrated the impact of landscape structure on the spatial movements of teal. Differences between agricultural and arid landscapes were found to be a constraining factor. This highlights the need to maintain viable landscapes at broad scales. Currently, data is available for only one species (grey teal); more data is required on habitats used, and landscape diversity needed to maintain viable landscapes for all functional groups.

Breeding cues

While it is understood that some waterbird species, particularly colonially breeding species have breeding cues related to hydrological triggers, the nature of the relationship is poorly understood. A greater understanding of breeding cues will assist with targeted water management and greater success in achieving management outcomes. Identifying breeding cues may be done using flow manipulation experiments at the wetland patch scale.

Waterbird movements

Our knowledge and understanding of large scale waterbird movements across landscapes are based on very few studies (Roshier *et al.* 2006, Kingsford and Auld 2003, McKilligan 1975). Previous studies have been restricted to small samples sizes, for example swans n=2 (J, Porter pers comm.), ibis n=3 (Kingsford and Auld, 2003). The only large sample size waterbird tracking study undertaken in Australia was by Roshier *et al.* 2006, with 26 grey teal. Unlike large scale movement studies undertaken overseas on migratory birds (http://www.werc.usgs.gov/sattrack/), Australia has made very little progress in understanding the landscape scale movements of resident waterbirds.

Greater knowledge on the movement of waterbirds is critical for both species management and habitat management. Waterbirds are indicators of wetland health (Kingsford and Auld, 2005). Knowledge about which habitats waterbirds use provides an indicator to wetland health and a great understanding of the characteristics of wetlands that are favoured by certain species of waterbirds e.g. ibis.

Aerial waterbird surveys of eastern Australia over the past 25 years have shown a decline in abundance of all waterbird species (Kingsford and Porter 2009). For the maintenance of waterbird populations it is imperative that we have a greater understanding of the way in which waterbirds interact with wetland habitat across the landscape.

Other knowledge gaps

Knowledge gaps in our understanding of waterbirds and their use of wetlands are at all scales, continental, regional and at the individual wetland scale. The impacts of global issues such as climate change and wetland loss on global waterbird populations are poorly understood. Similarly at the continental scale the impact of wetland loss on resident species and migratory species is also poorly understood. The use of large scale surveys and monitoring projects will improve our knowledge of these areas.

At the regional and individual wetland scale there are several key areas where our knowledge is lacking. These include the interactions of waterbirds with hydrology, wetland habitat and wetland ecosystem components. These key knowledge gaps are detailed below.

i. The impact of other environmental factors on waterbirds. While hydrology has been shown to be the greatest determinant of waterbird abundance and diversity there have been very few studies on the impact of other factors such as climate change, pest species, changes in fish community structures, clearing and grazing in riparian zones, and avian diseases. Greater understanding of these impacts may be achieved through the collection of baseline data and then conducting manipulative experiments.

ii. The cumulative effects of environmental impacts on waterbird population viability and recruitment ability. Other than reductions in total populations we have very little data on waterbird population functioning and recruitment processes. To address this question would require long term monitoring of populations and detailed studies of population structure including age, life span, and breeding age.

iii. The identification of population and habitat thresholds for concern. The use of adaptive management for wetlands includes the identification of thresholds of potential concern. This identifies the point for target species/habitat types that results in a specific management action. To identify thresholds requires a detailed understanding of the breeding biology and population ecology of the species of concern. For most species of waterbirds this data is lacking.

iv. The role of waterbirds as vectors for seed and egg dispersal of aquatic plants and invertebrates. Waterbirds are known to be the only vectors for some seeds and eggs from hydrologically isolated wetlands. The impact of reduced waterbird abundance and changes to waterbird movements on plant and invertebrate dispersal and population dynamics is unknown. Detailed studies of individual waterbirds and movements will increase our understanding of this issue.

Current gaps in our understanding of waterbirds mean that management policies need to be based on adaptive management frameworks (Ogden *et al.* 2005). Adaptive management allows for the ongoing assessment and modification of management policies in response to additional knowledge and the response of target species. Further research into waterbirds and they way they interact with the environment will inform management and improve the achievement of management targets. Targeted management of water for waterbirds provides an important tool in managing Australian waterbird populations.

9. Priorities for research

Research priority 1: Integration of flow regimes and habitat use by waterbirds

To develop spatio-temporal models of habitat distribution for key waterbird species in the Murray–Darling Basin.

Use the models to analyse the effects of various water management scenarios on the distribution of wetland habitats for for key waterbird species in the Murray–Darling Basin.

As in other wetland biomes, wading birds differ in their individual habitat requirements and some species (such as tactile feeders) are likely to be more sensitive to fine-scale changes in water depth and prey availability than others (Gawlik 2002). Thus, sensitive species may be used as model species for understanding the relationship between flow, inundation and waterbird distribution and abundance.

The chronology of peak abundance of suitable prey types is likely to be different in most floodplain wetlands. This provides a contrast that will aid in determining whether the birds are responding to structural or biotic aspects of resource distribution. If site selection choices between certain species are similar in type and timing then this will suggest habitat requirements are predominantly structural and related to the physiognomy of wetlands. Whereas, if they diverge, it will suggest that habitat requirements are functional and related to the impacts of water regime on biotic responses such as prey abundance. Alternatively, habitat selection choices may vary with spatial scale and be similar at broad scales but diverge at fine scales as local variation in prey availability or other resources impact the habitat selection choices of individuals.

For managers endeavouring to improve the suitability of riverine landscapes for iconic waterbirds, fine-scale differences in habitat selection choices between species may be of little consequence as long as the broad-scale utility of wetland mosaics is maintained for waterbirds. This is the 'Field of Dreams' outcome where the simple presence of suitable wetland habitats initiates a positive response in waterbird populations. However, if the habitat selection choices diverge, waterbird populations are likely constrained in different ways and the constraints are predominantly biotic.

We advocate a resource-based approach that uses the responses of marked individual birds to model resource availability and develop a spatio-temporal model of waterbird-habitat relationships at broad scales. In effect, birds are being used as a sensitive assay of ecosystem function. A resource-based approach has been advocated in recent reviews of wildlife-habitat relationship studies as this approach makes few assumptions about the structure and suitability of habitat (Marzluff and Ewing. 2001; Morrison 2001). A resource-based approach focuses on the distribution of resources such as wetlands of a particular type or depth and how these constrain the movements and distribution of animals. For marked individuals it is possible to model probabalistically an individuals use of space and relate outputs of the model to habitat structure (eg. Marzluff *et al.* 2004). Animals use space differently for different behaviours and the distribution of resources also varies in time and space. By using the location and behaviour of tagged individuals to define resource availability in time and space it is possible to explore resource selection across multiple scales in a single analytical framework (eg. Arthur *et al.* 1996; Cooper and Millspaugh 1999).

Research priority 2: Waterbird movement and habitat use studies

To provide information on where in Australia waterbirds go, whether they remain in, or travel outside the Murray–Darling *Basin.*

To identify the habitat types being used by species when not breeding.

To provide indicators of ecosystem health and identify habitats that may require targeted management.

The Murray–Darling Basin is the strong-hold for waterbird breeding in Australia (Brandis *et al*. 2009). Colonial waterbirds, which can breed in colonies of tens to hundreds of thousands of individuals, disperse individually or in small groups following completion of breeding. This behaviour provides opportunities for waterbird movement studies.

Many colonial breeding species do not live in colonies when not breeding. Very little is known about where birds disperse to post breeding. It is unknown whether they remain in the Murray–Darling Basin between breeding events or whether they travel to other parts of Australia. Satellite tracking provides a method of following bird movements that are unobtainable by any other method.

Knowledge about which habitats colonial nesting waterbirds use provides an indicator to wetland health and a greater understanding of the characteristics of wetlands favoured by colonial nesting waterbirds. Aerial waterbird surveys of eastern Australia over the past 25 years have shown a decline in abundance of all colonial nesting waterbird species (Kingsford and Porter 2009).

Wetland habitats are threatened by land clearing, climate change, drought and water resource development. It is key that wetlands are managed to maintain ecosystem health and provide habitat for a range of species. One of the tools available to wetland managers and custodians is water and the supply of water to wetlands through environmental flows. Identification of key wetland habitats is critical, so that water management decisions can be more strategic and better informed with rigorous scientific data.

Research priority 3: Testing hypotheses about waterbird response to flow manipulation and floodplain inundation

To achieve a greater understanding of the relationship between flow, floodplain inundation and waterbird responses. A greater understanding of these relationships is critical in enabling waterbird management strategies to achieve their targets.

As identified in the literature review and knowledge gap sections of this report there has been limited research in Australia on the response of waterbirds to manipulated flows and floodplain inundation. A series of flow manipulation and floodplain inundation experiments should be undertaken to better understand the drivers of waterbird responses and achieve more appropriate management strategies for waterbirds.

Flow manipulation experiments would allow for the collection of data on a range of issues. These include:

- wetland scale habitat use by waterbirds, changes in the availability of different habitat types and waterbird abundance and diversity.
- hydrological cues and responses for waterbirds for foraging and breeding.
- successional changes in waterbird community composition during flow.

Requirements for experiments:

- depth gauges in strategic locations such as colony and foraging sites
- flow data loggers: data collection on flow volumes, duration of flows.

Research priority 4: Waterbird movements between large-scale flooding events

To collect information on waterbird movements using community based data collection during periods of no overbank flooding.

Resighting and recording of tagged birds will provide information on bird movements and habitat use during non-flood periods. During periods of no overbank flooding , there may be resident birds at the wetland site, individual based approaches with simple schemes to mark birds at key colonies or sites will rapidly advance our understanding of population structure, origin and movements of iconic species.

This approach is an inexpensive method of obtaining waterbird movement data on the wetland or regional scale. It can provide a means to increase community education and involvement in wetland management.

Examples of community based survey programs include:

- Ferintosh Community Council—Community Bird Survey http://www.snh.org.uk/biodiversitycommstoolkit/assets/pdfs/tools/general_public/Ferintosh_Bird_Survey.pdf
- Tropical Savanna CRC- Nomadic Bird Survey http://savanna.cdu.edu.au/information/info_bird_survey.html
- UNESCO Community Biodiversity Survey Manual: Bird Survey Methods http://opentraining.unesco-ci.org/cgi-bin/page.cgi?g=Detailed%2F1146.html;d=1
- Birds Australia: Birds in Backyards http://www.birdsinbackyards.net/surveys/
- NSW Department of Environment, Climate Change and Water http://www.environment.nsw.gov.au/resources/howyoucanhelp/09BirdSurveysBaseline.pdf.

Research priority 5: Analyses of available data

Using historical data, aim to achieve a greater understanding of the relationships between hydrological conditions and waterbird breeding and abundance.

Modelling using available data is a commonly used method by management agencies to attempt to predetermine outcomes. It is a frequently used method as it is less expensive than data collection. Results to date have not helped in getting an understanding of waterbird responses to habitat availability or consequences of changes in inundation patterns, except in gross terms. One area where this approach could be productive is the association of breeding events with inundation patterns for colonial nesting species. Analysis of historical data can be used to identify flow and inundation patterns, thresholds for waterbird breeding and how opportunities for breeding have changed over time.

10. Data sources

Future research into waterbirds and responses to river flows and floodplain inundation may utilise a range of data sources. These include survey data, grey literature, scientific literature, hydrological data, and meteorological data (Table 2). These data are available at a range of scales (Table 2):

Table 2: Potential data sources to inform waterbird research

Data scale	Data sources
Continental	Annual aerial waterbird surveys 1983—2008 National Aerial Surveys of Wetland Birds The Australian Colonial Waterbird Breeding Database The New Atlas of Australian Birds Rainfall and weather data
Murray–Darling Basin	Roshier, D. A, *et al.*, (2001); Nebel, S., *et al.*, (2008); Roshier D.A., *et al.*, (2002); Kingsford, R.T., *et al.*, (1999);Braithwaite, L.W., *et al.*, (1986a); Kingsford, R. T. (1995); R.T. Kingsford, *et al.*, (1997); Scott, A. (1997); Braithwaite, L.W., *et al.*, (1985a & b); Braithwaite, L.W., *et al.*, (1986 b); Braithwaite, L.W., *et al.*, (1987); Kingsford, R.T. *et al.*, (1988); Kingsford, R.T., *et al.*, (1989); Kingsford, R.T. *et al.*, (1990); Kingsford, R.T. *et al.*, (1991); Kingsford, R.T., *et al.*, (1992); Kingsford, R.T. *et al.*, (1993); Kingsford, R.T. *et al.*, (1994); Kingsford, R.T. *et al.*, (1997); Kingsford, R.T. *et al.*, (2000); Kingsford, R.T. *et al.*, (2003); Porter *et al.*, (2006)
Regional	Driver, P.S. *et al.* (2004); Chowdhury, S., and Driver, P. (2007); Magrath, M. J. L. (1992). Kingsford, R. T. and Thomas, R.F. (2004); Maher 1990; Kingsford, R. T., *et al.*, (2008)
River reach	Kingsford, R. T. and Thomas, R.F. (2004); Maher 1990 Flow data
Wetland scale e.g Barmah–Millewa	Leslie, D. J. (2001); Briggs, S. V. and Thornton, S.A. (1995); Briggs, S. V. *et al.* (1997); Briggs, S. V. *et al.* (1998);

References in Appendix 2.

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Appendix 1

Examples of waterbird species by group found in the Murray–Darling Basin

Waterbird feeding group	Waterbird species
Dabbling and diving ducks	Pink-eared duck *Malacorhynchus membranaceus*
	Hardhead *Aythya australis*
	Freckled duck *Stictonetta naevosa*
	Pacific black duck *Anas superciliosa*
	Chestnut teal *Anas castanea*
	Grey teal *Anas gracilis*
Grazing waterfowl	Australian wood duck *Chenonetta jubata*
	Australian shelduck *Tadorna tadornoides*
	Black swan *Cygnus atratus*
Piscivores	Australian pelican *Pelecanus conspicilliatus*
	Darter *Anhinga melanogaster*
	Pied cormorant *Phalacrocorax varius*
	Great cormorant *Phalacrocorax carbo*
	Little black cormorant *Phalacrocorax sulcirostris*
Large waders	Glossy ibis *Plegadis falcinellus*
	Australian while ibis *Threskiornis molucca*
	Straw-necked ibis *Threskiornis spinicollis*
	Royal spoonbill *Platalea regia*
	Yellow-billed spoonbill *Platalea flavipes*
	Great egret *Ardea alba*
	Intermediate egret *Ardea intermedia*
	Little egret *Egretta (Ardea) garzetta*
	White-necked heron *Ardea pacifica*
	White-faced heron *Egretta (Ardea) novaehollandiae*
	Australasian bittern *Botaurus poiciloptilus*
	Rufous night heron *Nycticorax caledonicus*
Small waders	Purple swamphen *Porphyrio phorphyrio*
	Eurasian coot *Fulica atra*
	Bar-tailed godwit *Limosa lapponica*
	Black-tailed godwit *Limosa limosa*
	Red-necked stint *Calidris ruficollis*
	Sharp-tailed sandpiper *Calidris acuminate*
	Australian pratincole *Stiltia Isabella*
	Little bittern *Ixobrychus minutus*

Appendix 2

Waterbird references (Table 2)

Continental scale

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