Environmental benefits assessment – Waterbirds

Project area – Murrumbidgee River

Final report

June 2022

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Waterbird spring ground surveys in the Mid-Murrumbidgee Wetlands are coordinated by NSW DPE (formerly OEH and other NSW agencies) from 2012 onwards. Charles Sturt University (CSU) staff assistance with the spring surveys from 2019 onwards through funding by the Commonwealth Environmental Water Office Flow MER program. Our thanks to Rick Webster and Ali Borrell (NPWS) for collection of waterbird data for the Mid-Murrumbidgee wetland reserves in the 2012-2018 period.

We also thank Carmen Amos, Thomas Job, Paul Doyle, Samantha Dawson, Jessica Heath, Markus Bauerle and Nicholas Streeton (DPE) for providing project support.

Cover image: Yarradda Lagoon, Mid-Murrumbidgee Wetlands (Photo: D. Michael, CSU).

Executive Summary

The Waterbird Environmental Benefits Assessment (EBA) project is part of the NSW *Reconnecting River Country Program* which aims to improve wetland and floodplain connectivity in southern NSW. The EBA project is focused on the Murrumbidgee River and River Murray systems. In this report we assessed the likely benefits to waterbirds of relaxed constraint options in the Mid-Murrumbidgee Wetlands downstream of Darlington Point, in the Murrumbidgee Catchment. The results for the Murray River system are presented in a separate report.

We focused on the Mid-Murrumbidgee Wetlands as it is recognised as a nationally important wetland but has suffered declines in wetland health in the last 20 years which has impacted waterbird populations in the region, including the extent of colonial waterbird breeding. We used available ground waterbird survey data for the Mid-Murrumbidgee Wetlands to model waterbird responses (species richness and abundance) to river flows and inundated area.

Although the Lowbidgee Floodplain, located further downstream, provides significant habitat for waterbirds in the Murrumbidgee Catchment, we were not able to include any analysis for this region in this assessment. This was because in most years, the area inundated in the Lowbidgee floodplain is not easily related to the main river flow gauges: it has more to do with flow deliveries made via infrastructure.

While the relationships were not strong, we determined that cumulative river flows in the 180 days prior to spring ground surveys was the best predictor for waterbird species richness and waterbird abundance in the Mid-Murrumbidgee Wetlands. We assessed expected benefits for waterbirds for three relaxed constraints scenarios by comparing responses under relaxed constraints to current operational constraints of 22,000 ML/day in the Murrumbidgee River at Wagga Wagga.

Overall, there was only subtle differences in predicted number of waterbird species and abundance across the modelled flow scenarios. However, the low numbers of waterbirds in the observed data may have influenced the strength of the predictive relationships. Under the relaxed constraint scenarios, a higher proportion of years supported relatively higher species richness and waterbird densities compared to current constraints. While under the current constraints there were a higher proportion of years when species richness and waterbird density were low.

In the most recent decade (2000-2019) of modelled flows, there were increasing benefits predicted for waterbirds for most years under the highest relaxed constraint scenarios (W36 and W40) compared to the lower scenario relaxed constraint scenario (W32). This predicted benefit for the 2000-2019 period, which included the millennium drought, varied from 6-10% maximum increase in species richness and 4-7% maximum increase in waterbird abundance for the higher flow scenarios compared to current constraints.

As the ground survey data was recent (2011-2020) it reflected the current condition of the wetlands, with many of the wetlands in poor condition due to limited inflows in the last 20 years. This may have limited our ability to predict improvements for waterbirds under greater river flows for this region. However, available records show that the Mid-Murrumbidgee Wetlands can support a range of waterbird species including threatened and migratory species, and small-scale colonial waterbird breeding in some years in response to wetland inundation.

The relaxation of constraints is likely to provide greater opportunities to deliver flows to low-lying wetlands, including lagoons and billabongs of the Mid-Murrumbidgee Wetlands, that would otherwise only be possible during high river flows or through infrastructure assisted delivery options. The NSW and Commonwealth governments have been delivering flows to support waterbird and other wetland fauna in the Mid-Murrumbidgee Wetlands for more than 10 years. These flows have improved habitat condition in many key sites, but flow constraints have limited volumes of water than can be delivered to inundate the wetlands, particularly for wetland sites in higher parts of the floodplain. The current constraints limit means that it is difficult to raise river flows above 15,500 ML/day at Darlington Point, but flows need to exceed 21,000 ML/day to create significant wetland connection. This flow height would be possible under the relaxed constraint scenarios of 32,000 ML/day or higher at Wagga Wagga.

Increases in the area and duration of wetland inundation created by higher river flows would provide habitat for waterbirds in the region including greater opportunities for initiating and maintaining small-scale colonial waterbird breeding. The relaxation of constraints in both the Murrumbidgee and Murray Rivers are likely to provide cumulative benefits to waterbird populations by inundating key wetland areas in the southern Basin more frequently, which would support improvements in waterbird populations, a key objective of the Basin Plan.

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List of acronyms

AIC	Akaike’s Information Criterion
BC Act	Biodiversity Conservation Act (NSW)
BWS	Basin Wide Environmental Watering Strategy
CEWO	Commonwealth Environmental Water Office
CSU	Charles Sturt University
DPE	Department of Planning and Environment (NSW)
EBA	Environmental Benefits Assessment
JAMBA	Japan-Australia Migratory Bird Agreement
LTWP	Long Term Water Plan
ML	Megalitre
NDVI	Normalised Difference Vegetation Index
NPWS	National Parks and Wildlife Service (NSW)
ROKAMBA	Republic of Korea-Australia Migratory Bird Agreement
RRCP	*Reconnecting River Country* Program
UNSW	University of New South Wales

Background

Waterbird benefits assessment

The Waterbird Environmental Benefits Assessment (EBA) Project is part of the NSW *Reconnecting River Country Program* (RRCP) which aims to improve wetland and floodplain connectivity in southern NSW. The Waterbird EBA Project is part of a suite of environmental assessment projects developed to assess the likely benefits of relaxed constraint options in the Murrumbidgee and Murray River Systems. The RRCP is focused on relaxing or removing constraints to allow for more efficient delivery of water for the environment in key project areas including:

- Murrumbidgee River
- Hume to Yarrawonga (Murray River)
- Yarrawonga to Wakool (Murray River)

In this report we evaluated the potential benefits of relaxing constraints for waterbird communities in the Murrumbidgee River catchment only. The potential benefits for the Murray River catchment are assessed in a separate report by Bino et al. (2022). Both projects were part of Phase 2 of the Waterbird EBA Project which aimed to provide a detailed assessment of the potential benefits of relaxed constraints to waterbird communities.

Approach

The focus area for this part of the Waterbird EBA Project was limited to the Mid-Murrumbidgee Wetlands (Figure 1) which is recognised as a nationally important wetland (DAWE 2005) and in the past has supported widespread colonially waterbird breeding (Briggs et al. 1997). Although the Lowbidgee Floodplain (Figure 1), located further downstream, provides significant habitat for waterbirds in the Murrumbidgee Catchment, we were not able to include any analysis for this region in this assessment.

Waterbird assemblages and breeding activity in the Lowbidgee region are heavily influenced by inundation of the large Gayini-Nimmie-Caira and Redbank sections of the Lowbidgee Floodplain where wetland inundation may be a result of delivery via infrastructure rather than high river flows. Two weirs were constructed in the 1940s: Maude Weir, which enable the inundation of the Gayini-Nimmie-Caira area, and Redbank Weir (see Figure 1), which can be used to direct flows into South Redbank (Yanga National Park) and the North Redbank area.

As inundation modelling was only available for the Redbank region and the river corridor between Maude and Redbank, and not the whole of the Lowbidgee Floodplain, we are unable to obtain reliable predictions of waterbird responses for the Lowbidgee region. Given these issues we focused on the Mid-Murrumbidgee Wetlands only in our assessment. In comparison the Mid-Murrumbidgee Wetlands are more heavily impacted by current operational constraints in the Murrumbidgee River. There has been limited inundation of parts of the wetlands in recent decades unless through naturally high river flows or infrastructure assisted/pumping watering events.

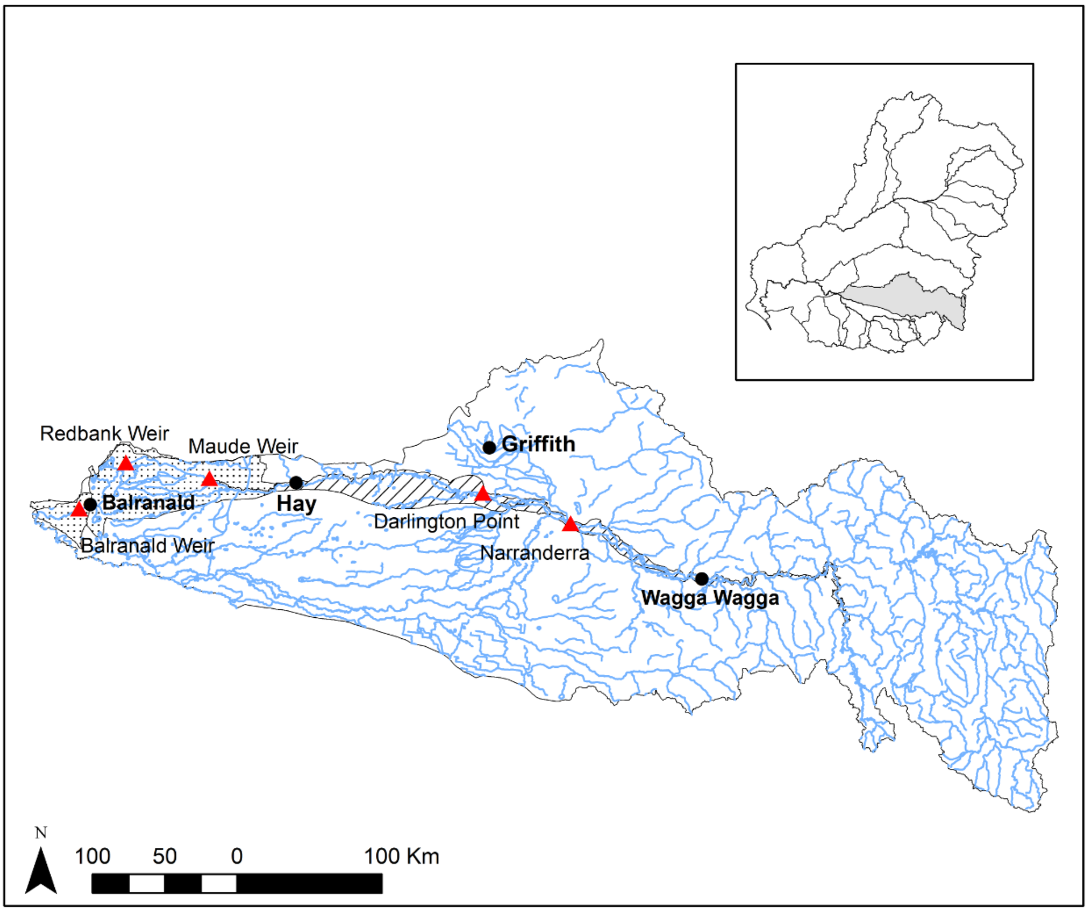

Figure 1 Location of the Mid-Murrumbidgee Wetlands (hatched area), Lowbidgee Floodplain (dotted area) and main river gauges (red triangles) in the Murrumbidgee catchment within the Murray-Darling Basin (inset).

Relaxed constraint scenarios

Four flow scenarios were investigated as part of this project to determine the predicted benefits for waterbirds in the Mid-Murrumbidgee Wetlands. The benefits of increased limits of 32,000 ML/day, 36,000 ML/day and 40,000 ML/day for the Murrumbidgee River at Wagga Wagga (Figure 1) were investigated and compared to the current operational limit of 22,000 ML/day.

The current flow constraint at Wagga Wagga in the Murrumbidgee River is designed to limit impacts on agricultural land. It is expected that relaxation of constraints to permit a higher flow rate would allow a greater area of the Mid-Murrumbidgee Wetlands to be inundated for longer periods, providing benefits for a range of wetland-dependent species including waterbirds. This area has supported more extensive colonial waterbird breeding in the past (Briggs et al. 1997) but breeding activity in recent years has been limited to only a small number of sites (Spencer 2017) located closest to the main river channel.

Flows that can inundate the Mid-Murrumbidgee Wetlands are measured downstream of Narrandera and Darlington Point river gauges (Figure 1). Flow thresholds for large freshes that inundate low-lying wetlands, and small and large overbank events have been documented in the Murrumbidgee Long Term Water Plan (LTWP) (DPIE 2020). The LTWP specifies the river flows at which wetland habitat in the Mid-Murrumbidgee Wetlands are inundated either through wetland connection or overbank events (see Table 1; Figure 2).

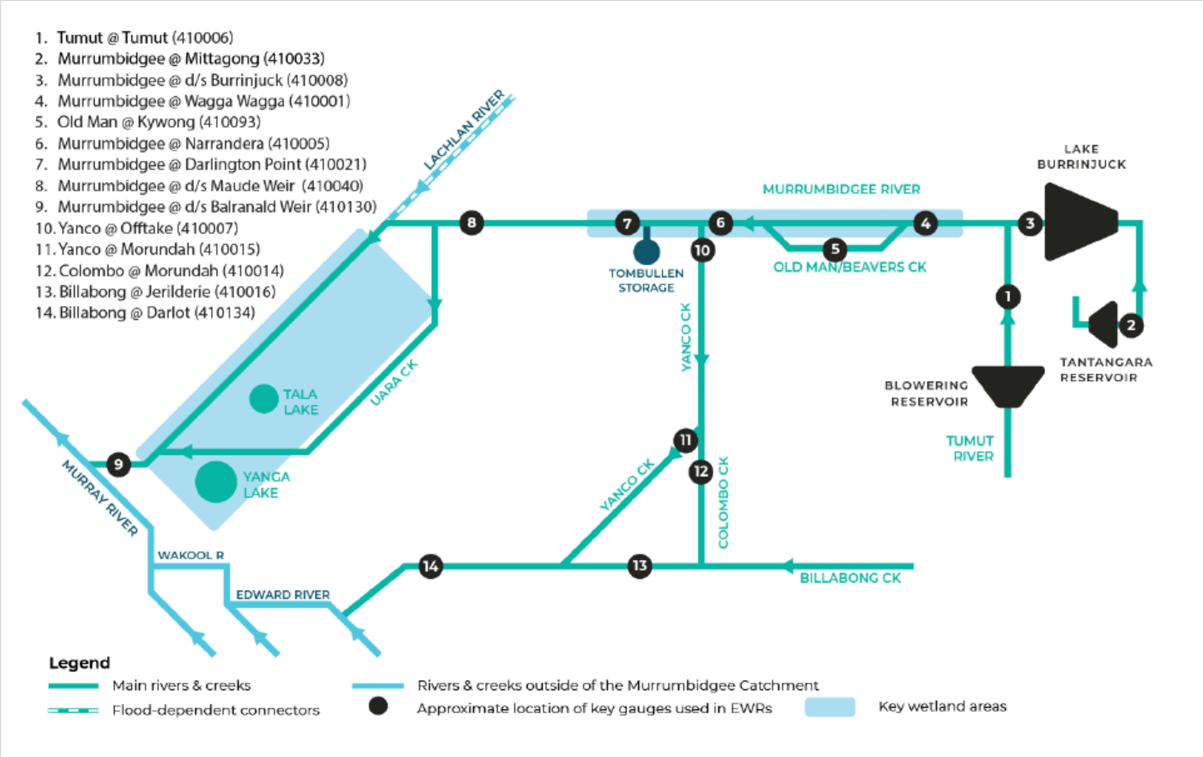

Figure 2 Schematic diagram showing main watercourses and gauges in the Mid-Murrumbidgee and Lowbidgee Floodplain. Reproduced from DPIE (2020).

Table 1 Summary of flow threshold estimates (ML/d) from DPIE (2020) for relevant flow categories (large fresh, small and large overbank events) that can inundate the Mid-Murrumbidgee Wetlands. *Note that wetland connection events were broken into two thresholds measured at Darlington Point (410021) to represent initial filling at >15,500 ML/day (Wetland Connection 1) and more widespread inundation at >21,000 ML/day (Wetland Connection 2).

Wetland area	LTWP Planning Unit	River gauge where threshold measured	Large Fresh Wetland Connection*	Small overbank	Large overbank
Mid-Murrumbidgee Wetlands	Berembed Weir to Gogelderie Weir	Narrandera (410005)	>25,000	>38,000	N/A
	Gogelderie Weir to Maude Weir	Darlington Point (410021)	>15,500 (1) >21,000 (2)	>28,000-40,000	>40,000

Expected waterbird responses

Waterbirds populations are in poor condition across the Murray Darling Basin (Kingsford et al. 2017) with declines in all guilds (1983-2021) recorded in the most recent annual spring aerial surveys coordinated by the University of New South Wales (UNSW) (Porter et al. 2021). At the time of these spring 2021 surveys waterbirds were widely dispersed across the Murray-Darling Basin and total numbers reflected low availability of wetland habitat and drought intensity experienced in the preceding four years across Eastern Australia (Porter et al. 2021).

Many waterbird species are highly mobile, undergoing periods of movement between different wetland regions to access suitable feeding and breeding habitats. Most waterbirds depend on aquatic food sources including wetland vegetation, aquatic invertebrates, fish and/or frogs (Kingsford and Norman 2002). Broadly, waterbird species can be grouped into five functional groups or guilds according to their foraging habitat preferences. This includes ducks and small grebes, herbivores, piscivores (or fish-eating waterbirds), large waders and shorebirds (or small waders) (see Kingsford et al. 2020). Variations in morphology and foraging techniques have allowed many species to co-exist in the same habitats. For example, many large waders, shorebird species and herbivores prefer to feed on the muddy edges of open waterbodies or shallow vegetated marshes, while deeper water foragers including some duck, grebe and fish-eating (piscivores) species prefer to feed in large open lakes and lagoons.

Waterbird species found in the Murray-Darling Basin can also be grouped according to their breeding strategy as either colonial, non-colonial or non-breeding. Colonial species can sometimes nest in very large mixed species colonies when widespread inundation occurs. These include egrets, ibis, spoonbills, cormorants, pelicans, and herons. Most waterfowl and resident shorebird species can be described as non-colonial species as they breed across a wetland complex (rather than in high densities in a location) when suitable habitat is inundated. Migratory shorebirds can also be observed feeding in some floodplain wetlands in the Murray-Darling Basin during spring and summer months, but they do not breed in Australia, instead they migrate each year to breeding habitat in the Northern Hemisphere during austral autumn and winter months.

Several strategies are being used for managing environmental water in the Murrumbidgee Catchment in order maximise outcomes for waterbirds (including colonially-nesting waterbird species). These include maintaining a mosaic of wetland habitats over spring and summer to provide feeding habitat for key species, including migratory species, and extending the duration of existing overbank events to maintain adequate water depths in any active colony sites to support colonial waterbird breeding events through to completion (minimum of three-four months from egg laying plus post-fledgling care for most species). Consideration to maintaining inundation of key foraging grounds for 4 months or more is also built into this water delivery. This provides opportunities for supporting active colonies and young birds from the Murrumbidgee and neighbouring catchments after the completion of breeding events.

We expect increases in the frequency and magnitude of overbank events in key sites in the Mid-Murrumbidgee Wetlands will contribute to Basin-wide (MDBA 2019) and catchment-specific objectives set for waterbirds in Murrumbidgee LTWP (DPIE 2020) (It was anticipated that waterbirds may benefit in two ways to relaxation of constraints downstream of Wagga Wagga including: 1) increases in species richness and 2) increases in abundance as a result of increases in the availability of inundated wetland habitat. We would expect that increased flow volumes will also meet the flow thresholds required for small-scale colonial waterbird breeding (<500 nests) in the Mid-Murrumbidgee Wetlands which would contribute to increased opportunities for breeding in the Murray-Darling Basin.

The success of breeding events is linked to the magnitude and duration of inundation of key breeding sites and surrounding foraging habitat. Inundation of these habitats is needed over the breeding cycle from nest building, egg laying, chick rearing through to fledging to support successful breeding. This is where relaxation of constraints may provide greater management options for delivering flows to extend inundation of active colony sites and surrounding habitat in the Mid-Murrumbidgee region.

Table 2). However, the expected responses of waterbirds to relaxation of flow constraints are likely to be complex and intricately linked with patterns in the availability of different wetland habitat types.

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Table 2 Murrumbidgee Long Term Water Plan (LTWP) waterbird objectives and Basin Wide Environmental Watering Strategy (BWS) expected environmental outcomes supported by the Reconnecting River Country Program.

LTWP objective ID	LTWP objective	BWS Expected waterbird outcomes
WB1	Maintain the number and type of waterbird species	The number and type of waterbird species present in the Basin will not fall below current observations
WB2	Increase total waterbird abundance	There is a significant improvement in waterbird populations in the order of 20 to 25% over the baseline scenario, with increases in all waterbird functional groups
WB3	Increase breeding activity in non-colonial nesting waterbirds	Breeding abundance (nests and broods) for all of the other functional groups to increase by 30–40% compared to the baseline scenario, especially in locations where the Basin Plan improves over-bank flows
WB4	Increase opportunities for colonial nesting waterbird breeding	Breeding events (the opportunities to breed rather than the magnitude of breeding per se) of colonial nesting waterbirds to increase by up to 50% compared to the baseline scenario
WB5	Maintain the extent and improve condition of waterbird habitats	Not specified in BWS but this habitat objective underpins four expected outcomes listed above

Certainty around waterbird responses to the relaxation of constraints is potentially lower than for other ecological responses being evaluated as part of the EBA project. Waterbirds are highly mobile organisms that make decisions around habitat use, which wetland to use, when, where and for what purpose (i.e., foraging, roosting, or nesting). The decision-making process is complex and can be influenced by factors in the larger landscape beyond the wetland scale (Kingsford and Norman 2002; Kingsford et al. 2010; Bino et al. 2020).

The availability of other suitable habitat may influence the use of the Murrumbidgee Wetlands by waterbirds including the timing of when habitat becomes available (prior or post flooding of other wetlands in neighbouring catchments and in other parts of the Murray-Darling Basin). Waterbird responses to relaxation of constraints may also be subdued in the short- to medium-term due to the impact of low population numbers. Long-term aerial surveys have shown that waterbird populations are severely degraded across the Murray-Darling Basin (Kingsford et al. 2017) with continued declines in waterbird abundance recorded in the most recent spring surveys (Porter et al. 2021).

Methods

Study area

Waterbird ground surveys were carried out in the Mid-Murrumbidgee Wetlands between Narrandera and Hay (Figure 3) from 2010 onwards. The wetlands are located on both private land or within the NSW National Park estate and are subject to periodic grazing by cattle. The majority of land surrounding the Mid-Murrumbidgee Wetlands is cleared for grazing and cropping. The hydrology of some of the wetlands is influenced by water extraction and storage.

The dominant vegetation community surrounding the wetlands is river red gum *Eucalyptus camaldulensis* woodland, which provided breeding habitat in the early 1990s for significant numbers of colonial waterbirds (500-2,000 nests), including Australasian Darters *Anhinga novaehollandiae*, cormorants, herons, egrets, Australian White Ibis *Threskiornis molucca* and spoonbills (Briggs et al. 1997).

There were eight survey wetlands in total, which included ox-bow lagoons (Yarradda Lagoon (YAR), Gooragool Lagoon (GOO), McKennas Lagoon (MCK)), large open depressions (Turkey Flat (TUF), McCaugheys Lagoon (YAA), Sunshower Lagoon (SUN) and Narrandera Regional Park Lagoon (NSF)), and a prior stream channel (Coonacoocabil Lagoon (COO)) (see Figure 3, Table 3 and Appendix 1).

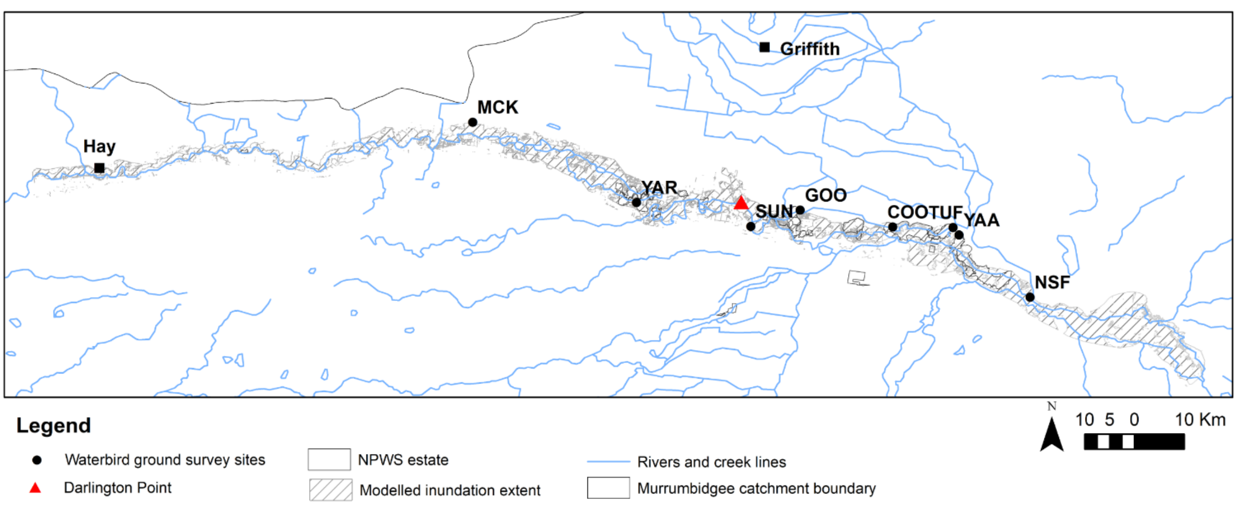


Figure 3 Location of waterbird ground survey sites and Darlington Point river gauge in the Mid-Murrumbidgee Wetlands.

Table 3 Ground survey site coverage in the Mid-Murrumbidgee Wetlands for the 2010-2020 period.

Site Code	Site Name	Tenure	Survey area (ha)	Monitoring commenced
COO	Coonancoocabil Lagoon	Murrumbidgee National Park	17.6	2011
GOO	Gooragool Lagoon	Murrumbidgee National Park	16.1	2011
MCK	McKennas Lagoon	Private land	29.6	2010
NSF	Narrandera Regional Park Lagoon	Murrumbidgee Regional Park	13.1	2011
SUN	Sunshower Lagoon	Private land	22.9	2011
TUF	Turkey Flat	Murrumbidgee National Park	112.5	2011
YAA	McCaugheys Lagoon	Murrumbidgee National Park	7.8	2011
YAR	Yarradda Lagoon	Murrumbidgee National Park	33.0	2010

River flow data

Daily flow data for the Murrumbidgee River recorded downstream of Darlington Point (gauge 410021) (sourced from Water NSW (2021)) were used to investigate relationships between flows and waterbird responses in the Mid-Murrumbidgee Wetlands. Modelled river flow data was available from the Murrumbidgee Source Model v94 (DPE 2022a) downstream of the Darlington Point gauges for the 1895-2019 period. There were four hydrological modelled scenarios completed in Source in March 2022 (DPE 2022a) made available for the EBA project. We used these modelled data to investigate the likely benefits to waterbirds under different relaxed constraints scenarios (Table 4). The relaxed constraint scenarios were compared to the current (or base case) scenario. The model outputs did not consider the impact of climate change and the flow delivery strategy was not to deliver over summer months to limit the risk of blackwater events (DPE 2022a).

Table 4 Flow scenarios assessed as part of the Waterbird EBA Project and relationships between the Wagga Wagga and the Darlington Point river gauges. Relationships at the gauges are based on median estimates of flow limits from the flow peak tracking tool (DPE 2022b). Note Darlington Point flows are the average (mean+median) of Darlington Point results from tracking tool of 3-day rolling average flows at Wagga (with flows following floods removed).

Scenario	Flows at d/s Wagga Wagga (410001) ML/day	Flows at d/s Darlington Point (410021) ML/day
W22 (Current)	22,000	15,000
W32	32,000	21,200
W36	36,000	23,600
W40	40,000	26,000

Inundated wetland area

To determine the inundation extent across the Mid-Murrumbidgee region water maps were created specifically by NSW Department of Planning and Environment (DPE) for the EBA Project (DPE 2022c). Water maps were derived from the Landsat (TM-5, ETM+7, OLI 8) and Sentinel-2 satellite archives (1987-2021). (Figure 4). Near cloud free satellite images were automatically downloaded from the USGS (Unites State Geological Survey's) Earth Explorer website (http://earthexplorer.usgs.gov) and from the Copernicus Sentinel Open Access Hub (https://scihub.copernicus.eu/dhus/#/home) as orthorectified images which were then processed to standardised surface reflectance (Flood et al. 2013). From each surface reflectance image a water index was generated using linear discriminant analysis (Fisher et al. 2016).

A threshold approach was used to classify pixels as water or non-water, using threshold values that allowed for the inclusion of mixed pixels because an open water classifier is known to underestimate flood extent in vegetated floodplain wetlands (Thomas et al. 2015). Inundation estimates from historical inundation mapping were clipped to the Beremed Weir to the Hay Weir (Figure 3) to match the predicted inundation area estimates available from the Computer Aided River Management (CARM) system modelling (DPI Water 2015).

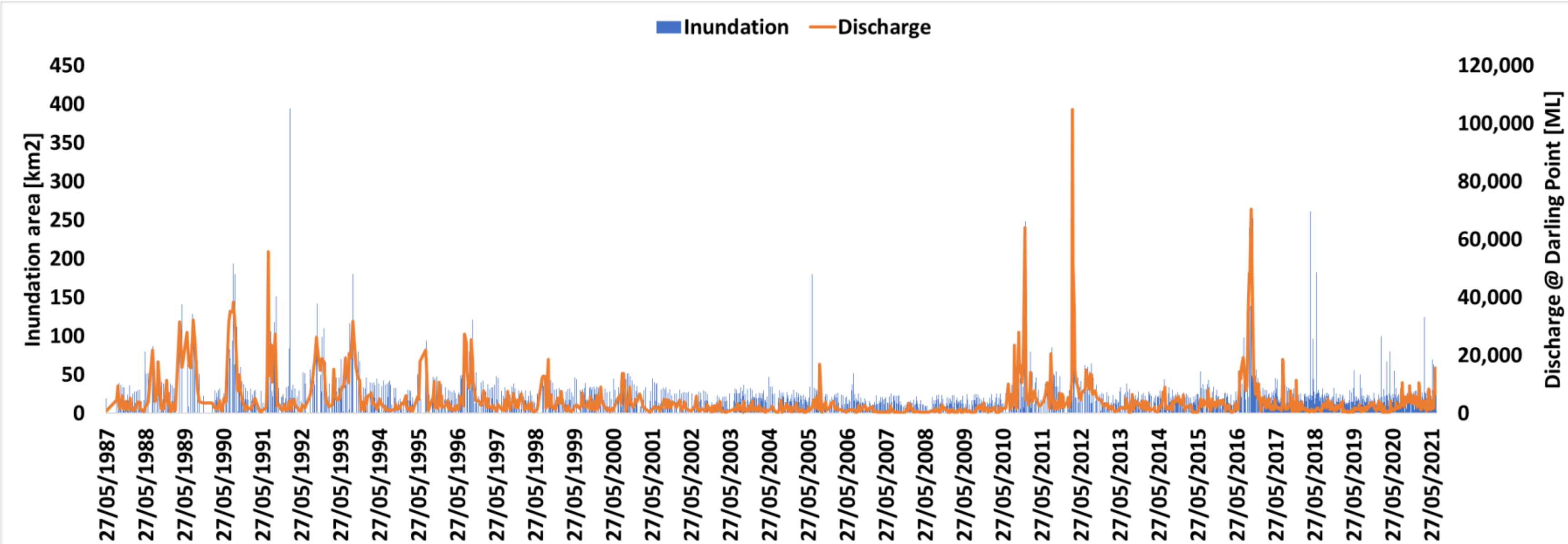


Figure 4 Daily river flow (ML/day) measured downstream of Darlington Point (410021) gauge, estimated area of inundation in the Mid-Murrumbidgee Wetlands based on Landsat (1987-2018) and Sentinel imagery (2018-2021).

Waterbird survey data

On ground surveys have been completed in the Mid-Murrumbidgee Wetlands from 2010 onwards (Table 3). The ground survey sites covered a range of habitat types and were accessible during a range of flow conditions (see Figure 4 and Table 3). The wetlands were surveyed in spring (early-mid October) each year with replicate counts for each site completed over separate days. Only single counts were done for dry sites (where sites were less than 10% inundated) (for more details see Spencer et al. 2014, 2018; Wassens et al. 2012, 2021).

Each wetland was surveyed for at least 20 minutes using a point based or transect based method is used to cover the defined survey area (see Table 3). The Point survey method is based on the BirdLife Australia Area Radius Method, whereby all birds observed from one or more survey points within the wetland are recorded. During the survey as much of each wetland as possible is accessed to include as many habitat types as possible. For larger sites, multiple points within the same wetland are surveyed to maximise survey coverage.

This method was used for large or linear waterbodies which were typically surveyed using a vehicle. Counts of species observed were recorded as a running tally as the observers moved/walked along a transect. Birds were observed using binoculars and/or a telescope. Total counts for each waterbird species, any evidence of breeding activity (including number of nests/ broods/ immatures) and water levels are recorded during each survey.

We collated colonial waterbird data available for the Mid-Murrumbidgee region from 2012 onwards but there were limited records before 2010 other than detailed surveys undertaken by Briggs et al. (1997) in the 1989-1994 period. This meant we were not able to undertake modelling of waterbird breeding responses to flows and inundation for the Mid-Murrumbidgee Wetlands.

Analyses

We used the ground survey data available for the Mid-Murrumbidgee Wetlands to investigate waterbird responses (species richness and abundance) to river flows and floodplain inundation. We adjusted for survey effort by estimating waterbird densities for each of the survey sites by dividing total waterbird abundance by the delineated survey area (in hectares) (see Table 3). We modelled total waterbird species and waterbird density in response to cumulative flow metrics, inundated area, and river flow thresholds (see Table 1) using Generalized Linear Models with a Poisson distribution suitable for count data (see Table 5).

We calculated cumulative flows at 10, 30, 60, 90, 120, 180 days prior to the survey dates for each water year using river flows recorded at the Darlington Point gauge (410021). We also used this flow data to calculate number of days flow thresholds for wetland connection events, small and large overbank events were exceeded in the July to October period each year in the lead up to the annual spring ground surveys. As noted above there were insufficient records to model breeding responses in the Mid-Murrumbidgee Wetlands with detailed surveys only undertaken in the 1989-1994 (Briggs et al. 1997) and 2010-2021 (Spencer et al. 2018; Wassens et al. 2021) periods.

Given high correlation among cumulative flows the predictor variables, we limited models to a single explanatory variable. We evaluated model performance of each explanatory variable using the Akaike's Information Criterion (AICc), considering best fit models within ΔAICc $\leq$2. Analyses were implemented in R (R Development Core Team 2022). Further analysis to link predicted waterbird responses (species richness and abundance only) under each flow scenario were also undertaken to investigate expected responses.

Table 5 Explanation of model codes used in the analysis

Model Code	Details
	Cumulative river flows
10D	Cumulative river flows at nearest gauge 10 days prior to the survey date/ start of breeding season (1 November)
30D	Cumulative river flows at nearest gauge 30 days prior to the survey date/ start of breeding season (1 November)
60D	Cumulative river flows at nearest gauge 60 days prior to the survey date/ start of breeding season (1 November)
90D	Cumulative river flows at nearest gauge 90 days to the survey date/ start of breeding season (1 November)
120D	Cumulative river flows at nearest gauge 120 days to the survey date/ start of breeding season (1 November)
180D	Cumulative river flows at nearest gauge 180 days to the survey date/ start of breeding season (1 November)
	Flow thresholds*
WC1	Number of days threshold for wetland connection events (1) were exceeded in July-October period
WC2	Number of days threshold for wetland connection events (2) were exceeded in July-October period
SO	Number of days threshold for small overbank events were exceeded in July-October period
LO	Number of days threshold for large overbank events were exceeded in July-October period
	Inundated area
InunMax	Maximum inundated area across the water year
InunAugDec	Maximum inundated area in the months prior to and during the spring period

* See Table 1 for explanation of river flow thresholds use to calculate these values.

Results

Current condition

At least 51 species of waterbirds have been recorded in Mid-Murrumbidgee Wetlands in the last decade of monitoring (see Appendix 1). This included 3 vulnerable species in NSW (Biodiversity Conservation Act 2016) and the migratory Latham's Snipe (listed under bilateral migratory bird agreements Australia and signed with Japan (JAMBA) and the Republic of Korea (ROKAMBA). Recent annual spring ground surveys have shown that the number of species and total abundance of waterbirds observed in Mid-Murrumbidgee Wetlands can be low in some years, and the waterbird community is dominated by ducks, herbivores and piscivores (Figure 5).

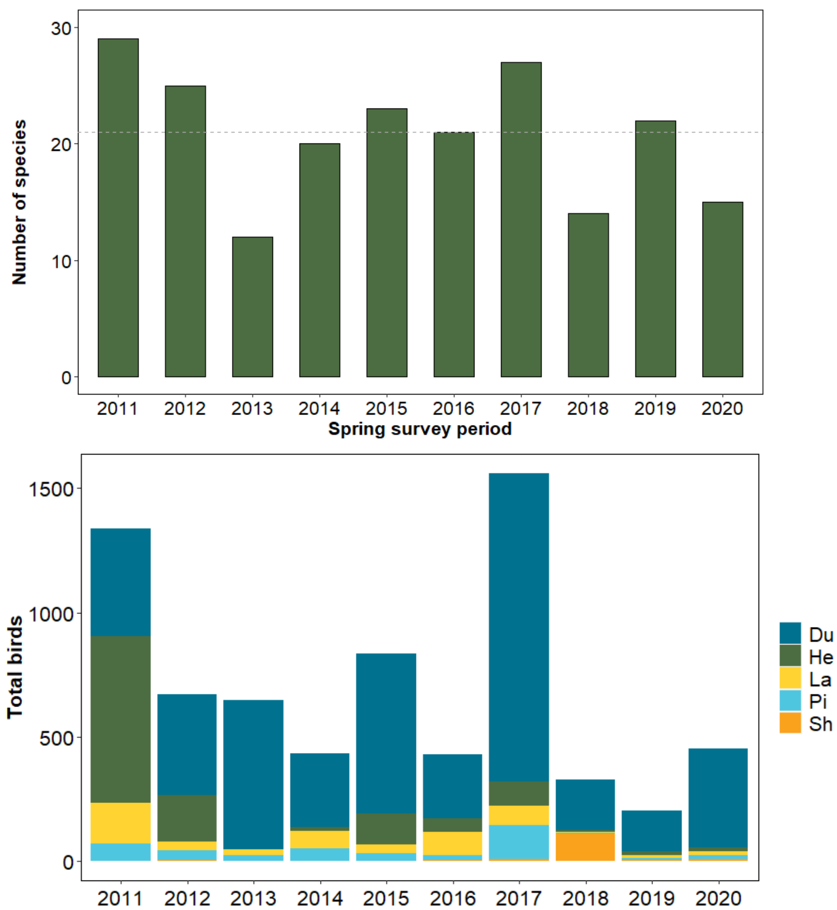


Figure 5 Total number of waterbird species (upper) and waterbird abundance (lower) (including abundance of each functional group (Ducks (Du), Herbivores (He), Large waders (La), Piscivores (Pi) and Shorebirds (Sh)) recorded during annual spring ground surveys in the Mid-Murrumbidgee Wetlands. The grey dotted line represents the average for the 2011-2020 period.

In total 12 species of colonially-nesting waterbirds were recorded nesting in the Mid-Murrumbidgee Wetlands in the 1989-2021 period (Briggs et al. 1997; Spencer 2017; Wassens et al. 2021). Although there is a lack of available records for the 1994-2010 period, piscivore species were most often recorded breeding in the wetlands. This included Little Pied Cormorants *Phalacrocorax melanoleucos*, Australasian Darters *Anhinga novaehollandiae* and Great Cormorants *Phalacrocorax carbo*.

In the 2010-2021 period large wader species, including the Eastern Great Egret *Ardea modesta*, Australian White Ibis, Nankeen Night-Heron *Nycticorax caledonicus* and Yellow-billed Spoonbill *Platalea flavipes*, were only confirmed nesting in the wetlands following widespread natural flooding in spring 2016 (Spencer et al. 2018). Overall, the frequency of large natural overbank events recorded at Darlington Point has declined over recent decades with most recent large-overbank events recorded in 2010-11, 2011-12 and 2016-17. The number of days of smaller wetland connection and small overbank events has also declined since the mid-1990s (Figure 6).

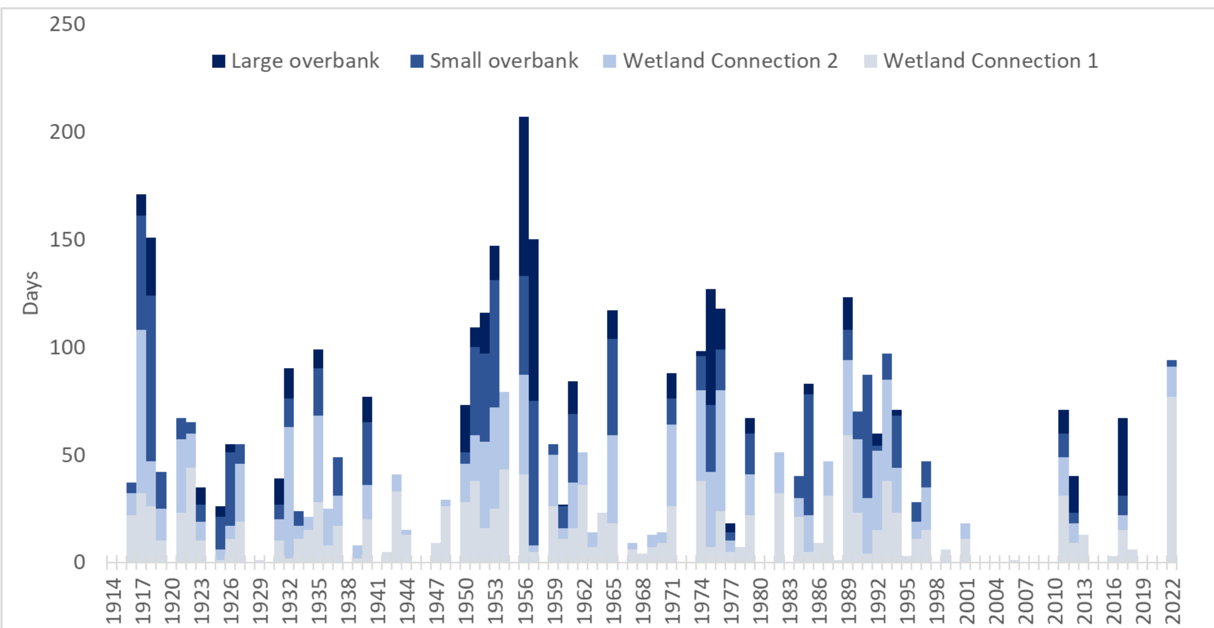


Figure 6 Number of days flow thresholds were met at Murrumbidgee River at Darlington Point gauge (410021) 1914-2021. See Table 1 for explanation of river flow thresholds for each type of flow event.

Observed relationships

We investigated waterbird responses to three types of predictor variables including cumulative river flows preceding the spring ground surveys measured at Darlington Point gauge (410021), maximum inundated area across the Mid-Murumbidgee region and river flow thresholds that represented filling of the wetlands either through wetland connections or overbank events.

The relationships with the predictor variables and waterbird responses were not strong. The best predictor for waterbird species richness and waterbird abundance in the Mid-Murrumbidgee region was cumulative river flows in the 180 days preceeding the ground surveys (see Figure 7 and Figure 8). The river flow thresholds did not explain relationships between waterbird responses and wetland filling (i.e. habitat availability) in the Mid-Murrumbidgee region.

Waterbird responses to flows varied among the individual survey sites. There were some positive associations with cumulative river flows over preceding 180 days before surveys and maximum inundated area across the broader region for many of the survey sites. This included Narrandera Regional Park Lagoon (NSF), Sunshower Lagoon (SUN) and McKennas Lagoon (MCK) (Figure 3) which are the sites most likely to connect naturally during higher river flows, rather than via pumped events or irrigation assisted delivery (Figure 9).

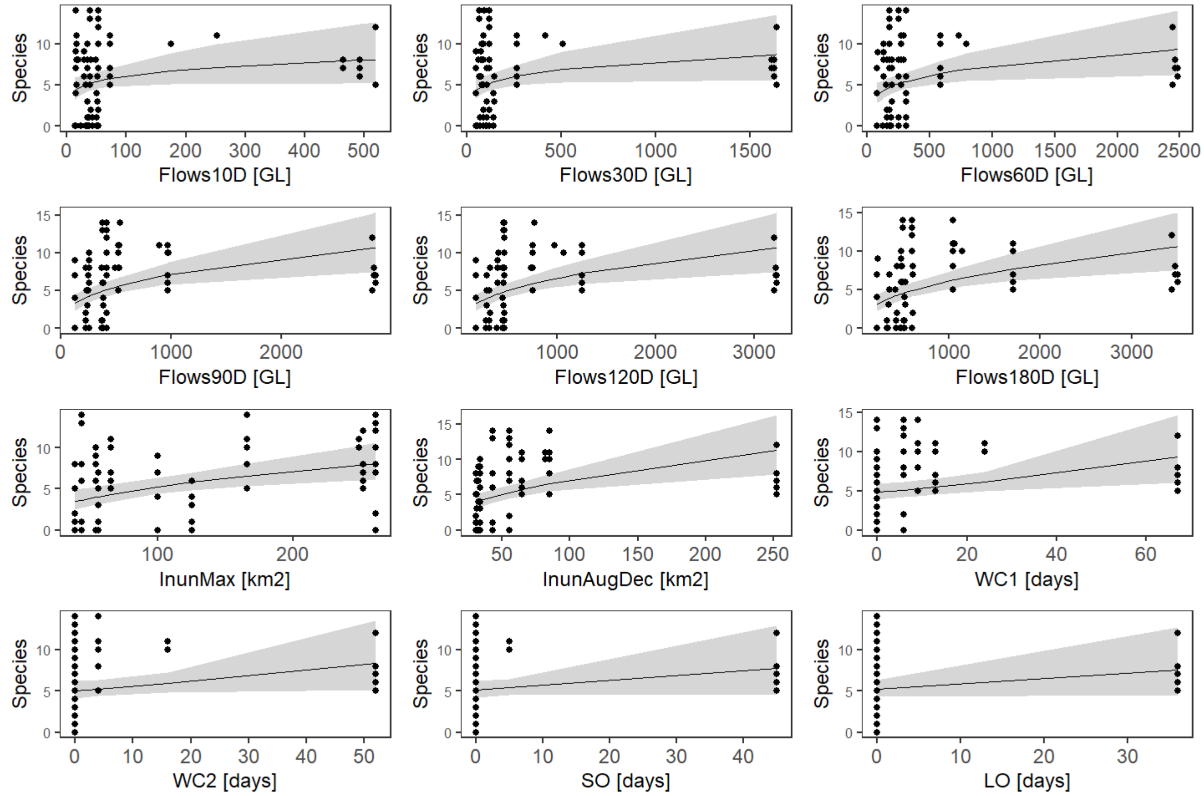


Figure 7 Waterbird species richness recorded in ground surveys in the Midbidgee Wetlands Floodplain each spring over the 2010-2020 period in relation to cumulative river flows 10, 30, 60, 90, 120, 180 preceding the surveys, maximum inundation extent across the water year (InunMax) and maximum inundation extent in August-December period each year (InunAugDec), and the number of days above flow thresholds for Wetland Connection events (WC1, WC2), Small overbanks (SO) and Large overbanks (LO) events (see Table 1).

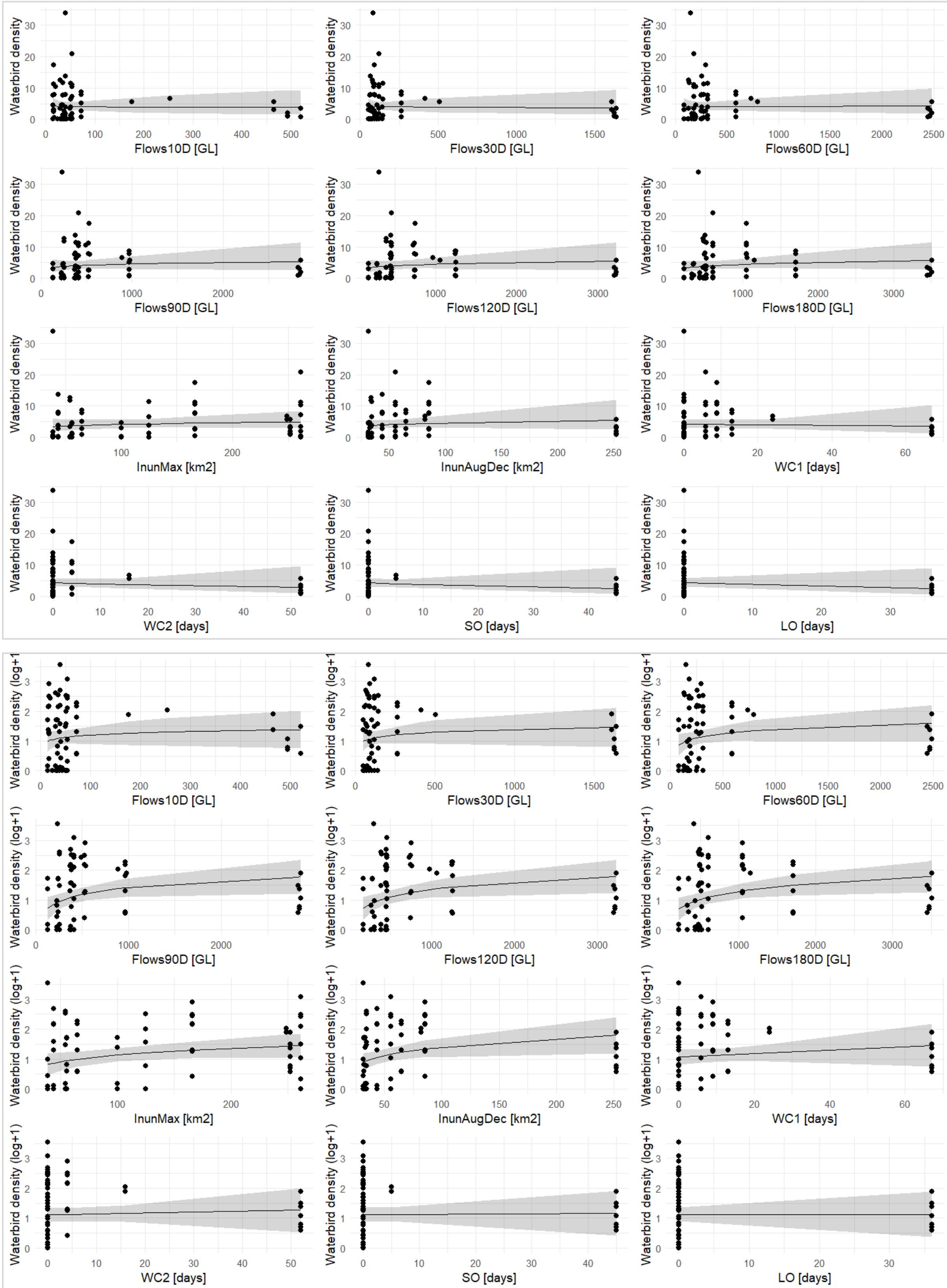


Figure 8 Waterbird density (birds/ha) (upper raw counts, lower log scale) recorded in ground surveys in the Midbidgee Wetlands Floodplain each spring over the 2010-2020 period in relation to cumulative river flows 10, 30, 60, 90, 120, 180 preceding the surveys, maximum inundation extent across the water year (InunMax) and maximum inundation extent in August-December period each year (InunAugDec), and the number of days above flow thresholds for Wetland Connection Events (WC1, WC2), Small overbanks (SO) and Large overbanks (LO) events (see Table 1).

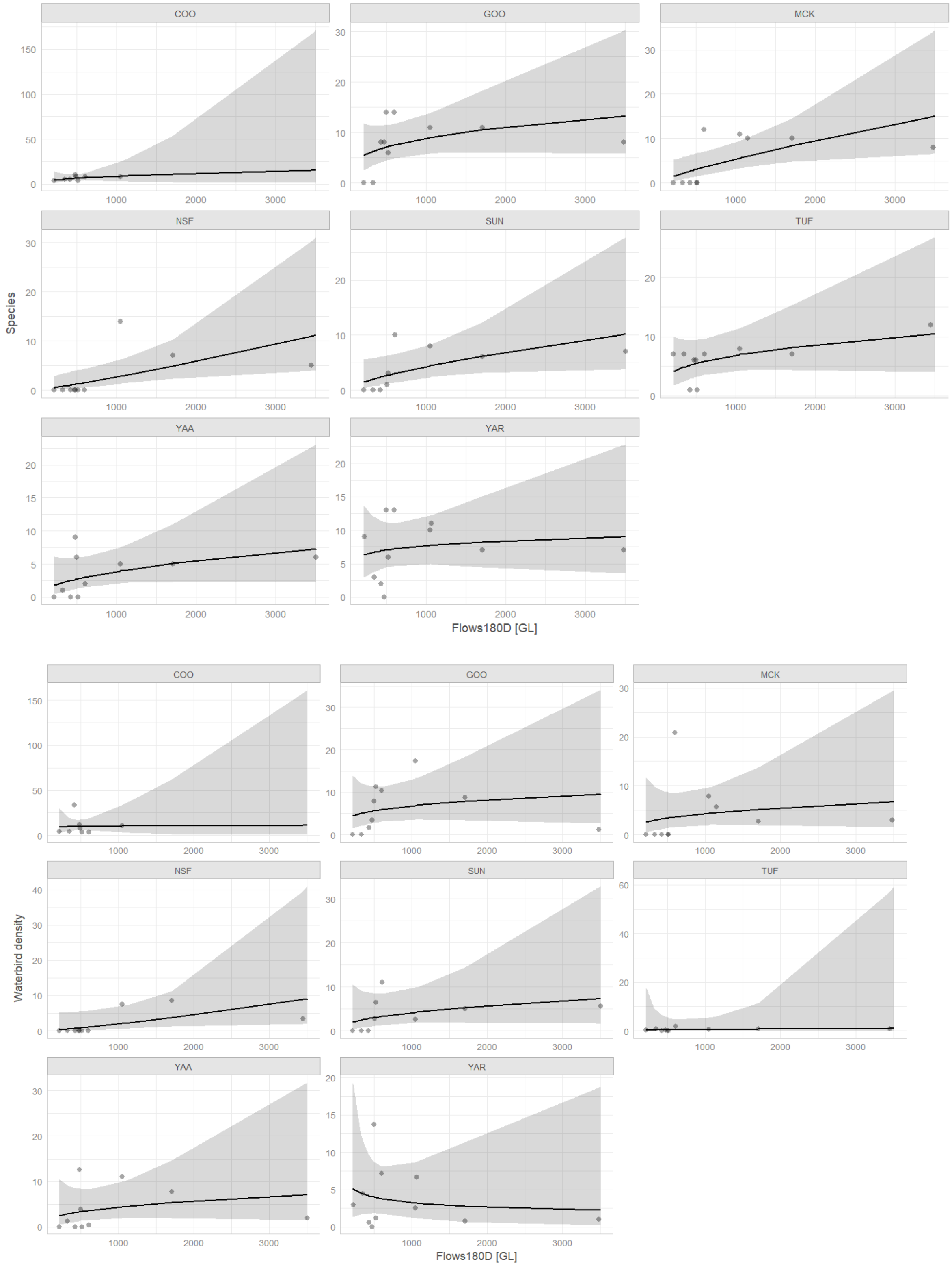


Figure 9 Number of waterbird species (upper) and waterbird density (lower) in 8 survey sites in the Mid-Murrumbidgee Wetlands (2010-2020) in relation to cumulative river flow 180 days preceding the spring ground surveys.

Predicted responses

We used 180 days of cumulative river flows for predicting waterbird response (species richness and abundance) in the Mid-Murrumbidgee Wetlands over the modelled flow time series (1896-2019). Overall, there were very little differences in predicted number of species, waterbird density and cumulative river flows across the flow scenarios (see Figure 10 and Figure 11). Most of these changes were seen for median (P50) conditions rather than the lower (P10 and P25, 10th and 25th percentile) or higher percentiles (P75 and P90, 75th and 90th percentile) (Table 6).

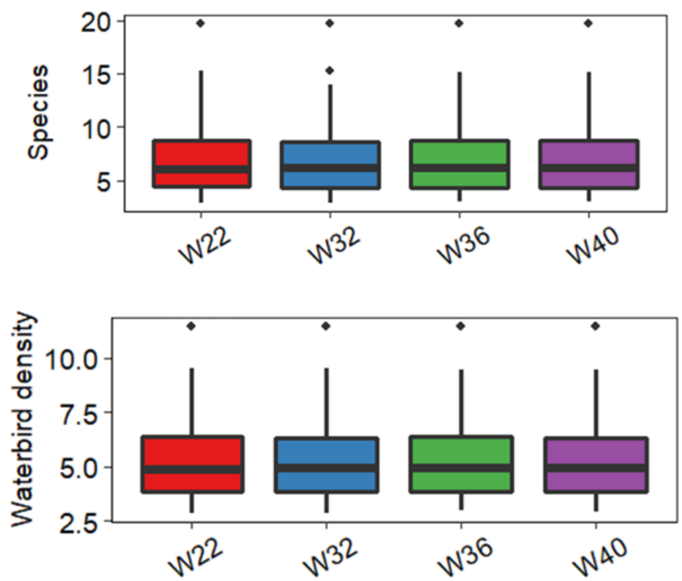


Figure 10 Predicted waterbird responses in the Mid-Murrumbidgee Wetlands based on the best predictor variable (Flows 180D) for number of species (upper) and waterbird density (lower) for the 1896-2019 period for: current constraints (22,000 ML/d), and three relaxed constraint scenarios (32,000, 36,000 and 40,000 ML/day).

Table 6 Mean predicted species richness and waterbird density (birds/ha) in the Mid-Murrumbidgee Wetlands (standard deviation (SD) values and percentiles are also presented) for each flow scenario in response to predicted 180 days cumulative river flows.

Scenario	Mean	SD	P10	P25	P50	P75	P90
Number of species							
W22	6.88	2.95	3.94	4.42	5.99	8.74	10.19
W32	6.88	2.96	3.75	4.35	6.17	8.66	10.18
W36	6.89	2.93	3.92	4.36	6.09	8.73	10.20
W40	6.89	2.93	3.93	4.34	6.17	8.73	10.19
Waterbird density							
W22	5.26	1.60	3.57	3.88	4.84	6.37	7.12
W32	5.26	1.61	3.45	3.84	4.95	6.32	7.11
W36	5.27	1.60	3.56	3.84	4.90	6.36	7.12
W40	5.27	1.60	3.57	3.83	4.94	6.36	7.11

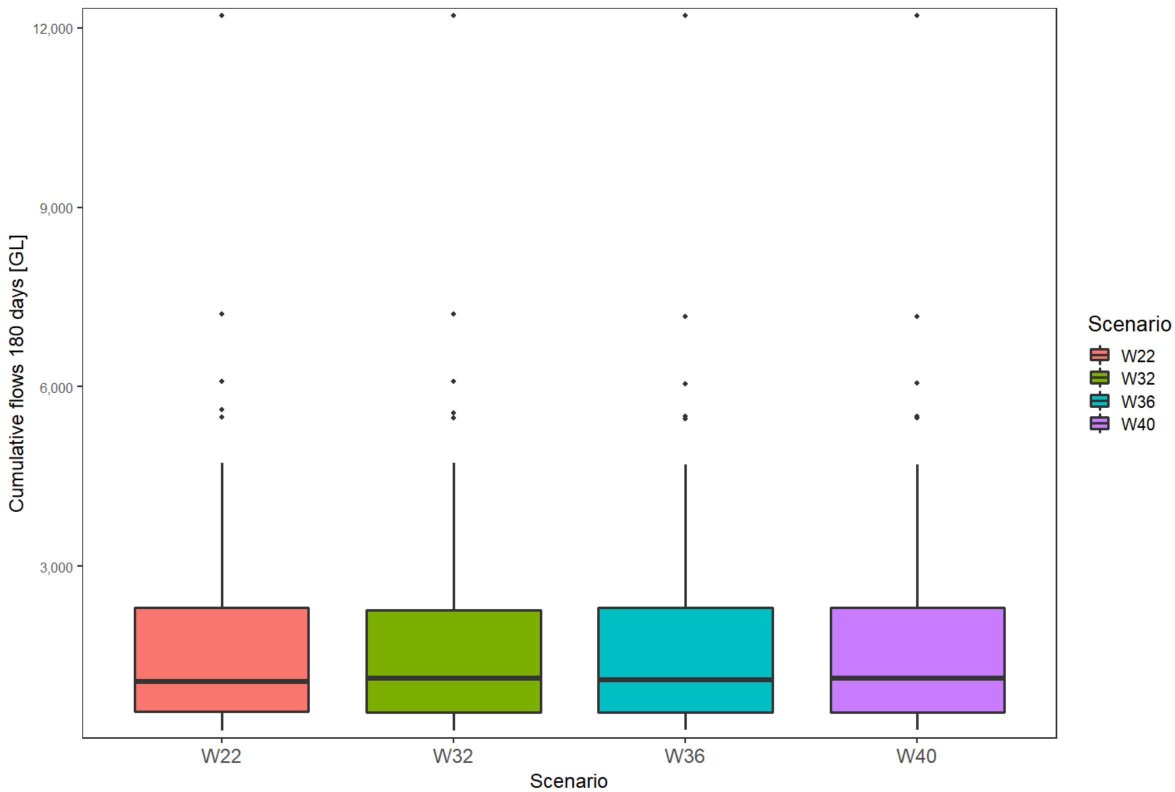


Figure 11 Boxplots showing variation in the key predictor of waterbird responses (cumulative river flows 180 days preceding the spring ground surveys) under each of the flow scenarios.

A kernel density analysis indicated that there were some small increases in predicted number of waterbird species and waterbird density for a higher proportion of years under the relaxed constraint scenarios compared to current constraints (W22). While under current constraints there were a higher proportion of years when predicted species richness and waterbird density was relatively low (Figure 12).

The boxplots and kernel plots shown in Figure 10 and Figure 12 summarise the relative change in waterbird responses across 124 years of modelled flows. We also examined the predicted annual waterbird responses over the flow time series, which showed there were relative increases and decreases in expected benefits for waterbirds compared to current constraints depending on the flow conditions for that year (Figure 13 and Figure 14). In the most recent decades (2000-2019) there were increased predicted benefits of the highest relaxed constraint scenarios (W36 and W40) compared to the lowest relaxed constraint scenario (W32). This maximum benefit varied from 6-10% increase in species richness and 4-7% increase in waterbird abundance for the higher flow scenarios compared to current constraints (Figure 13 and Figure 14).

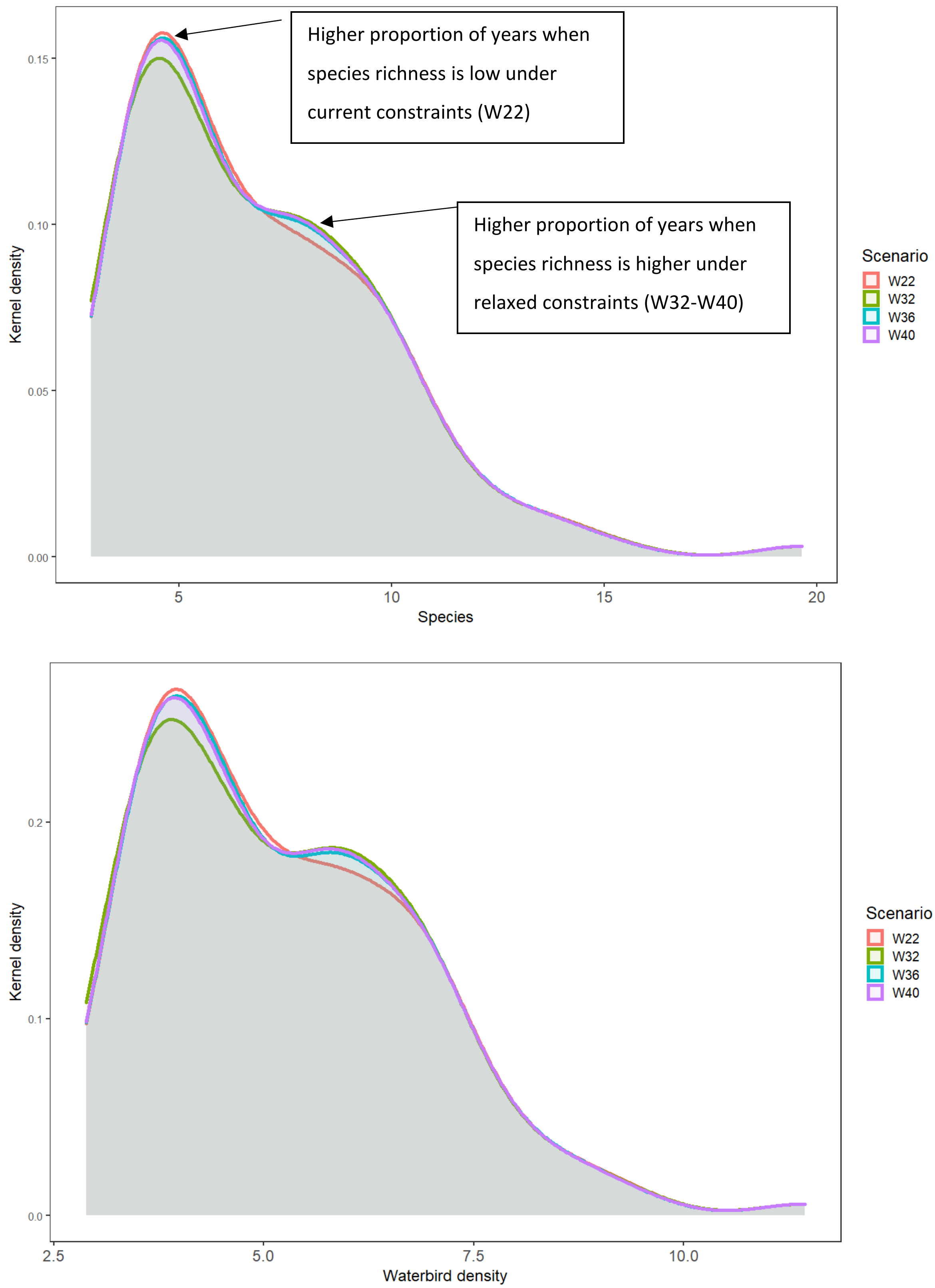


Figure 12 Kernel plot showing predicted number of waterbird species (upper) and waterbird density (birds/ha) (lower) for each scenario based on cumulative river flows 180 days preceding spring surveys as the main predictor variable.

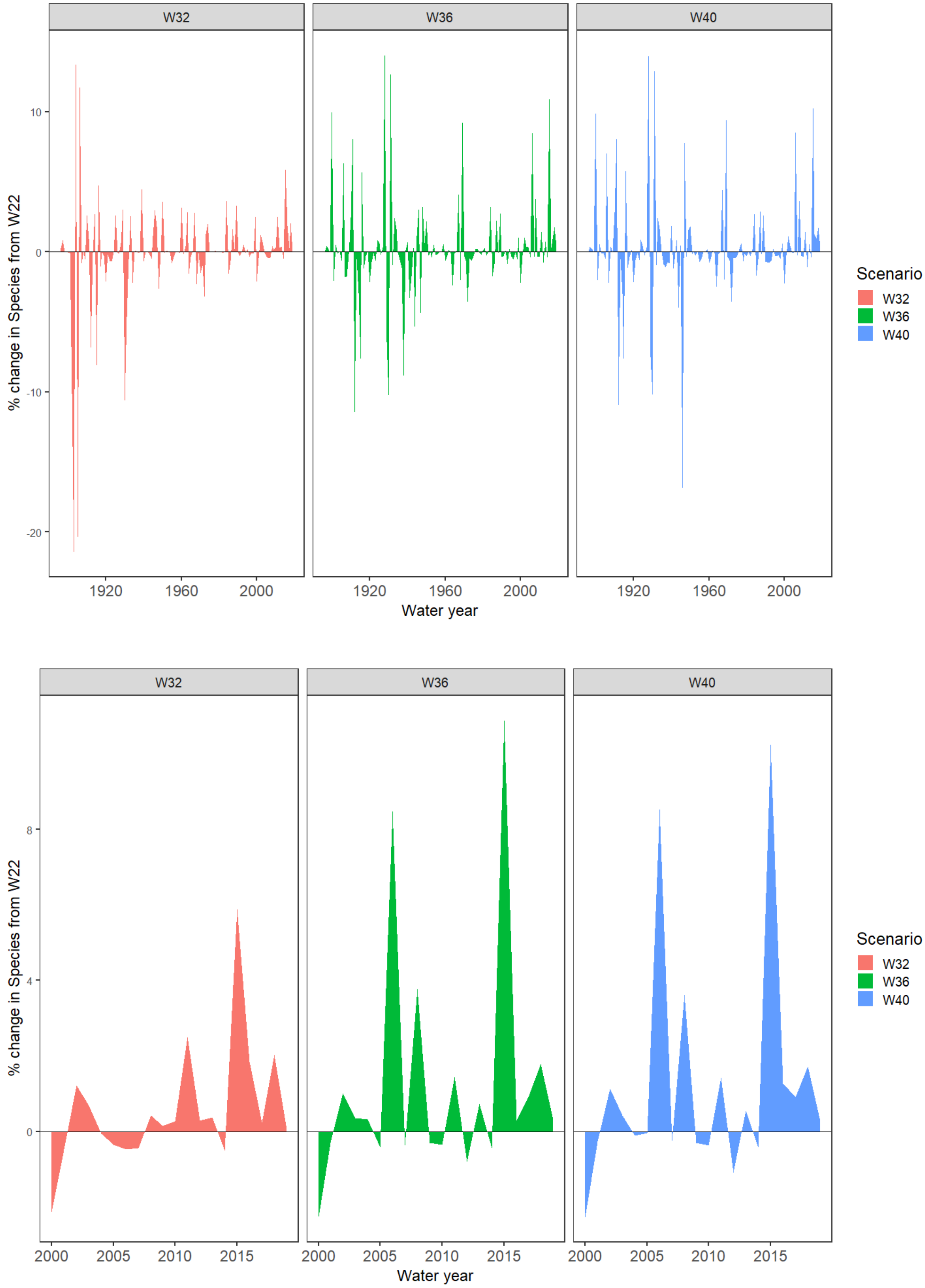
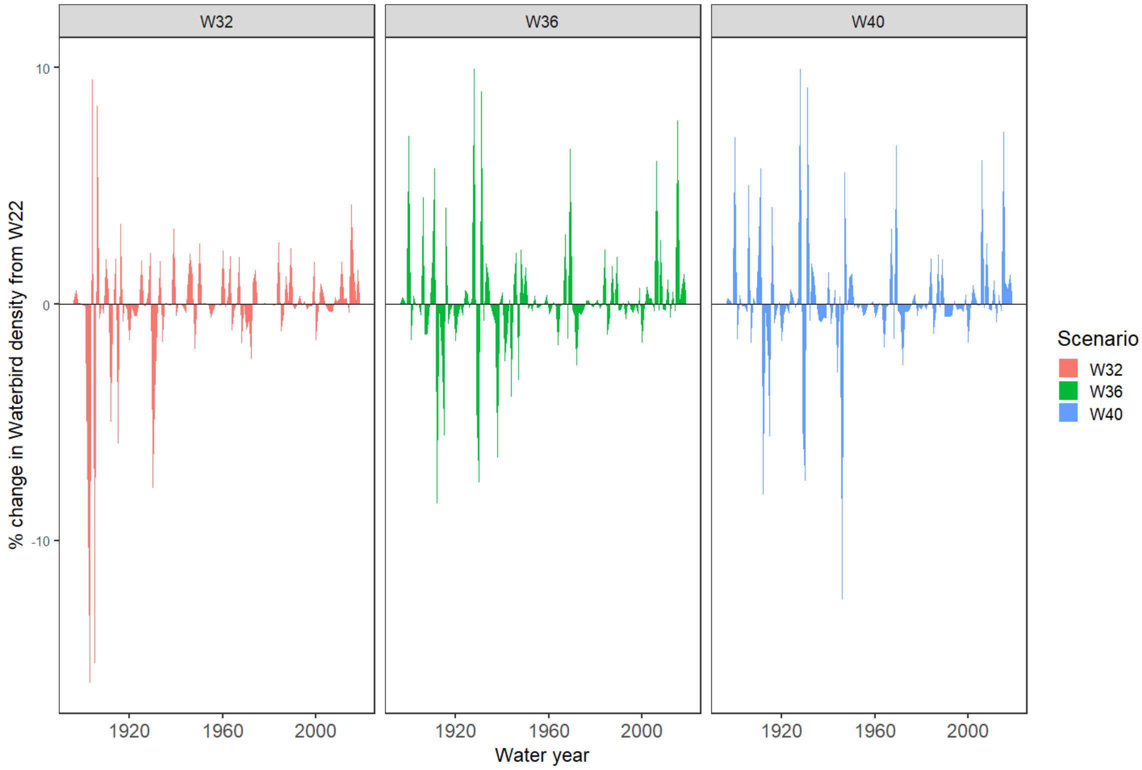


Figure 13 Time series of predicted species richness across the 1896-2019 time series (upper) and 2000-2019 period only (lower). Predicted change in number of waterbird species under each scenario compared to base case is based on cumulative rivers flows 180 days preceding spring surveys as main predictor variable. Note that the modelled time series assumes current levels of river regulation and water extraction throughout the whole period. Therefore, the base case (W22) trajectory does not represent actual waterbird populations under observed historical flows.



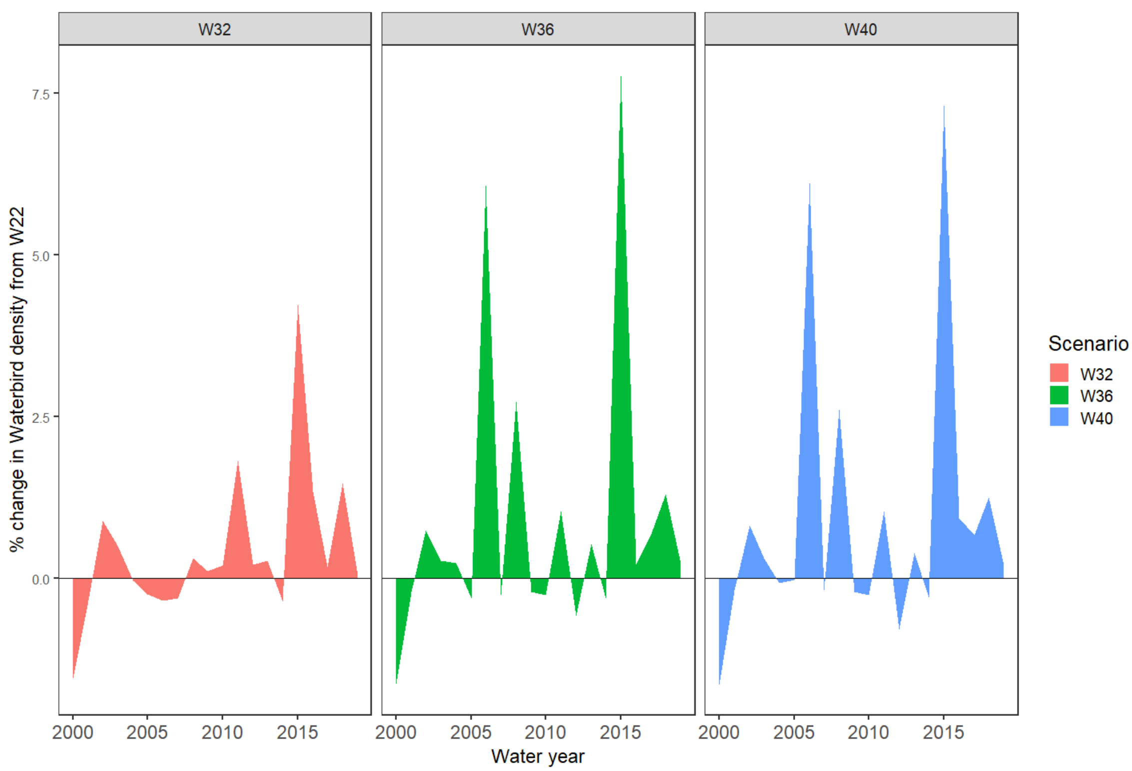


Figure 14 Time series of waterbird density (birds/ha) across the 1896-2019 time series (upper) and 2000-2019 period only (lower). Predicted change in number of waterbird abundance under each scenario compared to base case is based on cumulative river flows of 180 days preceding spring surveys as main predictor variable. Note that the modelled time series assumes current levels of river regulation and water extraction throughout the whole period. Therefore, the base case (W22) trajectory does not represent actual waterbird populations under observed historical flows.

Discussion

We expected that waterbird communities may benefit from the relaxation of constraints in the Murrumbidgee project area because of increased frequency and duration of wetland inundation in the Mid-Murrumbidgee Wetlands. Our analysis indicated that there were some expected benefits for waterbirds in this wetland region but the predicted increases in median number of species (3%) and median waterbird density (2%) were only small when compared to current constraints.

We would expect more frequent and longer wetland connection events to provide benefits to waterbirds in the Mid-Murrumbidgee region, but we were not able to demonstrate these benefits fully using the modelled data. The predictive relationships were based on recent ground survey data (2010-2020) and included periods of dry conditions and low waterbird numbers, and so represented the poor condition of some of the surveyed wetlands. This may have limited our ability to predict improvements in waterbirds in the Mid-Murrumbidgee Wetlands under relaxation of constraints.

The relaxation of constraints is likely to provide greater opportunities to deliver flows to low-lying wetlands, including lagoons and billabongs of the Mid-Murrumbidgee Wetlands, that would otherwise only be possible during high river flows or through infrastructure assisted delivery options. The NSW and Commonwealth governments have been delivering flows to support waterbird and other wetland-dependent fauna in the Mid-Murrumbidgee Wetlands for more than 10 years. These flows have improved habitat condition in many key sites, but flow constraints have limited volumes of water than can be delivered to inundate the wetlands, particularly sites in higher parts of the floodplain. The current operational limit means that it is difficult to raise river flows above 15,500 ML/day at Darlington Point, but flows need to exceed 21,000 ML/day at this gauge to create significant wetland connection. This flow height would be possible under the relaxed constraint scenarios of 32,000 ML/day or higher at Wagga Wagga.

Under the current operational limit managed flow delivery can also be difficult because of high irrigation demands during spring and summer. This means the duration of inundation for some wetland sites in the Mid-Murrumbidgee is short or sites stay drier for longer periods. With greater relaxation of constraints of 36,000 ML/day or 40,000 ML/day there would be more room to delivery flows to the wetlands alongside irrigation orders. This would provide areas of inundated habitat for waterbirds in a higher proportion of years and for a longer duration than under current conditions. Greater options to increase wetland duration is particularly important for colonial waterbird breeding sites, where flows are needed to maintain water depths in these locations for the duration of the nesting period from nest building, incubation and chick rearing through to fledging of young birds.

Flow volume, timing and duration statistics calculated from the modelled river flow data for the EBA project provided some insights into expected increases in flow events at the Darlington Point gauge between the delivery months of May to November (see Figure 15). In this analysis an event is counted where the flow threshold is exceeded for the specified duration, including a one-day event gap tolerance. A new event must be separated from the previous event by at least two days, to be counted as a distinct event. The results of this analysis indicated that overall, we would expect more frequent and longer wetland connection and small overbank events recorded at Darlington Point with relaxation of constraints (Figure 15). For the wetland connection flows of more 21,000 ML/day (WC2) at Darlington Point, which are needed to inundate a greater area of the Mid-Murrumbidgee Wetlands, there are incrementally more events of more than 5 and 10 days with increased relaxation of constraints (Figure 15).

In our analysis of the predicted benefits of the flow scenarios for waterbirds in the Mid-Murrumbidgee Wetlands we did not consider the influence of habitat availability in other parts of the Murray-Darling Basin on observed and modelled waterbird responses. It is likely that predicted benefits of relaxed constraints for waterbirds will be cumulative with the relaxation of constraints increasing habitat availability for waterbirds in both the Murrumbidgee River and Murray River (Yarrawonga to Wakool) project areas (see Bino et al. 2022). Although we considered these two RRCP project areas in isolation, their proximity to each other would mean many waterbird species can move easily between the systems if suitable habitat is available. The relaxation of constraints in these neighbouring systems would provide more water delivery options for inundation of key wetland areas in the southern Basin. This is likely to support improvements in waterbird populations, a key objective of the Basin Plan.

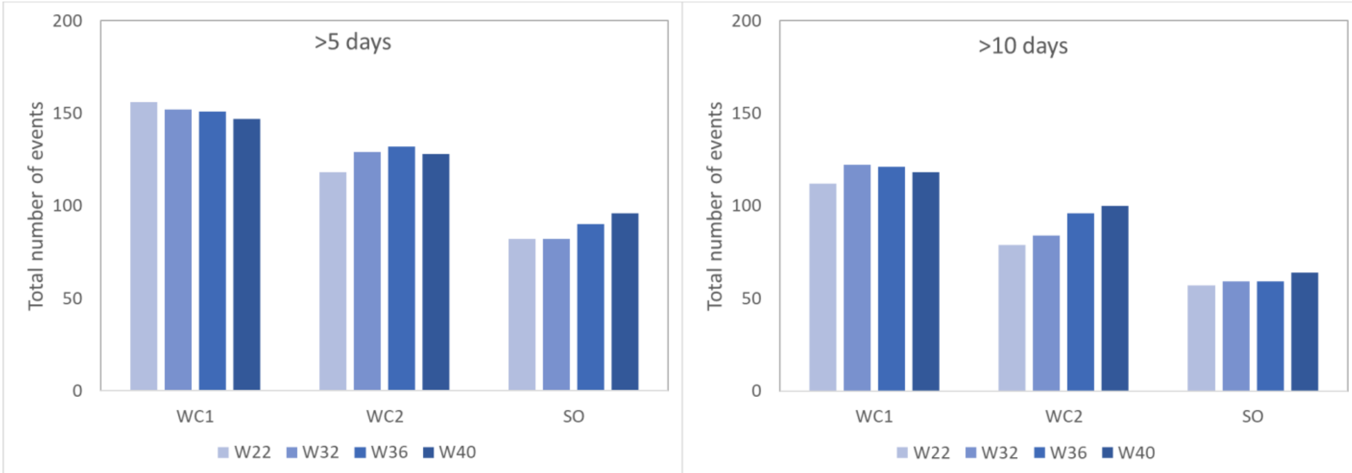


Figure 15 Count of three types of flow events recorded between May-November at Darlington Point (410021) for more than 5 days (left) and more than 10 days (right) for all flow scenarios (1985-2019): Wetland connection 1 (WC1, >15,500 ML/d), Wetland connection 2 (WC2, >21,000 ML/d) and small overbank (SO, >28,000 ML/d).

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Appendix 1 Survey Sites in the Mid-Murrumbidgee Wetlands

Clockwise from top left: Yarradda Lagoon (Oct 2019), Turkey Flats (Oct 2018), Sunshower Lagoon (Feb 2020), McKennas Lagoon (Feb 2022), McCaughey's Lagoon (Feb 2022), Gooragool Lagoon (Oct 2021), Narrandera Regional Park Lagoon (Oct 2021) and Coonacoocabil Lagoon (Feb 2020) (Credit: Carmen Amos, Amelia Walcott (DPE) and Damian Michael (CSU)).

Appendix 2 List of waterbird species

List of waterbird species recorded at Mid-Murrumbidgee Wetlands during ground surveys completed between 2010-2021

Common Name	Scientific Name	Guild	Status*
Australasian Grebe	*Tachybaptus novaehollandiae*	Ducks and small grebes	
Hoary-headed Grebe	*Poliocephalus poliocephalus*	Ducks and small grebes	
Australasian Shoveler	*Anas rhychotis*	Ducks and small grebes	
Blue-billed Duck	*Oxyura australis*	Ducks and small grebes	v
Chestnut Teal	*Anas castanea*	Ducks and small grebes	
Freckled Duck	*Stictonetta naevosa*	Ducks and small grebes	v
Grey Teal	*Anas gracilis*	Ducks and small grebes	
Hardhead	*Aythya australis*	Ducks and small grebes	
Musk Duck	*Biziura lobata*	Ducks and small grebes	
Pacific Black Duck	*Anas superciliosa*	Ducks and small grebes	
Pink-eared Duck	*Malacorhynchus membranaceus*	Ducks and small grebes	
Australian Spotted Crake	*Porzana fluminea*	Ducks and small grebes	
Spotless Crake	*Porzana tabuensis*	Ducks and small grebes	
Australian Shelduck	*Tadorna tadornoides*	Herbivore	
Australian Wood Duck	*Chenonetta jubata*	Herbivore	
Black Swan	*Cygnus atratus*	Herbivore	
Black-tailed Native-hen	*Tribonyx ventralis*	Herbivore	
Dusky Moorhen	*Gallinula tenebrosa*	Herbivore	
Eurasian Coot	*Fulica atra*	Herbivore	
Magpie Goose	*Anseranas semipalmata*	Herbivore	v
Plumed Whistling Duck	*Dendrocygna eytoni*	Herbivore	
Purple Swamphen	*Porphyrio porphyrio*	Herbivore	
Australian Little Bittern	*Ixobrychus dubius*	Large wader	
Australian White Ibis	*Threskiornis molucca*	Large wader	
Cattle Egret	*Bubulcus ibis*	Large wader	
Eastern Great Egret	*Ardea modesta*	Large wader	
Glossy Ibis	*Plegadis falcinellus*	Large wader	Bonn
Intermediate Egret	*Ardea intermedia*	Large wader	
Little Egret	*Egretta garzetta*	Large wader	
Nankeen Night-Heron	*Nycticorax caledonicus*	Large wader	
Royal Spoonbill	*Platalea regia*	Large wader	
Straw-necked Ibis	*Threskiornis spinicollis*	Large wader	
White-faced Heron	*Egretta novaehollandiae*	Large wader	
White-necked Heron	*Ardea pacifica*	Large wader	
Yellow-billed Spoonbill	*Platalea flavipes*	Large wader	
Australasian Darter	*Anhinga novaehollandiae*	Piscivore	
Australian Gull-billed Tern	*Gelochelidon macrotarsa*	Piscivore	
Australian Pelican	*Pelecanus conspicillatus*	Piscivore	
Great Cormorant	*Phalacrocorax carbo*	Piscivore	
Great Crested Grebe	*Podiceps cristatus*	Piscivore	
Little Black Cormorant	*Phalacrocorax sulcirostris*	Piscivore	
Little Pied Cormorant	*Phalacrocorax melanoleucos*	Piscivore	
Pied Cormorant	*Phalacrocorax varius*	Piscivore	

Common Name	**Scientific Name**	**Guild**	**Status***
Silver Gull	*Chroicocephalus novaehollandiae*	Piscivore	
Whiskered Tern	*Chlidonias hybrida*	Piscivore	
Black-fronted Dotterel	*Elseyornis melanops*	Shorebird	
Black-winged Stilt	*Himantopus himantopus*	Shorebird	
Latham's Snipe	*Gallinago hardwickii*	Shorebird	J, R
Masked Lapwing	*Vanellus miles*	Shorebird	
Red-kneed Dotterel	*Erthrogonys cintctus*	Shorebird	
Red-necked Avocet	*Recurvirostra novaehollandiae*	Shorebird	

Note this species list was compiled from all available ground survey data for the Mid-Murrumbidgee Wetland region in the October 2010 to February 2021 period and not limited to spring survey periods. *Status: Species listed as vulnerable (v) under the NSW BC Act (2016). Migratory species listed under bilateral migratory bird agreements JAMBA (J) and ROKAMBA (R) and the Convention of Migratory Species (Bonn).