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RESEARCH ARTICLE

Colonial waterbird breeding in the Gayini-Nimmie-Caira wetlands, Australia, 2010-2011

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Abstract Globally, irrigated agricultural landscapes represent about 20% of all cultivated land. In many areas of the world they can provide significant waterbird habitat. In Australia, the Murray Darling Basin, the stronghold of colonial waterbird breeding wetlands, contains 70% of the nation's irrigation resources. In 2010 two colonial waterbird colonies were established on natural wetlands in an irrigated agricultural landscape on the lower Murrumbidgee floodplain in eastern Australia. An estimated 50,000 ibis, spoonbill and cormorants bred at the two colonies. A total of 1,555 nests were monitored throughout the breeding event. Overall nest success was high (72% to 75%). Water was actively managed for the two colonies to ensure that falling water levels which can cause nest desertion were avoided and the two colonies recorded high reproductive success.

Keywords Ibis, Lowbidgee, Murray-Darling Basin, reproductive success, water management.

Introduction

Irrigation is the largest global water use sector accounting for ~70% of freshwater extraction and covering an area of 301 million ha (Siebert *et al*. 2010). Traditionally there has been a competition for water resources for wildlife conservation and irrigated agriculture (Lemly *et al*. 2000). However, areas of irrigated agriculture can provide critical habitat for many species of waterbirds in areas that have been heavily modified by anthropogenic changes (Czech and Parsons 2002). In the United States, croplands cover one fifth of the country's total area, forming an extremely large part of the ecological landscape (Huner *et al*. 2002). Similarly, in China, irrigated agriculture covers 66.1 million ha (Hu 2016) and can provide key breeding and feeding habitat for a range of waterbird species (Wood *et al*. 2010). In Australia, areas of irrigated agricultural areas are increasing, while natural wetlands are lost or degraded due to river regulation and water development (Kingsford 2000).

In Australia, a small number of key wetlands (less than 4% of all wetlands) are used by colonial waterbirds for breeding (Brandis 2010). The Murray Darling Basin (MDB) is the main region for wetlands used by colonially breeding waterbirds in Australia with 46% (2,596,209 ha; Bino *et al*. 2016) of wetlands in the Basin supporting breeding. The MDB covers 14% of Australia's land area, but accounts for 52% of Australia's total water consumption. In 2018-19, 94% of water consumed in the MDB was consumed by the agriculture industry (ABS 2020). In 2014 - 15, the MDB contained 66% of Australia's irrigated land (ABARES 2020).

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Impacts from water resource development have been recorded at several key waterbird breeding sites in the MDB. In the Macquarie Marshes, colony sizes, species abundance, species diversity and breeding frequency have all been reduced following reductions in flows (Kingsford and Thomas 1995, Kingsford and Johnson 1998). Similar impacts have also been reported in other major wetlands in the MDB including the Narran Lakes (Brandis *et al*. 2018), the Barmah-Millewa Forest (Leslie 2001) and the lower Murrumbidgee Floodplain (Kingsford and Thomas 2004).

The lower Murrumbidgee River floodplain, hereafter referred to as the Lowbidgee (Figure 1), has a long history of water development with the first flow altering structures established in 1928 (Murrumbidgee Catchment Management Authority 2009). Since then at least 77% of wetlands in the Lowbidgee have been impacted as a result of dams, diversions and floodplain development. Consequently, long-term monitoring found that that waterbird abundance dropped by 90% in the period 1983-1999 (Kingsford and Thomas 2004), however since 2010, post drought and changes to water management at waterbird colonies, abundances have stabilised (Kingsford *et al*. 2020).

The region contains a mosaic of pasture, irrigated agriculture, forestry and floodplain wetlands on private and protected lands (Yanga National Park), which support a range of waterbird habitats when inundated including breeding, roosting and foraging sites. During this study, the region was one of Australia's most intensively farmed with extensive water management infrastructure including large channels, levee banks, pumps and weirs to regulate overland flow movements. More recently (2018) this area has been returned to conservation through the Gayini-Nimmie-Caira project and transferred to indigenous ownership (https://www.natureaustralia.org.au/what-we-do/our-priorities/land-and-freshwater/land-freshwater-stories/gayini/).

This study aimed to monitor and quantify the reproductive success of two colonial waterbird colonies to advise on water requirements for successful ibis and spoonbill breeding in these wetlands and other sites in the Murray-Darling Basin.

Methods

Significant local and upper catchment rainfall during 2010 resulted in localised flooding and large river flows in the Murrumbidgee River catchment in southern New South Wales (NSW), Australia. The Murrumbidgee River is the third largest river in Australia flowing for 1,485 km with a catchment area of 81,641 km^2 (MDBA 2020). The Murrumbidgee

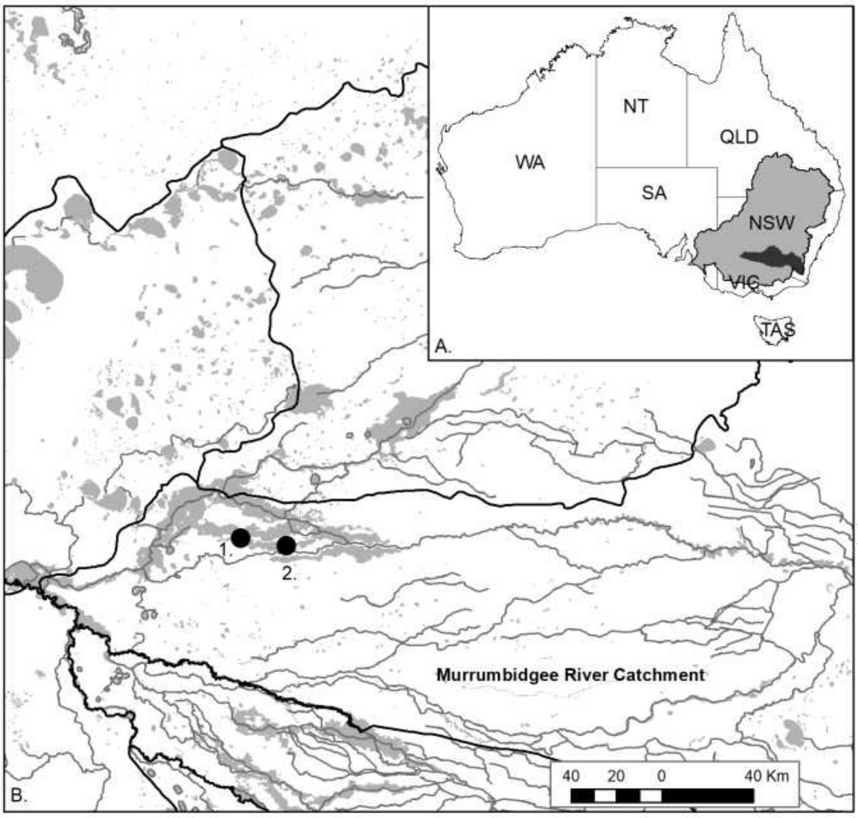

Figure 1. A. Location of the Murrumbidgee Catchment (dark grey) within the Murray Darling Basin (light grey) in south-eastern Australia. B. The location of 1. Telephone Bank Swamp and 2. Eulimbah Swamp waterbird breeding colonies in the lower Murrumbidgee floodplain (Lowbidgee). Catchment boundaries (black lines), river channels (grey lines) and wetland areas (grey shading) also shown.

River is regulated for most of its length with 26 dams and wiers and over 10,000 km of irrigation canals (Page *et al*. 2005).

The Lowbidgee covers an area of 217,000 ha km^2 and contains the largest areas of wetlands (Rogers *et al*. 2013) remaining in the Murrumbidgee River. It is an area of national and international significance providing habitat for fifteen migratory bird species listed on international agreements (JAMBA 1981, CAMBA 1988, ROKAMBA 2006), and endangered and vulnerable flora (6) and fauna species (32; EPBC Act 1999). The Lowbidgee is key breeding area for colonial waterbirds in Australia (Brandis 2010), with breeding recorded at 34 wetlands 2006-2016 (Spencer 2017). In October 2010 two colonial waterbird breeding colonies established on private wetlands in the Gayini-Nimmie-Caira system in the Lowbidgee (Figure 1).

Study site

The 'Torry Plains' property is situated on the floodplain of the Nimmie-Caira Creek in the Lowbidgee, NSW. The Nimmie-Caira is a distributary creek system of the lower Murrumbidgee River. 'Torry Plains' was an agricultural property producing irrigated organic wheat. It employed a system of levee banks, flood gates and pumps to move water across the landscape. This infrastructure was utilised during the 2010/2011 colonial waterbird breeding event to manage water levels and flow rates at colony sites.

Local rainfall (measured at Nap Nap (075049) (Australian Government Bureau of Meterology 2011) during 2010 recorded eight months of higher than the long-term average (1889 - 2011). High local rainfall continued into early 2011 maintaining river flows (Figure 2). During late September 2010 Telephone Bank Swamp and Eulimbah Swamp on the Tori Plains property became inundated. These sites are the largest regularly used ibis colony sites in the Lowbidgee (Kingsford *et al*. 2020).

Eulimbah Swamp lies behind a levee bank created in 1986 that crosses the entire width of the Nimmie-Caira creek floodplain (Murrumbidgee Catchment Management Authority 2009; Figure 1). It is used for water holding and to supply water along channels to other parts of the floodplain. It covers an area of 600 ha and has a maximum capacity of 3,000 ML (DWR 1994), it is confined on all sides by levee banks. It is usually inundated once every two years (Wassens 2008). Eulimbah Swamp is a Lignum shrubland *Duma florulenta* dominated swamp with small areas of Common Reed *Phragmites australis* and cumbungi *Typha latifolia*.

Telephone Bank Swamp is located on Pollen Creek (Figure 1). The Telephone Bank levee was built in 1960. The Telephone Bank Swamp is approximately 1,000 ha when inundated (DWR 1994). The swamp consists of a mixed vegetation community, including

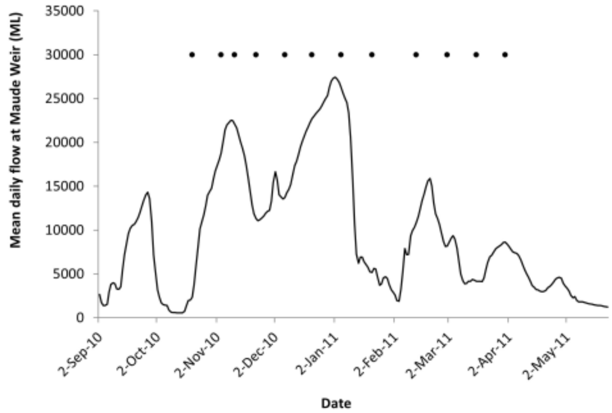

Figure 2. Mean daily river flow in the Murrumbidgee River (at Maude Weir 41010941) from September 2010 to May 2011 with timing of nest surveys indicated (black dots).

River Red Gums *Eucalyptus camaldulensis*, Lignum shrubland and Common Reed. This swamp retains high water levels for longer periods that other wetland storages in the Gayini-Nimmie-Caira system and provides valuable nesting habitat for a diverse range of waterbirds including cormorants and Australasian Darters *Anhinga novaehollandiae* (Murrumbidgee Catchment Management Authority 2009).

Following the establishment of colonial waterbird breeding colonies at Telephone Bank and Eulimbah swamps in October 2010, the first breeding event since 2005, a comprehensive nest monitoring program was undertaken. Straw-necked Ibis *Threskionis spinicollis*, Glossy Ibis *Plegadis falcinellus*, Royal Spoonbill *Platalea regia* and Little Pied Cormorant *Phalacrocorax melanoleucos* nests were monitored.

We undertook nest monitoring between November 2010 - April 2011 with a total of 12 surveys per colony were conducted throughout the breeding and flooding period (Figure 2). At each colony a sample of nest clumps were randomly selected. A nest clump is a grouping of nests (> 2) that are all placed together separated from the next nest clump by a channel of water or non-flattened vegetation (Figure 3). Each nest clump was assigned a unique number and the geographic location recorded using a GPS (5 - 10 m accuracy). At each nest clump, individual nests were labelled with a unique identifier. For each labelled nest, the number of eggs or chicks were recorded. Nests were monitored fortnightly. As new nests were established additional clumps were included in the monitoring program. Nest monitoring continued from November 2010 - April 2011 (Figure 2). Access to and around the colonies were by small motorised boat. Monitoring of individual nests was done by a person standing in the water recording individual nest contents. We also monitored water depth at each nest clump and water quality at three sites (pH, conductivity, dissolved oxygen, turbidity and temperature) at each colony at each survey time.

The colony boundary was mapped using GPS locations recorded at the maximum extent of nests. This

Figure 3. A photograph showing a nest clump of 10 Straw-necked Ibis nests with eggs, Telephone Bank colony. Photograph by Kate Brandis.

made statistical comparisons using t-tests. For Straw-necked Ibis we analysed temporal changes in clutch size as additional laying events occurred. As the most abundant species, and of key interest for water management, we also estimated total Straw-necked Ibis abundance at each colony site.

We calculated the hatching rates for each species in each colony. Data were categorised into three groups: egg, chick and nest. Success was determined for periods between surveys. For example, if at the end of each time period between surveys the nest contained eggs or chicks it was scored 1, if neither then 0 (Hazler 2004). Data for Straw-necked Ibis were further analysed based upon date of first survey. All initial surveys were at egg stage. We used date of first survey as a surrogate for laying period. Analyses were grouped based upon date of first survey of that site.

Generalised additive models (GAM) were developed to understand the relationships variables for breeding of Straw-necked Ibis. In model 1, we examined the relationship between clutch size, lay date and nest site size. In model 2, we examined the relationship between clutch size, nest site size and reproductive success. Laying periods were categorised into: early (< 50 days from first survey), middle (50 - 100 days) and late (> 100 days from first survey), from November 2010.

A total of 680 nests were monitored at Telephone Bank Swamp colony including four species of colonially breeding waterbirds, Straw-necked Ibis, Glossy Ibis, Royal Spoonbill and Little Pied Cormorant (Table 1). At Eulimbah Swamp colony, 795 nests were monitored including two species, Straw-necked Ibis and Royal Spoonbill (Table 1).

Results

Nesting surveys

Nesting at Telephone Bank Swamp was first established in early - mid October 2010 and Eulimbah Swamp late October - early November 2010. Breeding activity at these colonies continued until May 2011. Throughout this period there were several distinct laying events and the extent of the colonies shifted as new nests were built. Telephone Bank Swamp colony area was approximately 19 ha while the Eulimbah Swamp colony area was approximately 31 ha.

We estimated from aerial surveys (Kingsford *et al.* 2020) that there were approximately 15,000 - 20,000 Straw-necked Ibis at Telephone Bank Swamp and 20,000 - 30,000 at Eulimbah Swamp. Glossy Ibis were more numerous at Telephone Bank than Eulimbah Swamp. Both sites recorded breeding by several species, however Eulimbah Swamp colony was dominated by Straw-necked Ibis with few Glossy Ibis or Royal Spoonbill observed breeding and no Little Pied Cormorants were recorded breeding at this site.

At Telephone Bank a total of 1,361 Straw-necked Ibis eggs were monitored at 621 nests at 37 nests clumps. At Eulimbah Swamp colony a total of 1,885 eggs were monitored at 778 nests at 40 nest clumps.

During the breeding event there were four periods of egg laying by Straw-necked Ibis: early November, late November, late January and early March. Our observational data suggests that some Straw-necked Ibis pairs laid second clutches while other nests were established by newly arrived birds. This is illustrated by the changes in composition of eggs and chicks over time (Figure 4).

Glossy Ibis nesting at Telephone Bank had two laying periods, one in early November and a second in late December. Royal Spoonbill were present in both colonies for the entire breeding

Table 1. Reproductive success measures for each colony.

Species	Colony	Mean clutch size, ± SD, *N* (nests)	Egg hatch rate %, *N* (eggs)	Reproductive success % (eggs laid/chicks fledged)
Straw-necked Ibis	Telephone Bank	2.16 ± 0.75, 621	70, 1361	77
	Eulimbah Swamp	2.35 ± 0.69, 778	73, 1885	75
Glossy Ibis	Telephone Bank	3.26 ± 0.84, 45	70, 141	93
Royal spoonbill	Telephone Bank	2.64 ± 0.64, 13	72, 39	82
	Eulimbah Swamp	3.5 ± 1.5, 2	42, 7	33
Little pied cormorant	Telephone Bank	4.43 SD±0.53, 7	100	100

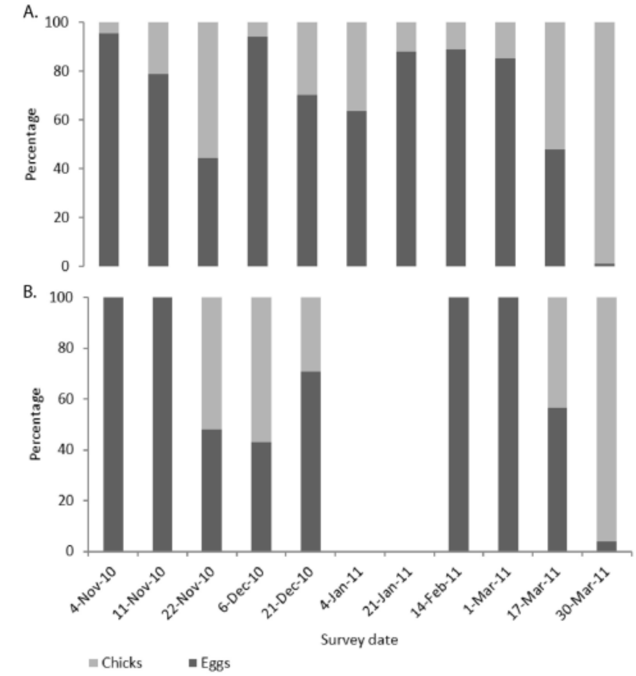

Figure 4. Changes in the relative composition of Straw-necked Ibis eggs and chicks at A. Telephone Bank and B. Eulimbah Swamp colony throughout the 2010-11 breeding period. 4-21 Jan. 2011 recorded no data at Eulimbah Swamp due to flooding and then drying of the colony site.

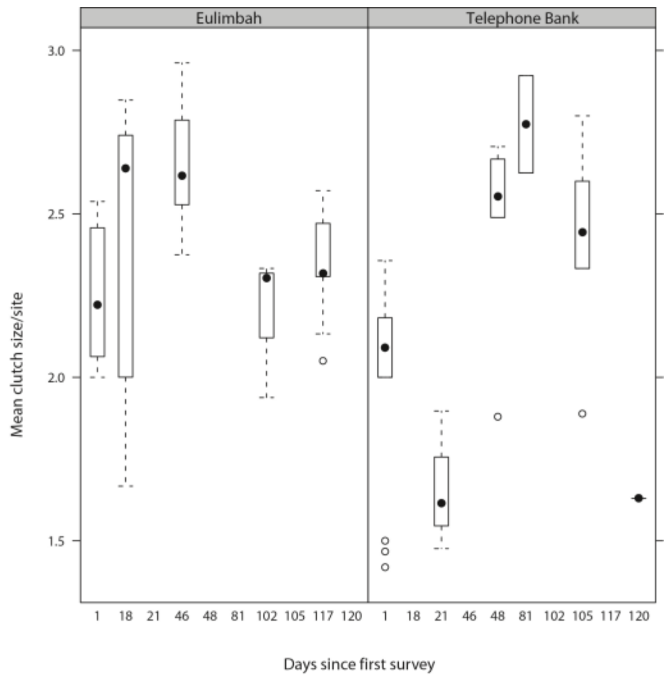

Figure 5. Changes in mean clutch size of Straw-necked Ibis at each colony over time.

period but were more numerous at Telephone Bank. They did not appear to have clearly defined laying events. All 13 nests that were monitored at Telephone Bank were first surveyed in early November (02 November 2010). Three Royal Spoonbill nests were monitored in Eulimbah Swamp, two nests were first surveyed in early November (02 November 2010), one nest was first surveyed in late December (20 December 2010). One site of Little Pied Cormorant nests was monitored at Telephone Bank. There were only two nest sites for this species observed at Telephone Bank. Little Pied Cormorant were not observed nesting at Eulimbah Swamp.

We measured a range of reproductive success measures including clutch sizes, egg hatch rates (% eggs laid that hatched) and overall reproductive success (eggs laid/chicks fledged; Table 1).

There was a significant difference in Straw-necked Ibis clutch sizes between Telephone Bank and Eulimbah swamps ($p < 0.001$), and there were some observed differences based on time of laying, particularly at Telephone Bank with eggs laid during the ‘middle’ of the breeding period being larger (Figure 5). This was also reflected the model results with clutches laid in the middle of the breeding period being larger (Figure 8). Similarly, clutch size data for Glossy Ibis varied with lay date. Nests established in early November 2010 (surveyed 02 November 2010) had a mean clutch size of 3.47 eggs/nest ($N = 30$, SD ± 0.77) while nests established in late December 2010 (surveyed 20 December 2010) had a mean clutch size of 4.23 ($N = 13$, SD ± 0.96). We did not undertake the same analyses for the other species due to low sample sizes.

Overall nest success Straw-necked Ibis for Eulimbah Swamp colony was 75% while Telephone Bank colony was 72%. Mean nest clump success for Eulimbah Swamp across all dates was 71% and 68% for Telephone Bank. Nest and nest clump success varied over time, most notably for Eulimbah Swamp where the wetland was firstly inundated (04 January) then dried (21 January; Figure 6). Removing the loss of nests to flooding in Eulimbah Swamp, the site success rates at Eulimbah Swamp were 60 - 100%. Telephone Bank, did not lose nests to flooding but had a wider range of site success from 0 - 100%. Overall success rates were relatively consistent irrespective of lay date (Figure 6).

Breeding models

Model 1: Clutch size

Nest clumps with a total number of nests between 20 - 40 nests had a higher probability of having clutch sizes greater than two (Figure 7). Nest

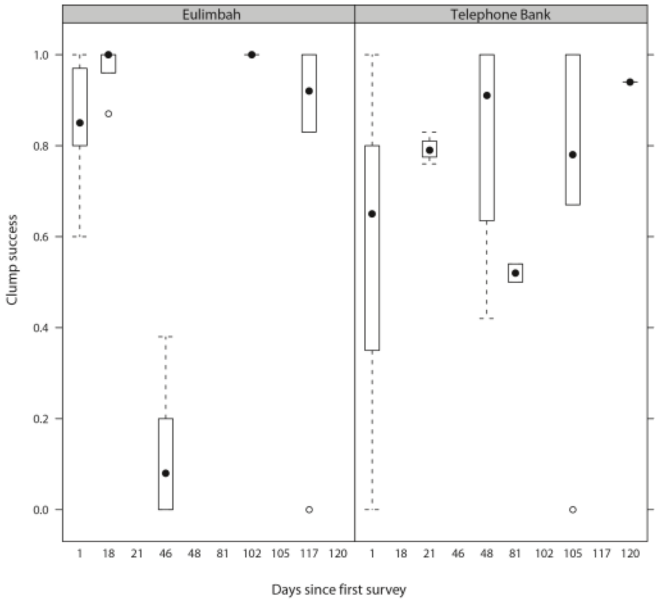

Figure 6. Success for individual clumps of nests over time for nests of Straw-necked Ibis at Eulimbah Swamp and Telephone Bank colonies.

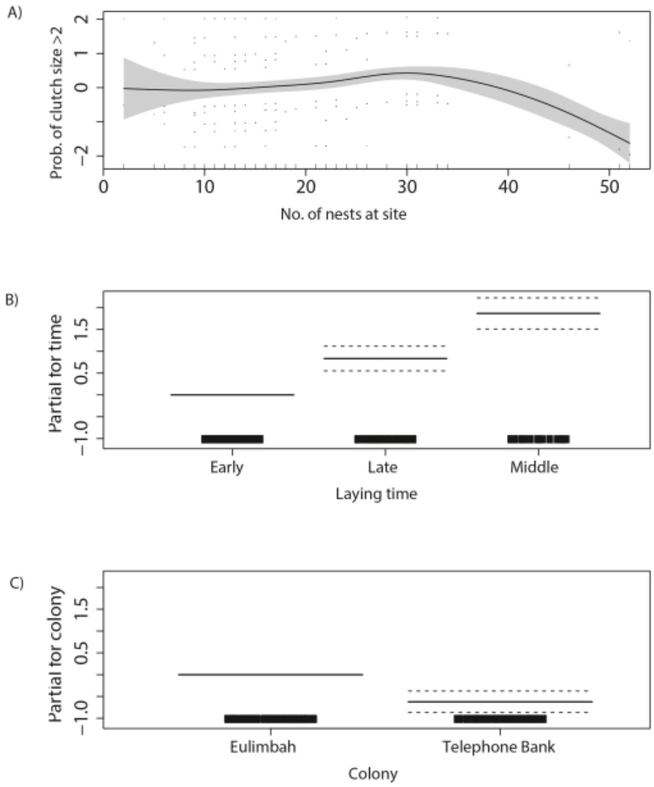

Figure 7. General Additive Models (GAMs) outputs illustrating the relationships between a) the number of nests at a nest clump and the probability of clutch sizes>2, b) the relationship between laying period and clutch sizes and c) clutch sizes at each colony.

clumps with > 40 nests had increasingly lower probabilities of having clutch sizes greater than 2. Early layers had a lower probability of having a large clutch size (more than two eggs) than birds that laid in the middle of the breeding event. Middle layers had the highest probability of having larger clutch sizes, while late layers had a lower probability, although not as low as early layers (Figure 7). There was a high probability of nests at Eulimbah Swamp having larger clutch sizes than nests at Telephone Bank (Figure 7).

Model 2: Reproductive success

The relationship between individual nest success and the size of the nest clump it was located within was variable with a general trend of greater nest success for nests in larger clumps (Figure 8). Middle and late nesters had greater nest success than early nesters (Figure 8). Larger clutch sizes had a greater overall success rate than small clutch sizes (Figure 8).

Colony conditions

Water depth

The two colonies experienced different water depth conditions. Water depths in Eulimbah were maintained at a relatively stable depth until early January 2011 when the third and largest flood pulse inundated the Eulimbah Swamp colony site. To minimise nest inundation and control flooding a hole was cut the levee bank to allow water to flow through the Eulimbah Swamp site. By late January Eulimbah Swamp had dried, the levee bank repaired and Eulimbah Swamp was refilled to approximately the same depth prior to flooding.

Water depth in the Telephone Bank colony was maintained at a relatively stable level (mean = 78 cm, min. 70 cm, max. 86 cm) for the duration of the ibis breeding event.

Water quality

pH is a measure of how acidic/basic water is, ranging from 0 - 14, with 7 being neutral. pH can be affected by chemicals in the water and is an important indicator of water that is changing chemically. Pollution is one source that can change a water's pH, which in turn can impact aquatic flora and fauna. pH was relatively stable at both colony sites for the duration of breeding (Eulimbah Swamp mean = 7.2, Telephone Bank mean = 6.8; Table 2).

Dissolved oxygen (DO) measurements record the amount of water dissolved in water. This is an important measure needed to sustain fish, aquatic invertebrate and macrophyte communities. Rapidly moving water general has a higher level of dissolved oxygen than stagnant water. This may

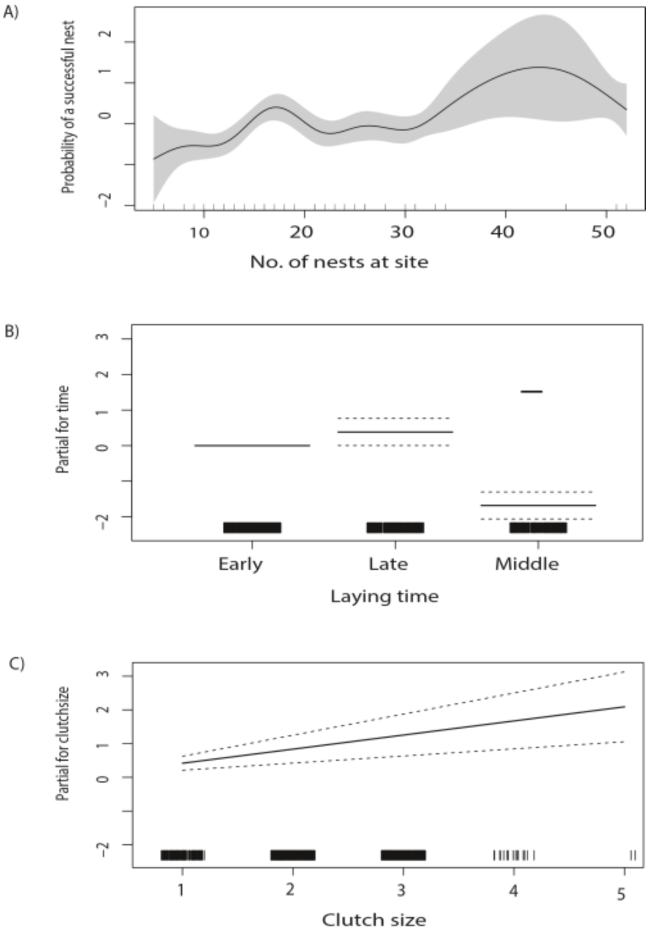

Figure 8. General Additive Models (GAMs) outputs illustrating the relationships between a) the probability of a nest being successful based upon the total number of nests at the nest clump, b) the relationship between laying time and nest success and, c) the relationship between clutch size and the overall success of the nest.

explain the higher reading at Eulimbah Swamp on the 14 February 2011 (Table 2) as the colony site has been recently refilled. Dissolved oxygen levels are also impacted on my water temperature and aquatic vegetation. Under normal atmospheric pressure and a temperature of 20^0 C water will contain about 2% (2 ppm by volume) dissolved oxygen (Gordon 2004).

Conductivity measures the ability of water to conduct an electrical current. It is highly dependent on the amount of dissolved solids, such as salt in the water. As water evaporates, or is used by vegetation the concentration of dissolved solids increases. This may explain the slight increase in conductivity at both sites over time (Table 2).

Turbidity is a measure of the particulate matter in the water. High levels of turbidity result in a higher scattering of light. Factors that can cause turbidity include: clay, silt, organic and inorganic matter, and microscopic organisms. Turbidity can be highly variable and is impacted by short term events such as increased flow velocity or rainfall runoff.

At the colony sites, turbidity levels would have been influenced by bird faecal matter and the inflow of water into the colony sites. The variation seen in the results for Eulimbah Swamp and Telephone Banks (Table 2) may be due to water management practices and the movement of water through colony sites, especially the high turbidity recorded at Eulimbah Swamp following refilling in late January.

Water temperature is an important measure for some aquatic organisms and can affect dissolved oxygen levels. Water temperature measures can be affected by the time of day that sampling was undertaken. Water temperatures at Eulimbah Swamp and Telephone Bank were relatively consistent, ranging from 18^0 C - 30^0 C (Table 2).

Discussion

This study highlighted the importance of the Lowbidgee wetlands as providing key breeding habitat for colonial waterbirds in the Murray Darling Basin and Australia. The diversity of wetland types and the managed delivery of flows to two key colony sites contributed to the breeding success of ~50,000 Straw-necked Ibis and high diversity of waterbird species breeding (N = 28) at these wetlands in 2010 - 11.

The breeding colonies at Telephone Bank and Eulimbah Swamps in 2010/2011 had high rates of reproductive success for all species monitored. Straw-necked Ibis were the most abundant species breeding at both sites with breeding success of 72% and 75% respectively. These colonies were unusual in the number of laying events that occurred throughout the breeding season. Reasons for this may include the management of water at the colony sites and the availability of suitable food resources for the duration of breeding. Water levels at colony sites and the availability of food resources are key factors in determining breeding success in colonially-breeding waterbirds (Tortosa *et al*. 2003; Djerdali *et al*. 2008; Brandis *et al*. 2011).

Water management during the breeding event aimed to maintain water levels without significant fluctuations. This was successfully achieved at Telephone Bank. While despite the unmanageable

Table 2. Mean water quality results per survey per colony.

Colony	Date	Dissolved oxygen (ppm)	Conductivity (µS)	pH	Turbidity (NTU)	Temp. (^{0}C)
Eulimbah Swamp	04 Nov. 2010	3.245	132.5	6.8	72.83	17.8
Telephone Bank		1.88	170.6	6.71	14.6	20.6
Eulimbah Swamp	11 Nov. 2010	2.50	198.5	8.33	6.5	29.4
Telephone Bank		1.10	168.3	6.71	18.4	22.8
Eulimbah Swamp	22 Nov. 2010	3.60	170.0	7.34	6.8	29.0
Telephone Bank		4.30	190.5	7.88	6.7	27.9
Eulimbah Swamp	4 Jan. 2011	3.39	261.0	6.93	8.3	24.2
Telephone Bank		4.11	286.0	7.4	5.3	27.7
Eulimbah Swamp	22 Jan. 2011	Dry				
Telephone Bank		2.34	198.3	5.97	77.8	29.5
Eulimbah Swamp	14 Feb. 2011	10.12	182.2	6.42	32.2	29.2
Telephone Bank		3.10	185.7	6.43	28.9	24.7
Eulimbah Swamp	1 Mar. 2011	3.41	199.3	7.25	24.2	24.3
Telephone Bank		6.93	221.5	6.93	70.1	25.5
Eulimbah Swamp	16 Mar. 2011	4.06	310.0	7.39	19.0	20.1
Telephone Bank		4.35	392.0	7.04	8.2	27.0

flooding of nests, and then drying at Eulimbah Swamp in January 2011, adult and juvenile birds remained in the colony site (pers. obs.) and new nests were built and clutches laid after the site was refilled with water. This observation was also made during a subsequent breeding event in 2016 when similar conditions occurred (Wassens *et al.* 2019).

This study demonstrated that with the support of landholders, beneficial outcomes for waterbirds and waterbird populations were achieved in an irrigated landscape. As floodplain wetlands in Australia continue to be threatened by water resource development and climate change it is critical that these wetland ecosystems are protected and managed effectively to support waterbird populations.

In 2016 - 17 colonial waterbird breeding colonies again established at these two sites with ~15,000 Straw-necked Ibis at Eulimbah Swamp and ~30,000 at Telephone Bank (Wassens *et al.* 2017). Most recently (2018) the Gayini-Nimmie-Caira region of the Lowbidgee has been returned to conservation with joint management by local indigenous groups (Nari Nari) in partnership with The Nature Conservancy, the University of New South Wales, and the Murray Darling Wetlands Working Group to manage the wetlands along with Commonwealth and state agencies who manage environmental water delivery. Results of this study and the 2016 - 17 monitoring will be used to inform the water requirements of colonial waterbird breeding so that flows can be managed to support further successful breeding at these important colony sites and elsewhere in the Murray-Darling Basin.

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