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Waterbird use of farm dams in south-eastern Australia: abundance and influence of biophysical and landscape characteristics

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Abstract

Background: While agriculture has taken much environmental water in Australia's Murray-Darling Basin, agricultural expansion has resulted in a vast number of farm dams, almost three-quarters of a million in the Murray-Darling Basin alone.

Methods: Over a summer we studied (1) waterbird abundance and species richness and (2) the influence of biophysical and landscape characteristics across 49 farm dams at a large mixed-enterprise farm in northern Victoria on the southern reach of the Murray-Darling Basin.

Results: On average, dams were found to host 27.1 ± 71.1 individuals/ha and 1.8 ± 2.9 species per pond. Such densities are comparable to those on natural wetlands. Dam surface area and perimeter and amount of vegetation were positively and strongly correlated with the Rallidae density (birds/ha), but no other parameters were strongly correlated with any other functional group. The landscape in which the dams were embedded had a highly significant effect ($p < 0.001$) on the number of birds found on a dam.

Conclusions: Our research needs to be complemented with further studies in other parts of the Basin and on other taxa, but given at our site they supported similar densities of individuals and species to natural wetlands, and given the fact that there are 710,539 farm dams in the Murray-Darling Basin, which hosts much of Australia's waterbird fauna, it is reasonable to suggest that farm dams are overlooked, and possibly very important, avian biodiversity hotspots. It also highlights the importance of a landscape setting, in which dams are situated, on the number of birds using the dams.

Keywords: Farm ponds, Waterbirds, Waterfowl, Zooplankton

Background

River regulation for irrigation and flood mitigation has dramatically altered wetland ecology and eliminated much wetland habitat, and the consequences for wetland-dependent species have been devastating and are particularly well documented for waterbirds (Kingsford and Johnson 1998; Kingsford 2000; Leslie 2001; Kingsford

et al. 2004; Brandis et al. 2011). Agriculture has unquestionably had a major impact on Australia's biodiversity—an impact that likely exceeds that of other sectors by orders of magnitude regardless of the metric used. Of the various systems to fall foul of agriculture's expansion, wetlands have been among the hardest hit (MDBA 2010).

Much of eastern Australia's waterbird fauna is produced in the "breeding factories" (Williams 2011) of Lake Eyre and the Murray-Darling Basin (MDB). Environmental flows to natural wetlands in the MDB, especially the large breeding sites such as the Macquarie Marshes, among others, have received much attention over the last

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decade and are absolutely crucial for maintaining viable population sizes of many species, particularly colonially nesting species (Arthur et al. 2012). Equally important though is the provision of habitat for these birds to disperse to following such episodic breeding; that is, massive recruitment is of little value to a species' long-term prospects if it is not matched by adequate survival (Kingsford and Norman 2002). To this end, agriculture may have something to give back—farm dams, possibly 710,539 of them in the MDB alone! We obtained this estimate from the database produced from the recently-completed Basin-wide remote-sensing survey of on-farm water storages (provided by GeoScience Australia). Note that the published estimate of 519,931 (MDBC 2008) relates to a preliminary remote-sensing exercise wherein only 82% of the area of the Basin was surveyed.

Wastewater treatment wetlands (sewage ponds and stormwater treatment ponds) have been the subject of much study in terms of waterbird conservation, particularly in south-eastern Australia (e.g., Hamilton et al. 2002, 2004, 2005; Hamilton and Taylor 2004, 2005; Murray and Hamilton 2010), but next to nothing is known about the role of farm dams in this context. There have been a few investigations of other taxa—invertebrates (Geddes 1986; Brainwood and Burgin 2006, 2009; Lake et al. 2010) and frogs (Hazell et al. 2001)—but even these are highly localised in their geographical coverage, involving surveys of merely a handful of dams; and there are no published studies of waterbird abundance, richness, or community structure. Presumably, farm dams have escaped our attention because they are small and dispersed and because they are on private property. They are the only major type of waterbody that is not covered by the Victorian Summer Waterfowl Count, which has been conducted every year since 1987 (Murray et al. 2012). Likewise, the annual Eastern Australian Aerial Survey of Waterbirds covers about 2000 wetlands, mostly >1 ha, as did the recently-completed National Waterbird Survey (Kingsford et al. 2012). Farm dams are not a formal part of these exercises and are observed on an ad hoc basis only (R Kingsford, pers. comm.).

The primary purpose of farm dams is of course to aid agricultural production, and this will remain so. So why do we need to understand the value of farm dams to waterbirds and how they are used by different species and functional groups? Firstly, knowledge of the degree to which waterbirds depend upon farm dams will be a major step forward in completing the picture of the conservation status of Australia's waterbird fauna, a picture that currently comprises mostly natural wetlands and large water storages. This is essential for the long-term management of this unique fauna as, for better or worse, the reality is that all wetland types will need to be

considered if we are to manage conservation effectively. Secondly, while the vast majority of farm dams are supplied by their own highly localised catchments and are topographically well beyond the reach of environmental flows, there is much scope for local management in the interests of particular functional groups of waterbirds, be it in terms of managing stock access, water levels, agrochemical use, surrounding habitat, physical form (including the use of spoil), or fringing or emergent vegetation. These are complex issues that require detailed, mechanistic understanding. For example, while emergent vegetation might provide useful habitat for some species, it may deter others by decreasing visibility and thus ability to maintain predator vigilance (Murray et al. 2013), and the sudden death of large swards of macrophytes can increase the risk of a deadly botulism outbreak (Blaker 1967; Rocke et al. 1999; Rocke and Samuel 1999). Thirdly, in some instances it may be desirable to deter birds from dams (Murray and Hamilton 2010).

Finally, and perhaps most important of all, despite the Murray-Darling Basin Authority's best efforts to strike an appropriate balance, most of the discourse around the MDB Plan has been a bitter battle between green and brown camps. It would appear that farmers are the stewards of a major environmental asset, farm dams, and it is in the interests of all that this asset be placed in context and managed accordingly. Somewhat ironically, the current debate around dams and the environment in the MDB revolves around their possible detrimental impact through interfering with stream and river recharge (Schreider et al. 2002; Lowe et al. 2005; Nathan et al. 2005; Jordan et al. 2008), and their potential positive contribution has virtually escaped attention. At this point it is crucial to address the nomenclature. In Australia, the word *dam* covers anything from a small pond on a farm used to water stock through to massive storage reservoirs for irrigation and rural supply. While it is indeed true that farm dams, including the many small stock watering dams, can affect stream recharge, and to quite a significant extent in some catchments (SKM 2008), the CSIRO's Sustainable Yields project estimated that "rural stock and domestic" dams accounted for 0.71% of surface water use in the MDB, in contrast to 84% for "net irrigation diversions" (CSIRO 2008, p. 32), which includes large storage reservoirs and associated channel networks. It is mostly this 84% that has had the devastating impact on Australia's wetland and riverine fauna (Kingsford and Thomas 2004; Kingsford 2000; Ren and Kingsford 2011), and it is time to look at the 0.71% for what it might have to offer rather than focus solely on the in-stream effects it may have in some catchments.

Farm dams will likely be of greater significance for certain species or functional groups of waterbirds than

others; there simply have not been any studies to ascertain to whom they might be more valuable. Community structure of waterbirds on farm dams has never been quantified. Also, although dams are likely to be non-breeding refuges rather than recruitment sites for many species, they may still be fulfilling a significant role in recruitment for certain species. For example, the only detailed published study on waterbird use of farm dams in Australia (Kingsford 1992) found that Australian Wood Ducks (*Chenonetta jubata*) undertook breeding near dams.

Given the dearth of information on waterbird numbers on Australian farm dams, it is hardly surprising that next to nothing is known about the influence of biophysical characteristics on waterbird use of these dams. Many different factors could affect species' preference for a dam, including, inter alia, water depth, total water surface area, steepness of the shoreline, fringing and emergent vegetation, logs/dead trees, agrochemical pollution, stock use, surrounding crop/pasture, visibility, and the composition and biomass of invertebrate communities. Kingsford's (1992) study on Australian Wood Duck's use of dams at three pastoral properties on the southern tablelands of New South Wales is the only published investigation into how an Australian waterbird species actually uses farm dams. Kingsford (1992) researched the influence of eleven habitat factors on farm dam use and found that during breeding proximity of a dam to a nest tree was the most significant predictor, and outside breeding the surface area was the most important factor. The Australian Wood Duck is a grazing species and hence vegetation was the only food source studied; to date there has been no published research on waterbird interactions with farm dam planktonic, nektonic, or benthic food-webs.

Here we take an initial step in redressing the imbalance by quantifying waterbird use of farm dams in northern Victoria in the southern reaches of the MDB. Firstly, species abundance and richness as well as community structure on farm dams are quantified. Secondly, the relationships between waterbirds and various landscape, physical, and biological factors on farm dams are investigated, with a view to identifying characteristics that might make dams more suitable to particular species or guilds of birds. Additionally, although farm dams are the primary consideration here, we also take the opportunity to quantify waterbird use of farm billabongs. A billabong is a dead branch of a river that no longer takes bed loads and fills when the main channel floods. Billabongs are most often oxbow lakes, as was the case here. They clearly differ from farm dams in that they are naturally formed, but in situations where they are located on a farm they are often used as agricultural

water storages. Henceforth, the term "farm ponds" or simply "ponds" will be used to collectively denote farms dams and billabongs.

A major objective of this research was to obtain baseline densities of waterbirds on farm dams and farm billabongs and to determine how these compared to natural wetlands. That is, the research question is what densities of waterbirds do farm dams and billabongs support? Another objective was to determine what biophysical and landscape factors influence the use of farm dams by waterbirds. The accompanying research question is what biophysical and landscape factors influence the use of farm dams by waterbirds?

Methods

Study area

The study was undertaken on The University of Melbourne's Dookie farm estate (36.37°S, 145.70°E) in the heart of the Goulburn Valley—colloquially known as the state's "food bowl" (Fig. 1). While owned by a university, the farm itself operates as a commercial enterprise and has done so for 129 years, and farming practices are typical of those in the Goulburn Valley. The site is agriculturally, environmentally, and topographically diverse. Bordered by the Broken River on its southern boundary and covering 2500 ha, it covers elevation clines up to 300 m (Mount Major) and comprises diverse soil types. It hosts grain, oilseed (canola), pig, sheep, dairy, orchard (apple and apricot), and viticulture operations, as well as a 400-ha White Box (*Eucalyptus albens*)/Grey Box (*Eucalyptus microcarpa*) remnant woodland. Thus, in addition to the advantage of ready access to a large number of dams, the site provides an ideal setting for studying these in all the common agricultural/environmental settings in the region.

The property hosts 55 farm dams, and 49 of these were surveyed. All dams that could be included in the study were included. Of those that were not surveyed, three were dry at the start of the survey period, one was inaccessible (in the middle of crop that we were not permitted to traverse), and two were heavily instrumented as part of an experiment on the use of a surface polymer for reducing evaporation. In addition to the farm dams and billabongs, the property hosts nine waste stabilisation ponds (WSPs)—one currently servicing the piggery, three decommissioned piggery waste ponds, one treating the dairy shed waste, and three servicing the sewage needs of the residential buildings of the campus. Because of the clustering of these ponds in series and owing to accessibility constraints, they were not included in the survey with the exception of the dairy WSP, which was surveyed because we had to drive along its edge on the way other ponds.

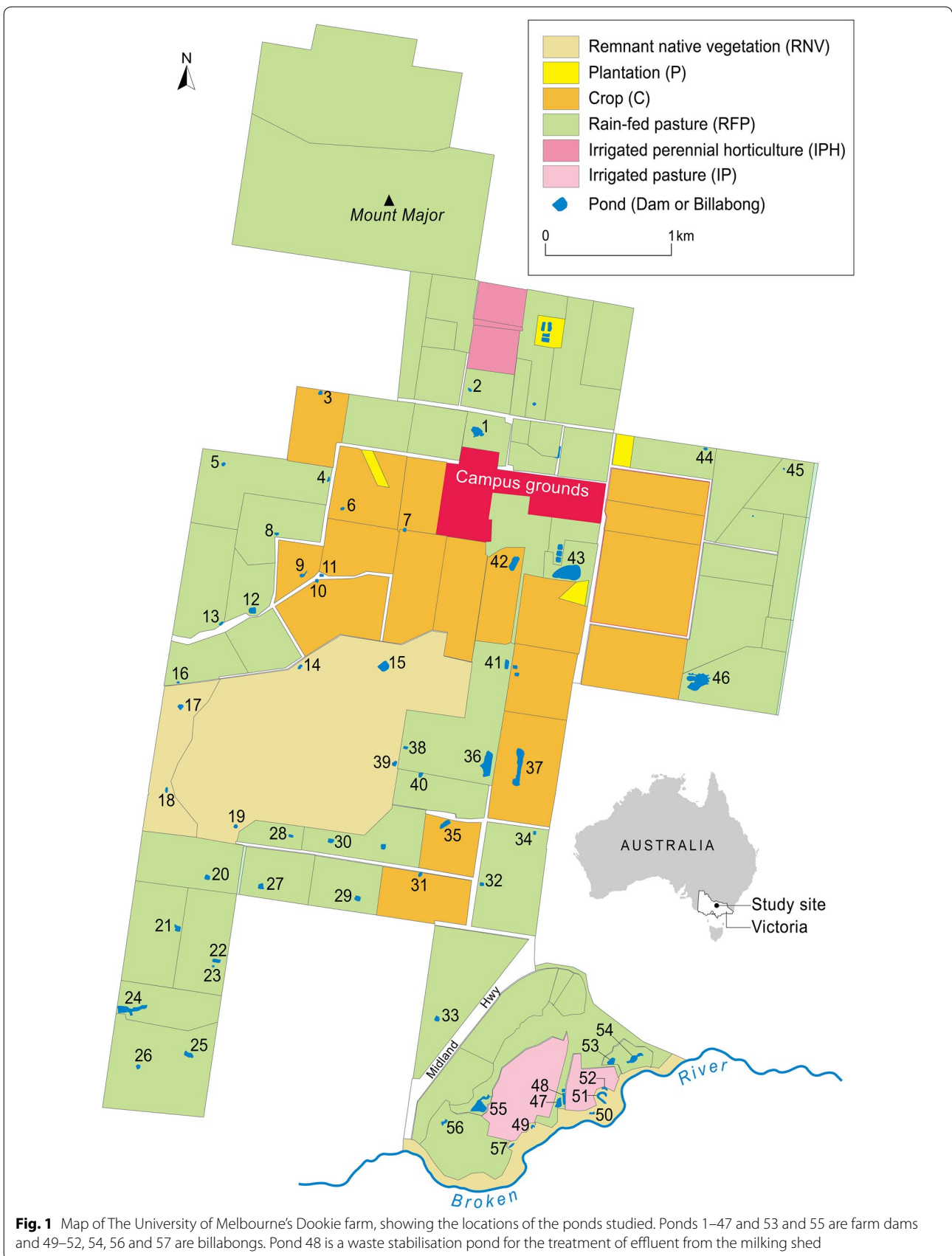


Fig. 1 Map of The University of Melbourne's Dookie farm, showing the locations of the ponds studied. Ponds 1–47 and 53 and 55 are farm dams and 49–52, 54, 56 and 57 are billabongs. Pond 48 is a waste stabilisation pond for the treatment of effluent from the milking shed

Waterbird surveys

All ponds were surveyed at approximately weekly intervals over the 2011/12 summer, commencing on 7 December 2011 and finishing on 23 February 2012. All bird counts were made by one of the authors (CC), with AB acting as scribe. Surveying was usually done on a Thursday, but three of the 11 surveys were switched to Wednesday because of staff availability. To assist the surveying, the ponds were grouped into four strata: Stratum A = Ponds 1–15; Stratum B = Ponds 16–30; Stratum C = Ponds 31–43; and Stratum D = Ponds 44–57 (Fig. 1), and the order in which these strata were surveyed was randomised for each date. Within strata the ponds were surveyed in the same order each time: lowest to highest number indicated in Fig. 1. The strata were used solely to aid sampling and to minimise any bias associated with the time of day that a pond was observed; they do not intentionally represent any natural feature. The daily timing of the surveys was designed to straddle solar noon (01:10–01:32 h over the survey period), and given it took about 6 h to complete the circuit, regardless of the order in which the blocks were surveyed, a buffer of at least 3 h was maintained between sunrise and start of the survey as well as between the completion of the survey and sunset. This is important because many waterbirds, especially ibides and piscivorous species such as cormorants and the Australian White Pelican (*Pelecanus conspicillatus*), use ponds with suitable habitat (e.g., trees) predominantly as roosting sites but feed elsewhere during the day (Hamilton et al. 2004). Numbers can vary wildly within minutes as a result of such crepuscular movements, and the consequent local redistribution also increases the risk of double counting. On the other hand, of course, it means that our inferences were restricted to the use of ponds during the daytime.

The average dam surface area was 0.42 ha (range: 0.02–3.54 ha; SD = 14.7 ha), the average billabong surface area was 52.71 ha (range: 0.04–0.43 ha; SD = 0.14), and the WSP was 0.211 ha. The many small, vegetation-free, oblong dams could be readily surveyed from a single vantage point with binoculars (Bausch and Lomb 8 × 40°). Similarly, the shapes of two of the largest dams, 1 and 43, while irregular, also permitted observation of the entire dam from one point with the aid of a telescope (Kowa® TSN-821 M: 20–60 × zoom magnification). Fortunately, both of these dams lacked interfering vegetation. In contrast, ponds with emergent or fringing vegetation had to be circumnavigated by foot, and this also served the purpose of attempting to flush hidden birds. All of the billabongs required multiple vantage points, if not circumnavigation, owing to their curved and convoluted perimeter and/or the presence of vegetation. Many of the small dams that were free of vegetation could be surveyed

very quickly, but we ensured that all were observed for at least 2 m to allow ample time for any submerged diving birds to surface [e.g., Hoary-headed Grebe (*Poliocephalus poliocephalus*): 16–24 s underwater (Marchant and Higgins 1990); Hardhead (*Aythya australis*): 4–28 s (Hamilton and Taylor 2006)].

Waterbird functional groups

Following the scheme of Murray et al. (2013, 2014) the 29 waterbird species were assigned to one of eight functional groups (Table 1).

Physical and landscape parameters

The depth and surface area of ponds clearly change as a function of evaporation, rainfall, and abstraction for irrigation in some cases. In an attempt to represent the average situation over the summer, we chose to estimate the depth of the ponds at about the half-way point through the survey period (1 December 2012). Maximum depth was estimated by dropping a sounding line from an inflatable canoe. The canoe was rowed across the approximate centre of each pond and the depth traced approximately every boat length (3 m), with the maximum recorded depth assumed to be the maximum depth of the pond.

For each pond, Google Earth Pro was used to determine the perimeter and surface area (both delimited by the water's edge), as well as the distance to the nearest pond, defined as the minimum distance between the shorelines of the pond in question and that of the nearest pond containing water, regardless whether or not it was included in the waterbird survey. The most recent Google Earth images were used for determining all of these two-dimensional metrics. These were taken in 2010 at the same time of year that our survey commenced (13th and 24th of December), and in both instances the ponds were near capacity following sustained spring rainfall and relatively low evaporation. We had no control over when the images were taken, and arguably it would have been more useful to have surface area and perimeter estimates mid-way through the summer, in line with the depth estimates. They nonetheless served the purpose of enabling relative quantification of pond sizes, and the variation within a pond over the summer is negligible when placed in the context of the orders-of-magnitude variation in size among ponds.

Pond shape was defined in terms of shoreline irregularity (complexity) and the steepness of the littoral zone. Shoreline irregularity was represented as the ratio of the perimeter of the pond to that of a circle of the same area, with higher values indicating increasing departure from a circle and thus greater irregularity (Patton 1975; Merendino and Ankney 1994). Littoral angle was determined at four points on each pond by measuring the horizontal

Table 1 Allocation of the 29 species of waterbirds observed to functional groups

Shorebirds (Charadriiformes)	Long-legged wading birds	Swamphens and coot (Rallidae)	Pursuit predators	Waterfowl and grebe	Dabbling	Filtering	Herbivorous
Wade in shallow water	Can wade in deeper water and often forage in moist grasslands. 'Stalk-wait-attack' predators	Spend most of their time on land amongst tall grasses, sedges	Active vertebrate predators at wetlands (may also feed on inverts, but not exclusively)	Generally spend much of their time on/in the water (especially when feeding) or grazing on adjacent vegetation			
Masked Lapwing (<i>Vanellus miles</i>)	Australian White Ibis (<i>Threskiornis Molucca</i>)	Eurasian Coot (<i>Fulica atra</i>)	Darter (<i>Anhinga melanogaster</i>)	Hardhead (<i>Aythya australis</i>)	Pacific black duck (<i>Anas superciliosa</i>)	Pink-eared Duck (<i>Malacorhynchus membranaceus</i>)	Australian Wood Duck (<i>Chenonetta jubata</i>)
Black-winged Stilt (<i>Himantopus himantopus</i>)	Straw-necked Ibis (<i>Threskiornis spinicollis</i>)	Dusky Moorhen (<i>Gallinula tenebrosa</i>)	Little Black Cormorant (<i>Phalacrocorax sulcirostris</i>)	Australasian Grebe (<i>Tachybaptus novaehollandiae</i>)	Grey Teal (<i>Anas gracilis</i>)	Australian Shoveler (<i>Anas rhynchotis</i>)	Australian Shelduck (<i>Tadorna tadornoides</i>)
	White-faced Heron (<i>Egretta novaehollandiae</i>)	Black-tailed Native Hen (<i>Gallinula ventralis</i>)	Little Pied Cormorant (<i>Phalacrocorax melanoleucos</i>)	Hoary-headed Grebe (<i>Polioccephalus poliocephalus</i>)			Black Swan (<i>Cygnus atratus</i>)
	Pacific Heron (<i>Ardea pacifica</i>)	Purple Swamphen (<i>Porphyrio porphyrio</i>)	Great Cormorant (<i>Phalacrocorax carbo</i>)				Plumed Whistling Duck (<i>Dendrocygna eytoni</i>)
	Cattle Egret (<i>Ardea ibis</i>)						
	Intermediate Egret (<i>Ardea intermedia</i>)						
	Great Egret (<i>Ardea alba</i>)						
	Yellow-billed Spoonbill (<i>Platalea flavipes</i>)						

distance from the water's edge to a depth of 40 cm (Powell 1987). The cardinal points were used so as to avoid conscious bias in site selection.

A five-point Likert scale (1–5) was used to represent the amount of emergent vegetation, with 1 representing the complete absence of vegetation and 5 the situation where over half of the pond was covered with emergent vegetation (i.e., 1 = 0%, 2 = 0.1–16.6%, 3 = 16.7–33.2%, 4 = 33.3–50%, 5 > 50%). Similarly, Likert scales were used for the amount of bare earth within a 2-m strip around the pond's perimeter (1 = none, 5 = completely surrounded by bare earth: i.e., 1 = 0%, 2 = 0.1–40%, 3 = 40.1–80%, 4 = 80.1–99.9%, 5 = 100%), tree density within 10 m of the pond (1 = no trees; 5 = typical tree density for a box (*Eucalyptus albens/microcarpa*) or River Redgum (*Eucalyptus camaldulensis*) woodland) (i.e., 1 = no trees, 2 = 0.1–40% of typical tree density, 3 = 40.1–80% of typical tree density, 4 = 80.1–99.9% of typical tree density, 5 = 100% of typical tree density), and low perching habitat (logs, rocks, and pipes) (1 = none, 5 = abundant: i.e., 1 = 0% of pond surface, 2 = 0.1–5.0%, 3 = 5.1–10.0%, 4 ≤ 10.1–19.9%, 5 = 20%). In addition to the last, the number of trees, dead or alive, in each pond was counted as a separate measure of potential perching habitat. Each of these parameters was estimated by two of the authors, CC and AB, and the average score taken.

Various parameters were used to define the environmental and agricultural settings of each pond. The land-use that a pond was embedded in was categorised as rain-fed pasture, irrigated pasture, irrigated perennial horticulture, wheat, canola, remnant native vegetation, or farm-building infrastructure. The dominant water source was categorised thus: localised runoff, river (floodwater), actively-abstracted groundwater, irrigation channel, effluent, and irrigation-bay runoff. The categories for dominant water use for the 2011/12 summer were stock watering, irrigation, or unused.

Water and sediment sampling and analysis

Water samples for zooplankton and chlorophyll *a* were collected from all ponds on the same day (1 December 2012). Three random sub-samples were collected from each pond and combined into one composite sample representing the pond (i.e., the sampling unit for all analyses). Because of the large number of ponds to be surveyed we needed a rapid sampling approach and thus samples were collected from the edge using a 6-L bucket attached to 2-m stick. For zooplankton, a composite sample from the three locations of 6 L was poured through a 150- μ m sieve (APHA et al. 2005), which was then thoroughly rinsed with 70% (v/v) ethanol to collect the organisms. Samples for chlorophyll *a* analysis were collected at the same locations as those for zooplankton by submerging

100-mL plastic bottles about 10 cm below the surface. Electrical conductivity, pH, dissolved oxygen, and turbidity were measured at the same three points (and on the same day) that the water samples were collected from using a HACH sensION 156 Multi-Parameter Meter (Loveland, Colorado). The arithmetic mean of these three subsamples was used as the estimate for the pond.

Data analysis

Pearson's Product Moment correlation coefficient (r) was used to analyse the strength of correlations between waterbird numbers and the various biophysical and landscape characteristics of the ponds. p values relating to the null hypothesis that $r = 0$ were reported, although we are cognisant of arguments questioning the value of such null-hypothesis significance testing (Goodman 1993, 1999), and regardless the strength of correlation is of more relevance here. Numerous correlations are made, and in such cases arguments can be proffered both for and against making adjustments to the significance level of the Type-I error rate. The likelihood of encountering a so-called "spurious" correlation may increase concomitantly with the number of comparisons, but on the other hand adjusting the significance level to a lower probability has the disadvantage of inflating the Type II error rate and makes the assumption that the multiple hypotheses are members of a common "hypothesis family," which is difficult to prove either way owing to the vagueness of the concept (Hochberg and Tamhane 1987). We have taken a pragmatic approach and denote un-adjusted significant probabilities ($p \leq 0.05$) and the Dunn-Šidák-corrected p value (Ury 1976). Because the various biophysical and landscape parameters were represented by a single estimate at each dam but the bird estimates were made weekly, we used the arithmetic mean of the bird counts over the summer for the correlations.

Being a categorical variable, the effect of landscape type could not be investigated using correlation. Rather, linear mixed models, specifically REML (Restricted Estimated Maximum Likelihood), were used (Patterson and Thompson 1971). REML is a more general procedure than ANOVA (Analysis of Variance) and is useful for unbalanced designs, as was the case here. It reduces to ANOVA in simple, balanced cases. Land use type (wheat, canola, rain-fed pasture, or remnant vegetation) was modelled as the fixed effect (analogous to treatment effects in ANOVA) and stratum was nested within date for the random effect model. The fixed effect of landscape type was tested using a Wald statistic (Buse 1982), and post hoc comparisons of means were tested using Fisher's Least Significant Difference (LSD). All correlations and REMLs were performed using the statistical

package Genstat (Edn. 16; Lawes Agricultural Trust, IACR-Rothamsted).

It is important to note that no attempt was made to compare farm dams with billabongs, because this would have involved severe pseudoreplication, with all of the billabongs being located in a cluster on the southern edge of the property along the broken river (i.e., high spatial autocorrelation) (Fig. 1). Rather, the data for billabongs were easy to collect and are included for interest alone.

Results

Significant and strong correlations (i.e., >0.6) between the abundance of Rallidae (swamphens and coot) and pond area, perimeter, and amount of emergent vegetation were observed. No strong correlations were observed for any other functional group or with total waterbird abundance (Table 2).

There was significant effect ($p < 0.05$) of landscape setting (canola, wheat, rain-fed pasture, or remnant native vegetation) on bird density for all functional groups save filtering waterfowl (Table 3). For shorebirds and swamphens, rain-fed pasture hosted significantly more birds than did any other landscape setting. Significantly more diving birds were observed in ponds imbedded in wheat crops/stubble than any other landscape, whereas herbivorous waterfowl were found in significantly greater numbers in canola crops/stubble than any other setting. Long-legged wading birds were found in significantly greater numbers on ponds embedded in wheat and rain-fed pasture than those in remnant native vegetation, and pursuit predators.

On a per-hectare basis, the farm dams supported 27.1 ± 71.1 (SD) waterbirds, and an average of 1.8 ± 2.9 species were observed per dam across the survey period (computed from weekly counts). The billabongs hosted far fewer birds, and the one dairy waste stabilisation pond observed hosted large numbers of dabbling ducks only, mostly Grey Teal (*Anas gracilis*) (Table 4).

Discussion

Species abundance and species richness on farm dams

Farm dams are the most abundant waterbodies in the MDB, and indeed Australia, yet virtually nothing is known about their contribution to biodiversity. This stands in stark contrast to the situation for rivers/streams and floodplain wetlands, which have been the focus of an intimidating amount of scientific research, covering much of the Basin and on numerous taxa (well summarised in MDBA 2010). In fact, unquestionably the most significant “environmental attention” that farm dams have received relates to the potential impact they have on stream systems through reducing recharge. With the massive destruction of Australia’s wetlands, mostly at the expense of

agricultural expansion, it is crucial that the role these artificial wetlands might play in biodiversity conservation be quantified. While individual farm dams are only ever likely to host a small number of waterbirds relative to much larger wetland systems, it may be that the sheer number of them means that the total contribution of this type of waterbody as habitat for waterbirds is quite significant.

It is dangerous to extrapolate from the dams studied in this area alone. Nevertheless, if one makes the bold assumption that similar numbers of birds are found on farm dams throughout the MDB, then, given there are 710,539 farm dams in the Basin, a back-of-the-envelope calculation suggests that they may collectively host 12 million waterbirds (average of 16.45 birds per dam in this study regardless of size). Owing to the massive year-to-year fluctuations in abundance of Australian waterbirds, it is difficult to place this number in context but a very rough attempt can be made via equally crude extrapolation from the annual aerial surveys of eastern Australia. Sampling of eastern Australia (south of the tropics and bounded to the west by the longitude of the NT-QLD border) is undertaken by surveying along 10 transects that cover about 12% of the region. The average number of birds observed from 1996 to 2004 was about 238,000 (Kingsford and Porter 2006), and thus, placing aside problems associated with spatial heterogeneity *inter alia*, one could cautiously posit that eastern Australian wetlands >1 ha host just under 2 million birds. Caveats abound around such estimates, but even if either is out by an order of magnitude, farm dams clearly provide significant habitat for waterbirds throughout the MDB. On the other hand, judging the value of a habitat type simply on the number of individuals it hosts is somewhat superficial, and clearly ignores the essential quality of breeding habitat, which farm dams generally offer little of for most species.

Biophysical and landscape impacts on waterbird use of farm dams

Birds found in greater densities on dams set in crops or rain-fed pasture than in remnant native vegetation. The reason for this is unclear. Our sampling straddled the harvest period, but stubble was present for most of the time (i.e., harvest toward the start of our survey period). It may be that spilled grain attracted some species, but this would not explain the relatively high numbers also on dams in rain-fed pasture. The other possibility is that the dams embedded in native vegetation provided poorer access and egress due to the presence of trees and other vegetation, and this has been noted previously to deter birds (Kingsford 1992).

Different species will use farm dams in different ways. For some species dams may serve as important foraging sites, yet for others they might function as safe-havens (or

Table 2 Pearson's Product Moment correlation coefficients for density (birds/ha) of different functional groups and biophysical variable

	Shorebirds (Charadriiformes)	Long-legged wading birds	Swampheens and coot (Rallidae)	Pursuit predators	Diving	Dabbling	Filtering	Herbivorous	Total abundance	Species richness
Area (ha)	0.499	-0.115	0.787	-0.105	0.269	0.330	0.275	-0.085	0.157	-0.389
Perimeter (m)	0.434	-0.102	0.635	-0.121	0.188	0.248	0.173	-0.094	0.092	-0.446
Shoreline irregularity	0.161	-0.018	0.189	-0.106	0.007	-0.046	-0.072	0.027	0.046	-0.341
Maximum depth (m)	0.373	0.030	0.273	0.095	0.158	0.221	0.222	-0.150	-0.012	-0.208
Distance shallow slope (m)	0.380	-0.120	0.4923	-0.183	0.116	0.155	0.109	0.008	0.128	-0.395
% Shallow slope	0.155	0.005	0.092	-0.243	-0.162	-0.006	-0.119	0.270	0.237	-0.273
Bare earth	0.058	0.068	0.132	-0.256	-0.289	0.090	0.003	0.358	0.335	-0.009
Distance to nearest pond (m)	-0.280	0.158	-0.266	0.022	-0.115	-0.139	0.055	-0.113	-0.182	0.075
Emergent vegetation	0.151	-0.124	0.617	-0.101	0.208	0.235	0.188	-0.201	-0.016	-0.136
Non-tree perches	0.193	0.039	0.471	0.212	0.026	0.317	0.163	-0.159	0.021	-0.024
Tree cover	-0.019	0.059	0.016	0.127	0.117	-0.106	-0.046	-0.221	-0.197	0.013
Trees in pond	-0.028	0.212	0.033	0.293	-0.069	0.020	-0.012	-0.072	-0.028	0.029
Chlorophyll <i>a</i> (mg/L)	-0.124	0.116	-0.147	0.180	-0.081	-0.088	0.181	0.0173	-0.018	0.153
Conductivity (μ S/cm)	0.323	0.148	0.314	-0.200	0.030	0.273	0.296	0.059	0.185	-0.044
Dissolved O ₂ (mg/L)	0.159	0.198	-0.001	0.050	0.081	-0.007	0.003	-0.007	0.032	0.114
Turbidity (NTU)	0.026	0.051	-0.123	0.006	-0.159	-0.124	-0.092	0.100	0.030	-0.029
pH	0.208	0.144	0.0849	-0.064	0.281	0.130	0.223	0.039	0.137	0.191
Total invertebrates	-0.026	0.002	0.065	0.066	0.0738	0.097	-0.048	0.056	0.097	-0.010

*Denotes $p < 0.05$ for the null hypothesis that $r = 0$, and # denotes that p was significant after the Dunn-Sidak correction was applied ($p < 0.0003$)

Strong correlations (>0.6) are presented in italics. Factors without units reported were measured on the 1–5 Likert scale described above

Table 3 Mean density of birds (birds/ha) on different functional groups and species richness (species/pond) on dams in different landscape settings

	Shorebirds (Charadriiformes)	Long-legged wading birds	Swampheens and coot (Ral- lidae)	Pursuit predators	Diving	Dabbling	Filtering	Herbivorous	Total abundance (birds/ha)	Species richness (species/pond)
F probability	0.001	0.013	<0.001	0.001	<0.001	<0.001	0.463	<0.001	<0.001	<0.001
Canola	2.3×10^{-5} a	0.334ab	0.000a	0.147ab	0.130a	1.141b	0.001	1.796c	4.744b	0.495a
Wheat	0.001a	0.519b	0.000a	0.343b	1.499c	1.456b	0.012	0.604b	5.618b	0.567ab
Rain-fed pasture	0.096b	0.365b	0.522b	0.387b	0.640b	1.508b	0.018	0.813b	4.920b	1.130b
Remnant native vegetation	0.000a	0.079a	0.000a	0.047a	0.387ab	0.174a	0.041	0.026a	0.746a	0.567a

Values represent back-transformed means. Means with the same letter are not significantly different at a probability of <0.05 according to Fisher's LSD test. Letters are not presented if the fixed effect was insignificant ($p > 0.05$)

Table 4 Mean density of birds (birds/ha) by functional groups and species (species/pond) on farm dams, billabongs, and the single dairy waste stabilisation pond (WSP)

	Shorebirds (Charadriiformes)	Long-legged wading birds	Swampheens and coot (Rallidae)	Pursuit predators	Diving	Dabbling	Filtering	Herbivorous	Total abundance (birds/ha)	Species richness (species/pond)
Farm dams	0.219 (2.501)	1.970 (10.113)	1.975 (7.883)	1.250 (4.635)	2.434 (6.204)	5.938 (13.065)	0.043 (0.549)	13.302 (67.889)	27.131 (71.167)	1.750 (2.879)
Billabongs	0.000 (0.000)	3.0×10^{-4} (0.002)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.003 (0.006)	0.000 (0.000)	0.001 (0.005)	0.005 (0.008)	1.062 (1.261)
Dairy WSP	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.005 (0.006)	0.000 (0.000)	0.000 (0.000)	0.005 (0.006)	1.900 (1.197)

Note that these data are included purely for descriptive purposes, not comparative purposes. There is only one WSP and all the billabongs are located in the same area, so it is not possible to infer differences between the types of ponds. (Numbers in parentheses represent 1 standard deviation. Not shown for WSP because there is only one pond)

permanently-wet drought refuges in some cases, depending on where the water is sourced from), with feeding taking place elsewhere, such as on natural wetlands or pasture. Kingsford (1992) argues that the Australian Wood Duck has likely been a particular beneficiary among Australia's waterbird fauna of the massive expansion in the number of farm dams over the last century. The fact that Wood Ducks breed in the vicinity of farm dams as well as use them outside breeding probably does mean that they have benefited more from their proliferation than most other species, which tend to breed on ephemeral inland wetlands, but the function of dams as non-breeding sites for other species demands attention. Of the 30 species observed over the Dookie survey, three (Australasian Grebe *Tachybaptus novaehollandiae*, Pacific Black Duck *Anas superciliosa*, and Black Swan *Cygnus atratus*), were breeding. The extent of breeding by different species on farm dams across the MDB needs to be quantified so that their contribution to recruitment can be placed in context.

Authors' contributions

AJH conceived, designed, and led the study, and he did all the statistical analyses and wrote significant portions of the text. CC made all of the bird observations and AB assisted by driving and taking notes as CC called out the observations. AB and CC collated the data and prepared them for analysis, and they both completed all of the laboratory work for water-quality parameters. CGM helped with the writing of the text, especially placing the work in a broader context. CGM also considered statistical analyses with AJH. JRG collected all the physical information on the dams. All the authors have read and approved the final manuscript.

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Competing interests

The authors declare that have no competing interests.

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